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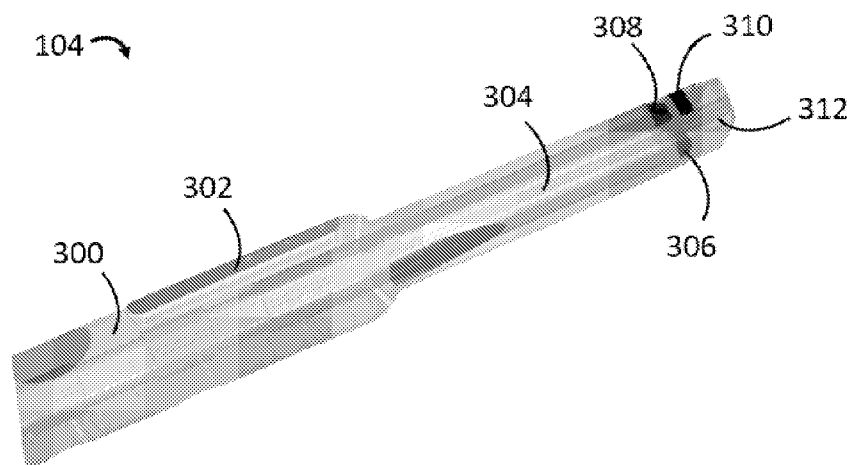


FIG. 3A

(57) Abstract: Provided herein are systems, devices, and methods for imaging tissue in a subject's oral cavity for diagnostic and/or screening purposes.

[Continued on next page]



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SYSTEMS, DEVICES, AND METHODS FOR GINGIVAL HEALTH MONITORING**CROSS-REFERENCE**

[0001] This application claims the benefit of U.S. Provisional Application No. 63/234,156, filed August 17, 2021, and U.S. Provisional Application No. 63/325,381, filed March 30, 2022, which application is incorporated herein by reference.

BACKGROUND

[0002] Determining the oral health of a subject is often completed through conventional oral examination by the naked eye, and/or by physical mechanical interactions (e.g., palpation, probing, etc.). These methods alone are insufficient in classifying or categorizing the delicate intricacies of human oral physiology. Therefore, there exists an unmet need for an advancement in technology capable of sensing and categorizing the rich physiological and anatomical features to further improve screening of oral health.

SUMMARY

[0003] Described herein are systems, devices, and methods for gingival health monitoring. In some cases, the systems, devices, and methods may be configured to determine one or more oral health metrics. In some instances, the one or more oral health metrics may be utilized by a machine learning model to determine a clinical state of a subject. In some cases, the clinical state of the subject may comprise healthy or diseased. In some cases, the diseased state may comprise individuals suffering from periodontal disease.

[0004] Aspects of the disclosure described herein comprise an intraoral imaging device comprising: a scan head configured to be placed inside a subject's mouth, the scan head comprising at least one ultrasonic transducer configured to detect one or more pressure waves with a signal to noise ratio of at least 3dB and at least one light source, wherein the at least one light source or the at least one ultrasonic transducer is configured to generate the one or more pressure waves within one or more tissues of the subject's mouth. In some embodiments, the at least one light source comprises one or more fibers. In some embodiments, the at least one light source comprises a fiber bundle. In some embodiments, the fiber bundle comprises at least 1 fiber. In some embodiments, the fiber bundle comprises at least 2 fibers. In some embodiments, the fiber bundle comprises at least 4 fibers. In some embodiments, the fiber bundle comprises at least 6 fibers. In some embodiments, the fiber bundle comprises at least 8 fibers. In some embodiments, the fiber bundle comprises at least 10 fibers. In some embodiments, the fiber bundle comprises at least 12 fibers. In some embodiments, the fiber bundle comprises at least 14 fibers. In some embodiments, the fiber bundle comprises at least 16 fibers. In some

embodiments, the fiber bundle comprises at least 19 fibers. In some embodiments, the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, vertical cavity scanning electron laser (VCSEL), VCSEL array, or any combination thereof. In some embodiments, the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns). In some embodiments, the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm. In some embodiments, the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 (Hz). In some embodiments, the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW). In some embodiments, the at least one light source comprises a pulse energy of about 0.01 milli Joule (mJ) to about 40 mJ. In some embodiments, the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth. In some embodiments, the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm . In some embodiments, the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof. In some embodiments, the device further comprising one or more optical elements in optical communication with the at least one light source. In some embodiments, the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof. In some embodiments, the device further comprises one or more sensors configured to sense light reflected off of the one or more tissues within the subject's mouth. In some embodiments, the one or more sensors comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof sensor. In some embodiments, the one or more tissues of the subject's mouth comprise gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, or any combination thereof tissue. In some embodiments, the one or more pressure waves are converted into one or more ultrasonic and/or photoacoustic images, wherein the ultrasonic and/or photoacoustic images comprise one or more oral health metrics. In some embodiments, the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof. In some embodiments, the device further comprises a pulser in electrical communication with the at least one ultrasonic transducer.

[0005] Aspects of the disclosure described herein comprise a method of determining one or more health metrics of a subject's oral cavity, comprising: (a) providing at least one light source and at least one ultrasonic transducer incident on one or more tissues of the oral cavity; (b) generating one or more pressure waves through the interaction of the at least one light source or the at least one ultrasonic transducer and the one or more tissues of the oral cavity; (c) detecting the one or more pressure waves with an ultrasonic transducer thereby generating one or more detected ultrasound signals with a signal to noise ratio of at 3dB; and (d) determining one or more health metrics of the oral cavity from the one or more detected ultrasound signals. In some embodiments, the at least one light source comprises one or more fibers. In some embodiments, the at least one light source comprises a fiber bundle. In some embodiments, the fiber bundle comprises at least 1 fiber. In some embodiments, the fiber bundle comprises at least 2 fibers. In some embodiments, the fiber bundle comprises at least 4 fibers. In some embodiments, the fiber bundle comprises at least 6 fibers. In some embodiments, the fiber bundle comprises at least 8 fibers. In some embodiments, the fiber bundle comprises at least 10 fibers. In some embodiments, the fiber bundle comprises at least 12 fibers. In some embodiments, the fiber bundle comprises at least 14 fibers. In some embodiments, the fiber bundle comprises at least 16 fibers. In some embodiments, the fiber bundle comprises at least 19 fibers. In some embodiments, the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, vertical cavity scanning electron laser (VCSEL), VCSEL array, or any combination thereof. In some embodiments, the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns). In some embodiments, the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm. In some embodiments, the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 (Hz). In some embodiments, the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW). In some embodiments, the at least one light source comprises a pulse energy of about 0.01 milli Joule(mJ) to about 40 mJ. In some embodiments, the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth. In some embodiments, the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm . In some embodiments, the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof. In some embodiments, the at least one light source is in optical communication with one or more optical elements. In some embodiments, the one or more optical elements comprise a plano-convex

lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof. In some embodiments, the method further comprises detecting light reflected off of one or more tissues within the subject's mouth with one or more sensors. In some embodiments, the one or more sensors comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof sensor. In some embodiments, the one or more tissues within the subject's mouth comprise gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, or any combination thereof tissue. In some embodiments, the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof. In some embodiments, determining comprises applying a processing algorithm to one or more ultrasound and/or photoacoustic images generated by the one or more ultrasound signals to a processing algorithm. In some embodiments, determining is completed on a local processor, cloud-based processor, or any combination thereof. In some embodiments, the one or more health metrics are used to suggest a therapeutic, treatment, procedure, or any combination thereof to the subject. In some embodiments, the processing algorithm comprises a trained predictive model, wherein the trained predictive model is trained with one or more statistical features of one or more regions of interest of the one or more images and an annotated label of the one or more regions of interest. In some embodiments, the one or more statistical features comprise mean, variance, standard deviation, skewness, median, entropy, kurtosis, or any combination thereof. In some embodiments, the one or more statistical features comprise texture features of the gray level co-occurrence matrix (GLCM) in one or more directions of the detected ultrasound signals. In some embodiments, the texture features comprise homogeneity, contrast, energy, entropy, correlation, or any combination thereof. In some embodiments, the statistical features comprise texture features of the gray level run length matrix (GLRLM) in one or more directions. In some embodiments, the texture features of the GLRLM comprise short run emphasis, long run emphasis, gray-level non-uniformity, run percentage, run length nonuniformity, low gray-level run emphasis, high gray-level run emphasis, or any combination thereof. In some embodiments, the one or more directions comprise 0 degrees, 45 degrees, 90 degrees, 135 degrees, or any combination thereof. In some embodiments, the trained predictive model comprises a machine learning model, a neural network, a convolutional neural network, or any combination thereof. In some embodiments, the one or more regions of interest comprises a width of at least two pixels and a height of at least two pixels. In some embodiments, the trained predictive model comprises an accuracy of at least 70%, at least 75%, at least 80%, at

least 85%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, or at least 99%.

[0006] Aspects of the disclosure described herein comprise a wireless intraoral imaging device, comprising: a tip, wherein the tip comprises at least one light source and at least one ultrasonic transducer; and a processor in communication with the at one light source and the at least one ultrasonic transducer, wherein the processor is located on a body of the wireless intraoral imaging device, and wherein the processor is configured to process data obtained from the ultrasound transducer. In some embodiments, the processor is configured to wirelessly transmit and receive information with a second processor of an external system. In some embodiments, the device further comprises a pulser receiver electrically coupled to the processor configured to process an ultrasound pressure wave echo detected by the at least one ultrasonic transducer. In some embodiments, the processor comprises a field programmable gate array. In some embodiments, the device further comprises a processor configured to transmit the processed data obtained from the at least one ultrasonic transducer to a system for further processing, display, or any combination thereof. In some embodiments, the device further comprises a light source driver in electrical communication with the at least one light source and the processor. In some embodiments, the device further comprises a heat sink configured to distribute heat generated by the at least one light source. In some embodiments, the device further comprises a fan in fluid communication with the heat sink. In some embodiments, the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof. In some embodiments, the device further comprises a sensor. In some embodiments, the sensor comprises a gravitational sensor, a light base sensor, a gyroscope, a magnetometer, an accelerometer, or any combination thereof. In some embodiments, the device further comprises a battery, wherein the battery comprises a lithium-ion polymer battery. In some embodiments, the battery comprises a rechargeable battery. In some embodiments, the body is comprised of stainless steel or a plastic. In some embodiments, the at least one light source comprises one or more fibers. In some embodiments, the at least one light source comprises a fiber bundle. In some embodiments, the fiber bundle comprises at least 1 fiber. In some embodiments, the fiber bundle comprises at least 2 fibers. In some embodiments, the fiber bundle comprises at least 4 fibers. In some embodiments, the fiber bundle comprises at least 6 fibers. In some embodiments, the fiber bundle comprises at least 8 fibers. In some embodiments, the fiber bundle comprises at least 10 fibers. In some embodiments, the fiber bundle comprises at least 12 fibers. In some embodiments, the fiber bundle comprises at least 14 fibers. In some embodiments, the fiber bundle comprises at least 16

fibers. In some embodiments, the fiber bundle comprises at least 19 fibers. In some embodiments, the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns). In some embodiments, the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm. In some embodiments, the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 Hz. In some embodiments, the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW). In some embodiments, the at least one light source comprises a pulse energy of about 0.01 milli Joule(mJ) to about 40 mJ. In some embodiments, the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth. In some embodiments, the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm . In some embodiments, the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof. In some embodiments, the device further comprises one or more optical elements in optical communication with the at least one light source. In some embodiments, the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof. In some embodiments, the device further comprises one or more sensors configured to sense light reflected off of tissue within the subject's mouth. In some embodiments, the one or more sensors comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof sensor. In some embodiments, the data obtained from the at least one ultrasound transducer comprises ultrasound echo data of one or more pressure waves emitted by one or more tissues detected by the at least one ultrasound transducer. In some embodiments, the one or more tissues comprise gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, tooth enamel, or any combination thereof tissue. In some embodiments, the one or more pressure waves are converted into one or more ultrasonic images, wherein the ultrasonic images comprise one or more oral health metrics. In some embodiments, the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof. In some embodiments, the device further comprises a pulser in electrical communication with the at least one ultrasonic transducer.

[0007] Aspects of the disclosure described herein comprise a device for oral imaging, comprising: a probe, wherein the probe comprises: a tip, wherein the tip comprises at least one

light source, at least one ultrasound transducer, and a coupling interface, wherein the coupling interface is configured to expand upon pressing the coupling interface onto a surface of an oral tissue, and wherein the coupling interface applies a pressure to the surface of the oral tissue. In some embodiments, the oral tissue comprises gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, tooth enamel, or any combination thereof tissue. In some embodiments, the at least one light source and the at least one ultrasound transducer are housed within the coupling interface. In some embodiments, the pressure applied by the coupling interface to the surface of the oral tissue is configured to provide at least 3dB signal to noise of a detected ultrasound signal by the at least one ultrasound transducer. In some embodiments, the pressure applied by the coupling interface to the surface of the oral tissue is applied normal to the surface of the oral tissue. In some embodiments, the coupling interface comprises at least one spring mechanically coupled to the coupling interface, wherein the at least one spring is configured to expand when the coupling interface is pressed onto a surface of an oral tissue. In some embodiments, the coupling interface comprises a shape memory material. In some embodiments, the shape memory material comprises a shape memory metal, plastic, or any combination thereof. In some embodiments, the probe comprises a handled probe. In some embodiments, the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof. In some embodiments, the at least one ultrasound transducer comprises a single element transducer or an array-based ultrasound transducer. In some embodiments, the device further comprises a processor electrically coupled to the at least one ultrasound transducer and the at least one light source, wherein the processor is configured to wirelessly transmit and receive information with a second processor of an external system. In some embodiments, the device further comprises a pulser receiver electrically coupled to the processor configured to process an ultrasound pressure wave echo detected by the at least one ultrasonic transducer. In some embodiments, the processor comprises a field programmable gate array. In some embodiments, the device further comprises a processor configured to transmit the processed data obtained from the at least one ultrasonic transducer to a system for further processing, display, or any combination thereof. In some embodiments, the device further comprises a light source driver in electrical communication with the at least one light source and the processor. In some embodiments, the device further comprises a heat sink configured to distribute heat generated by the at least one light source. In some embodiments, the device further comprises a fan in fluid communication with the heat sink. In some embodiments, the device comprises at least one light source comprises a laser,

pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof. In some embodiments, the device further comprises a sensor. In some embodiments, the sensor comprises a gravitational sensor, a light base sensor, a gyroscope, a magnetometer, an accelerometer, or any combination thereof. In some embodiments, the device further comprises a battery, wherein the battery comprises a lithium-ion polymer battery, and wherein the battery is configured to power the at least one ultrasound transducer, the at least one light source, or any combination thereof. In some embodiments, the battery comprises a rechargeable battery. In some embodiments, the probe comprises a body mechanically coupled to the tip, wherein the body, tip, or any combination thereof is comprised of stainless steel or a plastic material. In some embodiments, the at least one light source comprises one or more fibers. In some embodiments, the at least one light source comprises a fiber bundle. In some embodiments, the fiber bundle comprises at least 1 fiber. In some embodiments, the fiber bundle comprises at least 2 fibers. In some embodiments, the fiber bundle comprises at least 4 fibers. In some embodiments, the fiber bundle comprises at least 6 fibers. In some embodiments, the fiber bundle comprises at least 8 fibers. In some embodiments, the fiber bundle comprises at least 10 fibers. In some embodiments, the fiber bundle comprises at least 12 fibers. In some embodiments, the fiber bundle comprises at least 14 fibers. In some embodiments, the fiber bundle comprises at least 16 fibers. In some embodiments, the fiber bundle comprises at least 19 fibers. In some embodiments, the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns). In some embodiments, the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm. In some embodiments, the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 Hz. In some embodiments, the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW). In some embodiments, the at least one light source comprises a pulse energy of about 0.01 milli Joule (mJ) to about 40 mJ. In some embodiments, the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth. In some embodiments, the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm . In some embodiments, the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof. In some embodiments, the device further comprises one or more optical elements in optical communication with the at least one light source. In some embodiments, the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a

plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof. In some embodiments, the device further comprises one or more sensors configured to sense light reflected off the oral tissue. In some embodiments, the one or more sensors comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof sensor. In some embodiments, the at least one ultrasound transducer is configured to obtain data comprising ultrasound echo data of one or more pressure waves emitted by the oral tissue. In some embodiments, the one or more pressure waves are converted into one or more ultrasonic images, wherein the ultrasonic images comprise one or more oral health metrics. In some embodiments, the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof. In some embodiments, the device further comprises a pulser in electrical communication with the at least one ultrasonic transducer.

[0008] Aspects of the disclosure described herein comprise a device for oral imaging, comprising: a probe, wherein the probe comprises: a tip, wherein the tip comprises a coupling interface, wherein the coupling interface is configured to expand upon pressing the coupling interface onto a surface of an oral tissue thereby providing a signal to noise ratio of at least 3dB when collecting data with the probe. In some embodiments, the probe comprises a handheld probe. In some embodiments, the oral tissue comprises gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, tooth enamel, or any combination thereof tissue. In some embodiments, the tip comprises at least one ultrasound transducer housed within the tip. In some embodiments, the data comprises ultrasound data collected from the oral tissue by the at least one ultrasound transducer. In some embodiments, the pressure applied by the coupling interface to the surface of the oral tissue is applied normal to the surface of the oral tissue. In some embodiments, the coupling interface comprises at least one spring mechanically coupled to the coupling interface, wherein the at least one spring is configured to expand when the coupling interface is pressed onto a surface of the oral tissue. In some embodiments, the coupling interface comprises a shape memory material. In some embodiments, the shape memory material comprises a shape memory metal, plastic, or any combination thereof. In some embodiments, the tip further comprises at least one light source, at, at least one sensor, or any combination thereof. In some embodiments, the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof. In some embodiments, the at least one ultrasound transducer comprises a single element transducer or an array-based

ultrasound transducer. In some embodiments, the at least one sensor comprises a gravitational sensor, a light base sensor, a gyroscope, a magnetometer, an accelerometer, or any combination thereof. In some embodiments, the light base sensor comprises a charged coupled device (CCD) or a complementary metal oxide semiconductor sensor (CMOS). In some embodiments, the probe further comprises a processor electrically coupled to the at least one ultrasound transducer, the at least one light source, or any combination thereof. In some embodiments, the processor is configured to wirelessly transmit and receive information with a second processor of an external system. In some embodiments, the probe further comprises a pulser receiver electrically coupled to the processor configured to process an ultrasound pressure wave echo detected by the at least one ultrasonic transducer. In some embodiments, the processor comprises a field programmable gate array. In some embodiments, the probe comprises a processor configured to transmit the processed data obtained from the at least one ultrasonic transducer to a system for further processing, display, or any combination thereof. In some embodiments, the device further comprises a light source driver in electrical communication with the at least one light source and the processor. In some embodiments, the device further comprises a heat sink configured to distribute heat generated by the at least one light source. In some embodiments, the device further comprises a fan in fluid communication with the heat sink. In some embodiments, the probe further comprises a battery, wherein the battery comprises a lithium-ion polymer battery. In some embodiments, the battery comprises a rechargeable battery. In some embodiments, the probe comprises a body, wherein the body is comprised of stainless steel or a plastic. In some embodiments, the at least one light source comprises one or more fibers. In some embodiments, the at least one light source comprises a fiber bundle. In some embodiments, the fiber bundle comprises at least 1 fiber. In some embodiments, the fiber bundle comprises at least 2 fibers. In some embodiments, the fiber bundle comprises at least 4 fibers. In some embodiments, the fiber bundle comprises at least 6 fibers. In some embodiments, the fiber bundle comprises at least 8 fibers. In some embodiments, the fiber bundle comprises at least 10 fibers. In some embodiments, the fiber bundle comprises at least 12 fibers. In some embodiments, the fiber bundle comprises at least 14 fibers. In some embodiments, the fiber bundle comprises at least 16 fibers. In some embodiments, the fiber bundle comprises at least 19 fibers. In some embodiments, the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns). In some embodiments, the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm. In some embodiments, the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 Hz. In some embodiments, the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW). In some embodiments,

the at least one light source comprises a pulse energy of about 0.01 milli Joule(mJ) to about 40 mJ. In some embodiments, the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth. In some embodiments, the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm . In some embodiments, the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof. In some embodiments, the probe further comprises one or more optical elements optically coupled with the at least one light source. In some embodiments, the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof. In some embodiments, the data obtained by the probe comprises ultrasound echo data of one or more pressure waves emitted by one or more tissues obtained by the at least one ultrasound transducer. In some embodiments, the one or more pressure waves are converted into one or more ultrasonic images, wherein the ultrasonic images comprise one or more oral health metrics. In some embodiments, the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof. In some embodiments, the device further comprises a pulser in electrical communication with the at least one ultrasonic transducer.

INCORPORATION BY REFERENCE

[0009] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference. To the extent publications and patents or patent applications incorporated by reference contradict the disclosure contained in the specification, the specification is intended to supersede and/or take precedence over any such contradictory material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings (also "Figure" and "FIG." herein), of which:

[0011] FIG. 1 illustrates an imaging system, intraoral imaging device, and foot pedal trigger, as described in some embodiments herein.

[0012] **FIG. 2** illustrates an overview of an ultrasound acquisition module, as described in some embodiments herein.

[0013] **FIGS. 3A-3C** illustrate a perspective and cross-sectional views of the intraoral imaging device showcasing the electrical and optical components of the intraoral imaging device, as described in some embodiments herein.

[0014] **FIG. 4** illustrates a flow diagram for determining one or more health metrics from photoacoustic data of a subject's oral cavity, as described in some embodiments herein.

[0015] **FIG. 5** illustrates a computer system configured to process ultrasound and/or photoacoustic data and/or images, as described in some embodiments herein.

[0016] **FIG. 6** illustrates a flow diagram for determining one or more health metrics from ultrasound data of a subject's oral cavity, as described in some embodiments herein.

[0017] **FIG. 7** illustrates a wireless handheld oral imaging probe, as described in some embodiments herein.

[0018] **FIGS. 8A-8B** illustrate data generated by the devices, systems, and/or methods described herein, and the resulting region of interest sampling for generating training features for the machine learning models, as described in some embodiments herein.

[0019] **FIGS. 9A-9E** illustrate an ultrasound transducer array probe compared to other conventional ultrasound probes and ultrasound operational modes, as described in some embodiments herein.

[0020] **FIGS. 10A-10D** illustrate spatial resolution performance images and graphed data for the ultrasound transducer array probe with different modes of operation, as described in some embodiments herein.

[0021] **FIGS. 11A-11C** illustrate penetration depth images and graphed data for the ultrasound transducer array probe, as described in some embodiments herein.

[0022] **FIGS. 12A-12H** illustrate in-vivo images of subjects' tooth and surrounding oral tissue generated by the ultrasound transducer array probe, as described in some embodiments herein.

[0023] **FIGS. 13A-13E** illustrate in-vivo human subjects images and graphed data of gingival thickness measurements, where the images were generated by the ultrasound transducer array probe, as described in some embodiments herein.

[0024] **FIGS. 14A-14D** illustrate images and graphed data for light homogeneity, penetration depth, light stability, lateral resolution, and axial resolution of a combined ultrasound-photoacoustic imaging probe, as described in some embodiments herein.

[0025] **FIGS. 15A-15C** illustrate ultrasound images of swine and human teeth obtained by the ultrasound-photoacoustic imaging probe, as described in some embodiments herein.

[0026] FIGS. 16A-16D illustrate combined ultrasound and combined ultrasound-photoacoustic images of a swine subject's oral tissue with and without a contrast agent obtained by an ultrasound-photoacoustic imaging probe, as described in some embodiments herein.

[0027] FIGS. 17A-17C illustrate ultrasound and combined ultrasound-photoacoustic images of a human subject's oral tissue with and without a contrast agent obtained by an ultrasound-photoacoustic imaging probe, as described in some embodiments herein.

[0028] FIGS. 18A-18D illustrate combined ultrasound-photoacoustic images from poorly perfused and well perfused swine oral tissue, as described in some embodiments herein.

DETAILED DESCRIPTION

[0029] In the following detailed description, reference is made to the accompanying figures, which form a part hereof. In the figures, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, figures, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

[0030] Although certain embodiments and examples are disclosed below, inventive subject matter extends beyond the specifically disclosed embodiments to other alternative embodiments and/or uses, and to modifications and equivalents thereof. Thus, the scope of the claims appended hereto is not limited by any of the particular embodiments described below. For example, in any method or process disclosed herein, the acts or operations of the method or process may be performed in any suitable sequence and are not necessarily limited to any particular disclosed sequence. Various operations may be described as multiple discrete operations in turn, in a manner that may be helpful in understanding certain embodiments, however, the order of description should not be construed to imply that these operations are order dependent. Additionally, the structures, systems, and/or devices described herein may be embodied as integrated components or as separate components.

[0031] For purposes of comparing various embodiments, certain aspects and advantages of these embodiments are described. Not necessarily all such aspects or advantages are achieved by any particular embodiment. Thus, for example, various embodiments may be carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein

without necessarily achieving other aspects or advantages as may also be taught or suggested herein.

Overview

[0032] Nearly 50% of Americans have periodontitis resulting in pain, tooth loss, reduced quality of life and system effects e.g., cardiovascular disease, yet there are limited tools, methods, systems, and/or devices to diagnose and/or monitor periodontitis. Clinical assessment by periodontal examination and radiography are current standard of care but suffer from a plethora of limitations. Radiography offers sensitivity to hard tissue (bone, enamel, etc.) but cannot discriminate between healthy and diseased gingiva or map disease within soft tissue.

Radiography also emits a small but non-negligible dose of harmful ionizing radiation.

Periodontal examination provides information such as periodontal probing depth (PPD indicative of current periodontal health) and clinical attachment loss (CAL). PPD, CAL, and other clinical parameters form the basis of periodontal diagnosis. However, periodontal examination is time-consuming for providers, painful for patients (due to invasive nature of periodontal probing), and suffers from large inter operator errors (e.g., greater than 40%) from variations in probing technique and subjective interpretation between healthcare providers. Moreover, clinical assessment (e.g., via periodontal probing) and radiographic examination may not capture all clinical information available (e.g., gingival thickness and inflammation).

[0033] To solve these shortcomings and limitations of the current standard of care, the disclosure provided herein, in an aspect describes devices, systems, and methods of ultrasound, photoacoustic, and/or a combined ultrasound and photoacoustic that address such limitations and shortcomings. Ultrasound, photoacoustic, or a combination thereof imaging is capable of visualizing anatomical features of oral tissue e.g., alveolar bone crest (ABC), cementoenamel junction (CEJ), gingival thickness (GT), edentulous crestal bone, greater palatine foramen, lingual nerve, oral mucosa, or any combination thereof oral tissues in human and/or non-human mammal subjects. The use of ultrasound, photoacoustic, or a combination thereof imaging modalities provides data of such oral anatomical features that may then be analyzed by one or more algorithms, predictive models, machine learning models, artificial intelligence, or any combination thereof automated processing methods, described elsewhere herein, to provide objective reproducible measurements that may be used in determining a classification, diagnosis, or a status (e.g., from monitoring over time) of a disease. However, current ultrasound transducers are bulky and are limited in resolution by their low operating resonance frequency that limit the usability of such imaging modality and/or modalities in the oral cavity. The devices and systems, described elsewhere herein, address such limitations with a compact

intraoral imaging device capable of high-resolution (e.g., 102.1 μ m axial and 142.9 μ m lateral spatial resolution) configured to image all areas and/or tissues of the oral cavity.

[0034] The disclosure provided herein describes systems, devices, and methods configured to screen the oral health of a subject. In some cases, the systems, devices, and methods provided herein may be configured to determine a physiologic state of a subject, diagnose disease, or differentiate and/or classify one or more tissues of a subject's oral cavity. In some cases, this may be achieved through scanning the oral cavity of the subject with an intraoral imaging device in electrical and/or optical communication with an imaging system. In some cases, the intraoral imaging device may comprise an ultrasound imaging probe, a photoacoustic imaging probe, or any combination thereof. The intraoral imaging device may comprise a combined ultrasound-photoacoustic imaging probe. In some instances, the ultrasound imaging probe may comprise an ultrasound transducer array probe. In some cases, the intraoral imaging device may comprise a wireless intraoral imaging device, described elsewhere herein. In some instances, the one or more tissues of a subject's oral cavity may comprise gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, or any combination thereof tissue. In some cases, the classification of tissue of a subject's mouth may comprise classifying tissue as diseased or healthy. In some instances, the disease may comprise periodontal disease, oral cancer, or any combination thereof diseases. In some cases, the systems and devices disclosed herein may measure gingival pocket depth, clinical attachment loss, gingival biotype, gingival inflammation, or any combination thereof. In some cases, the systems and devices may be configured to conduct minimally invasive measurements of the oral cavity. In some cases, the devices disclosed herein may comprise hand-held intraoral imaging devices.

[0035] In some instances, the systems, devices, and methods provided herein may comprise systems, devices, and methods configured to perform visible light, near-infrared, photo-acoustic, ultrasound, or any combination thereof imaging modality. In some cases, the devices, systems, and methods disclosed herein may be configured to perform one or more imaging modalities simultaneously. The systems and devices disclosed herein may utilize one or more imaging modalities to generate one or more data sets and/or data streams that may be interpreted by software stored on a non-transitory computer readable storage medium. In some cases, the software may comprise a machine learning model. In some instances, the machine learning model may be trained and/or configured to measure and/or classify gingival pocket depth, clinical attachment loss, gingival biotype, gingival inflammation, or any combination thereof.

[0036] In some cases, the system may comprise an imaging system, user-interface, processor, non-transitory computer readable storage medium including software, dedicated power supply, one or more light sources, control circuitry, ultrasound acquisition module, or any combination

thereof. In some instances, the system may be portable allowing for the imaging system to be moved around a dentist's office, outpatient clinic, hospital, or any combination thereof setting. Systems and devices or components thereof of the disclosure provided herein, may be in optical, electrical, mechanical, opto-mechanical or any combination thereof communication between one another.

[0037] In some cases, the devices, systems, and methods disclosed herein produce unexpected results of higher resolution, higher contrast, deeper imaging depth, faster scanning times, and reproducibility of imaging measurements. In some instances, the unexpected results may be attributed to combination of the one or more imaging modalities described elsewhere herein, and the miniature and maneuverable form factor of the intraoral imaging device configured to reach hard to reach areas of the oral cavity. The combination of one or more imaging modalities (e.g., visible light, near-infrared, photo-acoustic, ultrasound, or any combination thereof imaging modalities) may provide a deeper imaging penetration depth into tissue of the oral cavity yet maintain a high resolution to determine anatomical and/or physiologic features pertaining to oral cavity health (e.g., gingival pocket depth, clinical attachment loss, gingival biotype, or gingival inflammation).

Imaging System

[0038] In some cases, the systems of the disclosure provided herein may comprise an imaging system **116**, where the imaging system may comprise an imaging module **100**, display screen interface **108**, ultrasound acquisition module **200**, non-transitory computer readable storage medium including software, adjustable user-interface mechanism **102**, or any combination thereof, as seen in **FIG. 1** and **FIG. 2**. In some cases, the imaging system **116** may utilize a user interface external to the imaging system. In some cases, the user interface external to the imaging system may comprise a standalone personal computing device or laptop computing device. In some cases, the system may further comprise one or more user interactive devices e.g., a mouse, keyboard, controller, foot pedal **112**, intraoral imaging device **104** or any combination thereof. In some cases, the foot pedal **112** may be configured to initiate imaging, end imaging, pause imaging, select a menu option, or any combination thereof actions. In some instances, the adjustable user-interface mechanism **102** may comprise a pneumatic adjustable display arm or a tension-based lever arm. In some cases, the imaging module **100** may comprise a button **110** configured to initiate a power on and/or a power off sequence for the imaging module **100**. In some cases, pressing the button **110** for a prolonged period of time of up to 3 seconds may restart and/or reset the imaging module **100** device settings to default manufacturer settings. In some cases, the user-interface may comprise a display screen interface **108**. In some

instances, the display screen interface **108** may comprise a touch screen interface. In some instances, the display screen interface **108** may be the display screen of a standalone personal computer and/or personal laptop. In some cases, the display interface may comprise a light emitting diode and/or organic light emitting diode display. In some cases, the imaging system **116** may comprise a mount and/or holder **118** configured to mechanically couple to the intraoral imaging device **104**. In some cases, the mount and/or holder **118** may be configured as a dock for the intraoral imaging device **104** e.g., when the intraoral imaging device is not in use.

[0039] In some cases, the imaging module **100** may be in electrical and/or optical communication with the intraoral imaging device **104**. In some instances, the imaging module **100** and intraoral imaging device **104** may be connected to one another by an electro-optical connection **106**. In some cases, the electro-optical connection may comprise a SMA connection, fiber optic connection, or any combination thereof. In some cases, the fiber optic connection may couple light from the imaging module **100** to a fiber bundle **304**, of the intraoral imaging device **104**, as seen in **FIGS. 3A-3B**. In some cases, the electro-optical connection **106** may comprise electrical connections between the imaging module **100** and the ultrasonic transducer **310** of the intraoral imaging device **104**.

[0040] In some instances, the imaging system **116** may be housed on a cart that may permit the imaging system **116** to be moved around a dentist's office, outpatient clinic, hospital, or any combination thereof setting. In some instances, the non-transitory computer readable storage medium including software may comprise implementations of machine learning models that may analyze photoacoustic and/or ultrasound data generated by the imaging system.

[0041] In some cases, the imaging module **100** may comprise one or more light sources configured to generate a light emission. In some cases, the one or more light sources may comprise a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, incoherent laser, Mode-locked laser, light emitting diode, surface emitting diode, super luminescent diode, or any combination thereof.

[0042] In some cases, the light emission of the one or more light sources may comprise a wavelength range of about 400 nanometers (nm) to about 1,700 nm. In some cases, the light emission of the one or more light sources may comprise a wavelength range of about 400 nm to about 500 nm, about 400 nm to about 600 nm, about 400 nm to about 700 nm, about 400 nm to about 800 nm, about 400 nm to about 900 nm, about 400 nm to about 1,000 nm, about 400 nm to about 1,200 nm, about 400 nm to about 1,500 nm, about 400 nm to about 1,700 nm, about 500 nm to about 600 nm, about 500 nm to about 700 nm, about 500 nm to about 800 nm, about 500 nm to about 900 nm, about 500 nm to about 1,000 nm, about 500 nm to about 1,200 nm, about 500 nm to about 1,500 nm, about 500 nm to about 1,700 nm, about 600 nm to about 700 nm,

about 600 nm to about 800 nm, about 600 nm to about 900 nm, about 600 nm to about 1,000 nm, about 600 nm to about 1,200 nm, about 600 nm to about 1,500 nm, about 600 nm to about 1,700 nm, about 700 nm to about 800 nm, about 700 nm to about 900 nm, about 700 nm to about 1,000 nm, about 700 nm to about 1,200 nm, about 700 nm to about 1,500 nm, about 700 nm to about 1,700 nm, about 800 nm to about 900 nm, about 800 nm to about 1,000 nm, about 800 nm to about 1,200 nm, about 800 nm to about 1,500 nm, about 800 nm to about 1,700 nm, about 900 nm to about 1,000 nm, about 900 nm to about 1,200 nm, about 900 nm to about 1,500 nm, about 900 nm to about 1,700 nm, about 1,000 nm to about 1,200 nm, about 1,000 nm to about 1,500 nm, about 1,000 nm to about 1,700 nm, about 1,200 nm to about 1,500 nm, about 1,200 nm to about 1,700 nm, or about 1,500 nm to about 1,700 nm. In some cases, the light emission of the one or more light sources may comprise a wavelength range of about 400 nm, about 500 nm, about 600 nm, about 700 nm, about 800 nm, about 900 nm, about 1,000 nm, about 1,200 nm, about 1,500 nm, or about 1,700 nm. In some cases, the light emission of the one or more light sources may comprise a wavelength range of at least about 400 nm, about 500 nm, about 600 nm, about 700 nm, about 800 nm, about 900 nm, about 1,000 nm, about 1,200 nm, or about 1,500 nm. In some cases, the light emission of the one or more light sources may comprise a wavelength range of at most about 500 nm, about 600 nm, about 700 nm, about 800 nm, about 900 nm, about 1,000 nm, about 1,200 nm, about 1,500 nm, or about 1,700 nm.

[0043] In some cases, the pulse width of the one or more light sources may be about 1 nanosecond (ns) to about 1,000 ns. In some cases, the pulse width of the one or more light sources may be about 1 ns to about 50 ns, about 1 ns to about 100 ns, about 1 ns to about 150 ns, about 1 ns to about 200 ns, about 1 ns to about 350 ns, about 1 ns to about 500 ns, about 1 ns to about 700 ns, about 1 ns to about 900 ns, about 1 ns to about 1,000 ns, about 50 ns to about 100 ns, about 50 ns to about 150 ns, about 50 ns to about 200 ns, about 50 ns to about 350 ns, about 50 ns to about 500 ns, about 50 ns to about 700 ns, about 50 ns to about 900 ns, about 50 ns to about 1,000 ns, about 100 ns to about 150 ns, about 100 ns to about 200 ns, about 100 ns to about 350 ns, about 100 ns to about 500 ns, about 100 ns to about 700 ns, about 100 ns to about 900 ns, about 100 ns to about 1,000 ns, about 150 ns to about 200 ns, about 150 ns to about 350 ns, about 150 ns to about 500 ns, about 150 ns to about 700 ns, about 150 ns to about 900 ns, about 150 ns to about 1,000 ns, about 200 ns to about 350 ns, about 200 ns to about 500 ns, about 200 ns to about 700 ns, about 200 ns to about 900 ns, about 200 ns to about 1,000 ns, about 350 ns to about 500 ns, about 350 ns to about 700 ns, about 350 ns to about 900 ns, about 350 ns to about 1,000 ns, about 500 ns to about 700 ns, about 500 ns to about 900 ns, about 500 ns to about 1,000 ns, about 700 ns to about 900 ns, about 700 ns to about 1,000 ns, or about 900 ns to about 1,000 ns. In some cases, the pulse width of the one or more light sources may be

about 1 ns, about 50 ns, about 100 ns, about 150 ns, about 200 ns, about 350 ns, about 500 ns, about 700 ns, about 900 ns, or about 1,000 ns. In some cases, the pulse width of the one or more light sources may be at least about 1 ns, about 50 ns, about 100 ns, about 150 ns, about 200 ns, about 350 ns, about 500 ns, about 700 ns, or about 900 ns. In some cases, the pulse width of the one or more light sources may be at most about 50 ns, about 100 ns, about 150 ns, about 200 ns, about 350 ns, about 500 ns, about 700 ns, about 900 ns, or about 1,000 ns.

[0044] In some instances, the pulse energy of the one or more light sources may be about 0.01 millijoule (mJ) to about 40 mJ. In some instances, the pulse energy of the one or more light sources may be about 0.01 mJ to about 0.1 mJ, about 0.01 mJ to about 0.5 mJ, about 0.01 mJ to about 1 mJ, about 0.01 mJ to about 10 mJ, about 0.01 mJ to about 20 mJ, about 0.01 mJ to about 30 mJ, about 0.01 mJ to about 40 mJ, about 0.1 mJ to about 0.5 mJ, about 0.1 mJ to about 1 mJ, about 0.1 mJ to about 10 mJ, about 0.1 mJ to about 20 mJ, about 0.1 mJ to about 30 mJ, about 0.1 mJ to about 40 mJ, about 0.5 mJ to about 1 mJ, about 0.5 mJ to about 10 mJ, about 0.5 mJ to about 20 mJ, about 0.5 mJ to about 30 mJ, about 0.5 mJ to about 40 mJ, about 1 mJ to about 10 mJ, about 1 mJ to about 20 mJ, about 1 mJ to about 30 mJ, about 1 mJ to about 40 mJ, about 10 mJ to about 20 mJ, about 10 mJ to about 30 mJ, about 10 mJ to about 40 mJ, about 20 mJ to about 30 mJ, about 20 mJ to about 40 mJ, or about 30 mJ to about 40 mJ. In some instances, the pulse energy of the one or more light sources may be about 0.01 mJ, about 0.1 mJ, about 0.5 mJ, about 1 mJ, about 10 mJ, about 20 mJ, about 30 mJ, or about 40 mJ. In some instances, the pulse energy of the one or more light sources may be at least about 0.01 mJ, about 0.1 mJ, about 0.5 mJ, about 1 mJ, about 10 mJ, about 20 mJ, or about 30 mJ. In some instances, the pulse energy of the one or more light sources may be at most about 0.1 mJ, about 0.5 mJ, about 1 mJ, about 10 mJ, about 20 mJ, about 30 mJ, or about 40 mJ.

[0045] In some instances, the imaging system may comprise an imaging acquisition rate of about 1 frame per second (fps) to about 60 fps. In some instances, the imaging system may comprise an imaging acquisition rate of about 1 fps to about 2 fps, about 1 fps to about 5 fps, about 1 fps to about 10 fps, about 1 fps to about 15 fps, about 1 fps to about 25 fps, about 1 fps to about 35 fps, about 1 fps to about 45 fps, about 1 fps to about 55 fps, about 1 fps to about 60 fps, about 2 fps to about 5 fps, about 2 fps to about 10 fps, about 2 fps to about 15 fps, about 2 fps to about 25 fps, about 2 fps to about 35 fps, about 2 fps to about 45 fps, about 2 fps to about 55 fps, about 2 fps to about 60 fps, about 5 fps to about 10 fps, about 5 fps to about 15 fps, about 5 fps to about 25 fps, about 5 fps to about 35 fps, about 5 fps to about 45 fps, about 5 fps to about 55 fps, about 5 fps to about 60 fps, about 10 fps to about 15 fps, about 10 fps to about 25 fps, about 10 fps to about 35 fps, about 10 fps to about 45 fps, about 10 fps to about 55 fps, about 10 fps to about 60 fps, about 15 fps to about 25 fps, about 15 fps to about 35 fps, about 15

fps to about 45 fps, about 15 fps to about 55 fps, about 15 fps to about 60 fps, about 25 fps to about 35 fps, about 25 fps to about 45 fps, about 25 fps to about 55 fps, about 25 fps to about 60 fps, about 35 fps to about 45 fps, about 35 fps to about 55 fps, about 35 fps to about 60 fps, about 45 fps to about 55 fps, about 45 fps to about 60 fps, or about 55 fps to about 60 fps. In some instances, the imaging system may comprise an imaging acquisition rate of about 1 fps, about 2 fps, about 5 fps, about 10 fps, about 15 fps, about 25 fps, about 35 fps, about 45 fps, about 55 fps, or about 60 fps. In some instances, the imaging system may comprise an imaging acquisition rate of at least about 1 fps, about 2 fps, about 5 fps, about 10 fps, about 15 fps, about 25 fps, about 35 fps, about 45 fps, or about 55 fps. In some instances, the imaging system may comprise an imaging acquisition rate of at most about 2 fps, about 5 fps, about 10 fps, about 15 fps, about 25 fps, about 35 fps, about 45 fps, about 55 fps, or about 60 fps.

[0046] In some cases, the one or more lights sources may comprise a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 Hz. In some cases, the one or more lights sources may comprise a pulse repetition rate of about 1 Hz to about 100 Hz, about 1 Hz to about 1,000 Hz, about 1 Hz to about 2,500 Hz, about 1 Hz to about 5,000 Hz, about 1 Hz to about 25,000 Hz, about 1 Hz to about 50,000 Hz, about 1 Hz to about 100,000 Hz, about 1 Hz to about 250,000 Hz, about 1 Hz to about 500,000 Hz, about 1 Hz to about 1,000,000 Hz, about 1 Hz to about 10,000,000 Hz, about 100 Hz to about 1,000 Hz, about 100 Hz to about 2,500 Hz, about 100 Hz to about 5,000 Hz, about 100 Hz to about 25,000 Hz, about 100 Hz to about 50,000 Hz, about 100 Hz to about 100,000 Hz, about 100 Hz to about 250,000 Hz, about 100 Hz to about 500,000 Hz, about 100 Hz to about 1,000,000 Hz, about 100 Hz to about 10,000,000 Hz, about 1,000 Hz to about 2,500 Hz, about 1,000 Hz to about 5,000 Hz, about 1,000 Hz to about 25,000 Hz, about 1,000 Hz to about 50,000 Hz, about 1,000 Hz to about 100,000 Hz, about 1,000 Hz to about 250,000 Hz, about 1,000 Hz to about 500,000 Hz, about 1,000 Hz to about 1,000,000 Hz, about 1,000 Hz to about 10,000,000 Hz, about 2,500 Hz to about 5,000 Hz, about 2,500 Hz to about 25,000 Hz, about 2,500 Hz to about 50,000 Hz, about 2,500 Hz to about 100,000 Hz, about 2,500 Hz to about 250,000 Hz, about 2,500 Hz to about 500,000 Hz, about 2,500 Hz to about 1,000,000 Hz, about 2,500 Hz to about 10,000,000 Hz, about 5,000 Hz to about 25,000 Hz, about 5,000 Hz to about 50,000 Hz, about 5,000 Hz to about 100,000 Hz, about 5,000 Hz to about 250,000 Hz, about 5,000 Hz to about 500,000 Hz, about 5,000 Hz to about 1,000,000 Hz, about 5,000 Hz to about 10,000,000 Hz, about 25,000 Hz to about 50,000 Hz, about 25,000 Hz to about 100,000 Hz, about 25,000 Hz to about 250,000 Hz, about 25,000 Hz to about 500,000 Hz, about 25,000 Hz to about 1,000,000 Hz, about 25,000 Hz to about 10,000,000 Hz, about 50,000 Hz to about 100,000 Hz, about 50,000 Hz to about 250,000 Hz, about 50,000 Hz to about 500,000 Hz, about 50,000 Hz to about 1,000,000 Hz, about 50,000 Hz to about 10,000,000 Hz,

about 100,000 Hz to about 250,000 Hz, about 100,000 Hz to about 500,000 Hz, about 100,000 Hz to about 1,000,000 Hz, about 100,000 Hz to about 10,000,000 Hz, about 250,000 Hz to about 500,000 Hz, about 250,000 Hz to about 1,000,000 Hz, about 250,000 Hz to about 10,000,000 Hz, about 500,000 Hz to about 1,000,000 Hz, about 500,000 Hz to about 10,000,000 Hz, or about 1,000,000 Hz to about 10,000,000 Hz. In some cases, the one or more lights sources may comprise a pulse repetition rate of about 1 Hz, about 100 Hz, about 1,000 Hz, about 2,500 Hz, about 5,000 Hz, about 25,000 Hz, about 50,000 Hz, about 100,000 Hz, about 250,000 Hz, about 500,000 Hz, about 1,000,000 Hz, or about 10,000,000 Hz. In some cases, the one or more lights sources may comprise a pulse repetition rate of at least about 1 Hz, about 100 Hz, about 1,000 Hz, about 2,500 Hz, about 5,000 Hz, about 25,000 Hz, about 50,000 Hz, about 100,000 Hz, about 250,000 Hz, about 500,000 Hz, or about 1,000,000 Hz. In some cases, the one or more lights sources may comprise a pulse repetition rate of at most about 100 Hz, about 1,000 Hz, about 2,500 Hz, about 5,000 Hz, about 25,000 Hz, about 50,000 Hz, about 100,000 Hz, about 250,000 Hz, about 500,000 Hz, about 1,000,000 Hz, or about 10,000,000 Hz.

[0047] In some cases, the one or more light sources may comprise a peak power output of about 10 W to about 40,000,000 W. In some cases, the one or more light sources may comprise a peak power output of about 10 W to about 500 W, about 10 W to about 5,000 W, about 10 W to about 10,000 W, about 10 W to about 25,000 W, about 10 W to about 50,000 W, about 10 W to about 100,000 W, about 10 W to about 250,000 W, about 10 W to about 5,000,000 W, about 10 W to about 10,000,000 W, about 10 W to about 20,000,000 W, about 10 W to about 40,000,000 W, about 500 W to about 5,000 W, about 500 W to about 10,000 W, about 500 W to about 25,000 W, about 500 W to about 50,000 W, about 500 W to about 100,000 W, about 500 W to about 250,000 W, about 500 W to about 5,000,000 W, about 500 W to about 10,000,000 W, about 500 W to about 20,000,000 W, about 500 W to about 40,000,000 W, about 5,000 W to about 10,000 W, about 5,000 W to about 25,000 W, about 5,000 W to about 50,000 W, about 5,000 W to about 100,000 W, about 5,000 W to about 250,000 W, about 5,000 W to about 5,000,000 W, about 5,000 W to about 10,000,000 W, about 5,000 W to about 20,000,000 W, about 5,000 W to about 40,000,000 W, about 10,000 W to about 25,000 W, about 10,000 W to about 50,000 W, about 10,000 W to about 100,000 W, about 10,000 W to about 250,000 W, about 10,000 W to about 5,000,000 W, about 10,000 W to about 10,000,000 W, about 10,000 W to about 20,000,000 W, about 10,000 W to about 40,000,000 W, about 25,000 W to about 50,000 W, about 25,000 W to about 100,000 W, about 25,000 W to about 250,000 W, about 25,000 W to about 5,000,000 W, about 25,000 W to about 10,000,000 W, about 25,000 W to about 20,000,000 W, about 25,000 W to about 40,000,000 W, about 50,000 W to about 100,000 W, about 50,000 W to about 250,000 W, about 50,000 W to about 5,000,000 W, about 50,000

W to about 10,000,000 W, about 50,000 W to about 20,000,000 W, about 50,000 W to about 40,000,000 W, about 100,000 W to about 250,000 W, about 100,000 W to about 5,000,000 W, about 100,000 W to about 10,000,000 W, about 100,000 W to about 20,000,000 W, about 100,000 W to about 40,000,000 W, about 250,000 W to about 5,000,000 W, about 250,000 W to about 10,000,000 W, about 250,000 W to about 20,000,000 W, about 250,000 W to about 40,000,000 W, about 5,000,000 W to about 10,000,000 W, about 5,000,000 W to about 20,000,000 W, about 5,000,000 W to about 40,000,000 W, about 10,000,000 W to about 20,000,000 W, about 10,000,000 W to about 40,000,000 W, or about 20,000,000 W to about 40,000,000 W. In some cases, the one or more light sources may comprise a peak power output of about 10 W, about 500 W, about 5,000 W, about 10,000 W, about 25,000 W, about 50,000 W, about 100,000 W, about 250,000 W, about 5,000,000 W, about 10,000,000 W, about 20,000,000 W, or about 40,000,000 W. In some cases, the one or more light sources may comprise a peak power output of at least about 10 W, about 500 W, about 5,000 W, about 10,000 W, about 25,000 W, about 50,000 W, about 100,000 W, about 250,000 W, about 5,000,000 W, about 10,000,000 W, or about 20,000,000 W. In some cases, the one or more light sources may comprise a peak power output of at most about 500 W, about 5,000 W, about 10,000 W, about 25,000 W, about 50,000 W, about 100,000 W, about 250,000 W, about 5,000,000 W, about 10,000,000 W, about 20,000,000 W, or about 40,000,000 W.

[0048] In some cases, the imaging module **100** may comprise electronic circuitry configured to detect, control, and analyze electro-optical signals. In some cases, the electronic circuitry may comprise a processor configured to execute a series of steps in software to detect, control, and analyze electro-optical signals generated by the imaging module **100** and intraoral imaging device **104**. In some cases, the software may be stored on a non-transitory computer readable storage medium within contained within or external to the imaging module **100**. In some cases, the electronic circuitry may be embedded in the intra oral imaging device **104**, configured for onboard processing. In some cases, the electronic circuitry embedded in the intra oral imaging device may be electrically coupled to the imaging module **100**, through a wired physical connection e.g., the electro-optical connection **106**. In some cases, the electronic circuitry may be configured to send and receive signals from the one or more ultrasound transducers **310**, at least one light source (described elsewhere herein), or any combination thereof, as described elsewhere herein. In some instances, the electronic circuitry may be configured to send and receive data from the imaging module **100** e.g., ultrasound, photoacoustic, visible light, or any combination thereof data and/or image data, to be further processed and/or displayed to one or more users and/or operators.

[0049] In some cases, the resolution of the imaging system **116** may be about 1 micrometer (μm) to about 1,000 μm . In some cases, the resolution of the imaging system **116** may be about 1 μm to about 5 μm , about 1 μm to about 10 μm , about 1 μm to about 50 μm , about 1 μm to about 100 μm , about 1 μm to about 200 μm , about 1 μm to about 300 μm , about 1 μm to about 400 μm , about 1 μm to about 500 μm , about 1 μm to about 800 μm , about 1 μm to about 1,000 μm , about 5 μm to about 10 μm , about 5 μm to about 50 μm , about 5 μm to about 100 μm , about 5 μm to about 200 μm , about 5 μm to about 300 μm , about 5 μm to about 400 μm , about 5 μm to about 500 μm , about 5 μm to about 800 μm , about 5 μm to about 1,000 μm , about 10 μm to about 50 μm , about 10 μm to about 100 μm , about 10 μm to about 200 μm , about 10 μm to about 300 μm , about 10 μm to about 400 μm , about 10 μm to about 500 μm , about 10 μm to about 800 μm , about 10 μm to about 1,000 μm , about 50 μm to about 100 μm , about 50 μm to about 200 μm , about 50 μm to about 300 μm , about 50 μm to about 400 μm , about 50 μm to about 500 μm , about 50 μm to about 800 μm , about 50 μm to about 1,000 μm , about 100 μm to about 200 μm , about 100 μm to about 300 μm , about 100 μm to about 400 μm , about 100 μm to about 500 μm , about 100 μm to about 800 μm , about 100 μm to about 1,000 μm , about 200 μm to about 300 μm , about 200 μm to about 400 μm , about 200 μm to about 500 μm , about 200 μm to about 800 μm , about 200 μm to about 1,000 μm , about 300 μm to about 400 μm , about 300 μm to about 500 μm , about 300 μm to about 800 μm , about 300 μm to about 1,000 μm , about 400 μm to about 500 μm , about 400 μm to about 800 μm , about 400 μm to about 1,000 μm , about 500 μm to about 800 μm , about 500 μm to about 1,000 μm , or about 800 μm to about 1,000 μm . In some cases, the resolution of the imaging system **116** may be about 1 μm , about 5 μm , about 10 μm , about 50 μm , about 100 μm , about 200 μm , about 300 μm , about 400 μm , about 500 μm , about 800 μm , or about 1,000 μm . In some cases, the resolution of the imaging system **116** may be at least about 1 μm , about 5 μm , about 10 μm , about 50 μm , about 100 μm , about 200 μm , about 300 μm , about 400 μm , about 500 μm , or about 800 μm . In some cases, the resolution of the imaging system **116** may be at most about 5 μm , about 10 μm , about 50 μm , about 100 μm , about 200 μm , about 300 μm , about 400 μm , about 500 μm , about 800 μm , or about 1,000 μm .

[0050] In some cases, the ultrasound acquisition module **200** may be configured to acquire ultrasound signals from about 2 channels to about 2,048 channels. In some cases, the ultrasound acquisition module **200** may be configured to acquire ultrasound signals from about 2 channels to about 4 channels, about 2 channels to about 10 channels, about 2 channels to about 16 channels, about 2 channels to about 32 channels, about 2 channels to about 64 channels, about 2 channels to about 128 channels, about 2 channels to about 256 channels, about 2 channels to about 512 channels, about 2 channels to about 1,024 channels, about 2 channels to about 2,048 channels, about 4 channels to about 10 channels, about 4 channels to about 16 channels, about 4

channels to about 32 channels, about 4 channels to about 64 channels, about 4 channels to about 128 channels, about 4 channels to about 256 channels, about 4 channels to about 512 channels, about 4 channels to about 1,024 channels, about 4 channels to about 2,048 channels, about 10 channels to about 16 channels, about 10 channels to about 32 channels, about 10 channels to about 64 channels, about 10 channels to about 128 channels, about 10 channels to about 256 channels, about 10 channels to about 512 channels, about 10 channels to about 1,024 channels, about 10 channels to about 2,048 channels, about 16 channels to about 32 channels, about 16 channels to about 64 channels, about 16 channels to about 128 channels, about 16 channels to about 256 channels, about 16 channels to about 512 channels, about 16 channels to about 1,024 channels, about 16 channels to about 2,048 channels, about 32 channels to about 64 channels, about 32 channels to about 128 channels, about 32 channels to about 256 channels, about 32 channels to about 512 channels, about 32 channels to about 1,024 channels, about 32 channels to about 2,048 channels, about 64 channels to about 128 channels, about 64 channels to about 256 channels, about 64 channels to about 512 channels, about 64 channels to about 1,024 channels, about 64 channels to about 2,048 channels, about 128 channels to about 256 channels, about 128 channels to about 512 channels, about 128 channels to about 1,024 channels, about 128 channels to about 2,048 channels, about 256 channels to about 512 channels, about 256 channels to about 1,024 channels, about 256 channels to about 2,048 channels, about 512 channels to about 1,024 channels, about 512 channels to about 2,048 channels, or about 1,024 channels to about 2,048 channels. In some cases, the ultrasound acquisition module **200** may be configured to acquire ultrasound signals from about 2 channels, about 4 channels, about 10 channels, about 16 channels, about 32 channels, about 64 channels, about 128 channels, about 256 channels, about 512 channels, about 1,024 channels, or about 2,048 channels. In some cases, the ultrasound acquisition module **200** may be configured to acquire ultrasound signals from at least about 2 channels, about 4 channels, about 10 channels, about 16 channels, about 32 channels, about 64 channels, about 128 channels, about 256 channels, about 512 channels, or about 1,024 channels. In some cases, the ultrasound acquisition module **200** may be configured to acquire ultrasound signals from at most about 4 channels, about 10 channels, about 16 channels, about 32 channels, about 64 channels, about 128 channels, about 256 channels, about 512 channels, about 1,024 channels, or about 2,048 channels.

[0051] In some instances, a trigger **204** generated by the one or more light sources may be utilized as a trigger for the different elements (**206, 208, 209, 210**) of the ultrasound acquisition module **200**. In some cases, the ultrasound acquisition module **200** may comprise one or more pre-amplifiers **206**. In some instances, the pre-amplifier may be configured to amplify ultrasound and/or photoacoustic data signals **202** from one or more ultrasound transducers. In

some instances, the ultrasound acquisition module **200** may comprise a pulser. In some cases, the pulser may comprise a pulser receiver.

[0052] In some cases, the pre-amplifier **206** may comprise a tunable gain of about 30 dB to about 100 dB. In some cases, the pre-amplifier may comprise a tunable gain of about 30 dB to about 40 dB, about 30 dB to about 50 dB, about 30 dB to about 60 dB, about 30 dB to about 70 dB, about 30 dB to about 80 dB, about 30 dB to about 90 dB, about 30 dB to about 100 dB, about 40 dB to about 50 dB, about 40 dB to about 60 dB, about 40 dB to about 70 dB, about 40 dB to about 80 dB, about 40 dB to about 90 dB, about 40 dB to about 100 dB, about 50 dB to about 60 dB, about 50 dB to about 70 dB, about 50 dB to about 80 dB, about 50 dB to about 90 dB, about 50 dB to about 100 dB, about 60 dB to about 70 dB, about 60 dB to about 80 dB, about 60 dB to about 90 dB, about 60 dB to about 100 dB, about 70 dB to about 80 dB, about 70 dB to about 90 dB, about 70 dB to about 100 dB, about 80 dB to about 90 dB, about 80 dB to about 100 dB, or about 90 dB to about 100 dB. In some cases, the pre-amplifier may comprise a tunable gain of about 30 dB, about 40 dB, about 50 dB, about 60 dB, about 70 dB, about 80 dB, about 90 dB, or about 100 dB. In some cases, the pre-amplifier may comprise a tunable gain of at least about 30 dB, about 40 dB, about 50 dB, about 60 dB, about 70 dB, about 80 dB, or about 90 dB. In some cases, the pre-amplifier may comprise a tunable gain of at most about 40 dB, about 50 dB, about 60 dB, about 70 dB, about 80 dB, about 90 dB, or about 100 dB.

[0053] In some cases, the ultrasound acquisition module **200** may comprise one or more multiplexers **208**. In some cases, the amplified signal generated by the one or more pre-amplifiers **206** may then be routed to one or more multiplexers **208** each comprising up to 16 channels. In some instances, the one or more multiplexers **208** may be configured as 8-channel multiplexers.

[0054] In some cases, the signal from the one or more multiplexers **208** may then be routed to one or more second stage amplifiers **209**. In some instances, the one or more second stage amplifiers **209** may comprise a programmable gain of about 30 dB to about 100 dB.

[0055] In some instances, the one or more second stage amplifiers **209** may comprise a programmable gain of about 30 dB to about 40 dB, about 30 dB to about 50 dB, about 30 dB to about 60 dB, about 30 dB to about 70 dB, about 30 dB to about 80 dB, about 30 dB to about 90 dB, about 30 dB to about 100 dB, about 40 dB to about 50 dB, about 40 dB to about 60 dB, about 40 dB to about 70 dB, about 40 dB to about 80 dB, about 40 dB to about 90 dB, about 40 dB to about 100 dB, about 50 dB to about 60 dB, about 50 dB to about 70 dB, about 50 dB to about 80 dB, about 50 dB to about 90 dB, about 50 dB to about 100 dB, about 60 dB to about 70 dB, about 60 dB to about 80 dB, about 60 dB to about 90 dB, about 60 dB to about 100 dB, about 70 dB to about 80 dB, about 70 dB to about 90 dB, about 70 dB to about 100 dB, about 80

dB to about 90 dB, about 80 dB to about 100 dB, or about 90 dB to about 100 dB. In some instances, the one or more second stage amplifiers **209** may comprise a programmable gain of about 30 dB, about 40 dB, about 50 dB, about 60 dB, about 70 dB, about 80 dB, about 90 dB, or about 100 dB. In some instances, the one or more second stage amplifiers **209** may comprise a programmable gain of at least about 30 dB, about 40 dB, about 50 dB, about 60 dB, about 70 dB, about 80 dB, or about 90 dB. In some instances, the one or more second stage amplifiers **209** may comprise a programmable gain of at most about 40 dB, about 50 dB, about 60 dB, about 70 dB, about 80 dB, about 90 dB, or about 100 dB.

[0056] The output of the one or more second stage amplifiers **209** may then be routed to one or more analog-to-digital converters **210**. The converted analog-to-digital signal may then be routed to a processor **212** to record and further process the acquired ultrasound and/or photoacoustic signals. Alternatively, the ultrasound acquisition module **200** may comprise one 16 channel acquisition analog-to-digital converter.

[0057] In some cases, the electronic circuitry may comprise an ultrasound pulse generator in electrical communication with the transducer **310** of the intraoral imaging device **104**, as seen in **FIG. 3**, to generate ultrasound signals. In some instances, the ultrasound pulse generator may be configured to generate an ultrasonic transducer driving signal.

Intraoral imaging device

[0058] Aspects of the disclosure provided herein may comprise an intraoral imaging device **104**, as shown in **FIGS. 3A-3C**. In some cases, the intraoral imaging device **104** may be configured to emit excitation light directed at one or more tissues of a subject's oral cavity and detect ultrasonic pressure waves generated by the absorption of the excitation light by the one or more tissues of a subject's oral cavity.

[0059] The intraoral imaging device **104** may comprise a scan head sized and shaped to be placed inside a subject's mouth. In some cases, the intraoral imaging device **104** may comprise an imaging tip **311** that may house the electro-optical components (**308, 310, 311, 312, 306**) of the intraoral imaging device **104**. In some cases, the imaging tip **311** may comprise a glass window to prevent moisture or liquid from entering into the imaging tip **311**. In some instances, the imaging tip **311** may be wholly or partially covered by a disposable, single time use, sterile material. In some cases, the material may comprise a sterilizable sheath. In some instances, the material may be a polymer or plastic. In some cases, the material may comprise impedance matching properties between the imaging tip **311** and the one or more tissues of a subject's oral cavity. In some cases, the impedance matching properties of the material may provide unexpected added benefit of improving the signal to noise, described elsewhere herein, for

photoacoustic and/or ultrasound imaging otherwise unattainable without the sheath wholly or partially covering the imaging tip **311**.

[0060] In some cases, the imaging tip **311** may comprise a height of about 1 mm to about 40 mm. In some cases, the imaging tip **311** may comprise a height of about 1 mm to about 5 mm, about 1 mm to about 10 mm, about 1 mm to about 15 mm, about 1 mm to about 20 mm, about 1 mm to about 25 mm, about 1 mm to about 30 mm, about 1 mm to about 35 mm, about 1 mm to about 40 mm, about 5 mm to about 10 mm, about 5 mm to about 15 mm, about 5 mm to about 20 mm, about 5 mm to about 25 mm, about 5 mm to about 30 mm, about 5 mm to about 35 mm, about 5 mm to about 40 mm, about 10 mm to about 15 mm, about 10 mm to about 20 mm, about 10 mm to about 25 mm, about 10 mm to about 30 mm, about 10 mm to about 35 mm, about 10 mm to about 40 mm, about 15 mm to about 20 mm, about 15 mm to about 25 mm, about 15 mm to about 30 mm, about 15 mm to about 35 mm, about 15 mm to about 40 mm, about 20 mm to about 25 mm, about 20 mm to about 30 mm, about 20 mm to about 35 mm, about 20 mm to about 40 mm, about 25 mm to about 30 mm, about 25 mm to about 35 mm, about 25 mm to about 40 mm, about 30 mm to about 35 mm, about 30 mm to about 40 mm, or about 35 mm to about 40 mm. In some cases, the imaging tip **311** may comprise a height of about 1 mm, about 5 mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, about 35 mm, or about 40 mm. In some cases, the imaging tip **311** may comprise a height of at least about 1 mm, about 5 mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, or about 35 mm. In some cases, the imaging tip **311** may comprise a height of at most about 5 mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, about 35 mm, or about 40 mm.

[0061] In some cases, the imaging tip **311** may comprise a width of about 1 mm to about 40 mm. In some cases, the imaging tip **311** may comprise a width of about 1 mm to about 5 mm, about 1 mm to about 10 mm, about 1 mm to about 15 mm, about 1 mm to about 20 mm, about 1 mm to about 25 mm, about 1 mm to about 30 mm, about 1 mm to about 35 mm, about 1 mm to about 40 mm, about 5 mm to about 10 mm, about 5 mm to about 15 mm, about 5 mm to about 20 mm, about 5 mm to about 25 mm, about 5 mm to about 30 mm, about 5 mm to about 35 mm, about 5 mm to about 40 mm, about 10 mm to about 15 mm, about 10 mm to about 20 mm, about 10 mm to about 25 mm, about 10 mm to about 30 mm, about 10 mm to about 35 mm, about 10 mm to about 40 mm, about 15 mm to about 20 mm, about 15 mm to about 25 mm, about 15 mm to about 30 mm, about 15 mm to about 35 mm, about 15 mm to about 40 mm, about 20 mm to about 25 mm, about 20 mm to about 30 mm, about 20 mm to about 35 mm, about 20 mm to about 40 mm, about 25 mm to about 30 mm, about 25 mm to about 35 mm, about 25 mm to about 40 mm, about 30 mm to about 35 mm, about 30 mm to about 40 mm, or about 35 mm to about 40 mm. In some cases, the imaging tip **311** may comprise a width of about 1 mm, about 5

mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, about 35 mm, or about 40 mm. In some cases, the imaging tip 311 may comprise a width of at least about 1 mm, about 5 mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, or about 35 mm. In some cases, the imaging tip 311 may comprise a width of at most about 5 mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, about 35 mm, or about 40 mm.

[0062] The scan head of the intraoral imaging device **104** may comprise at least one ultrasonic transducer **310** configured to detect one or more pressure waves with a signal to noise ratio of at least 3dB and at least one light source for generating said one or more pressure waves within one or more tissues of the subject's mouth. In some cases, the one or more pressure waves may be generated by the at least one ultrasonic transducer **310** and/or the at least one light source. In some cases, the one or more pressure waves may be converted into one or more ultrasonic and/or photoacoustic images, wherein the ultrasonic and/or photoacoustic images may comprise one or more oral health metrics. In some instances, the one or more oral health metrics may comprise gingival pocket depth, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, or any combination thereof.

[0063] In some cases, the signal to noise ratio may be about 1 decibels (dB) to about 100 dB. In some cases, the signal noise to ratio may be about 1 dB to about 2 dB, about 1 dB to about 4 dB, about 1 dB to about 8 dB, about 1 dB to about 10 dB, about 1 dB to about 30 dB, about 1 dB to about 50 dB, about 1 dB to about 60 dB, about 1 dB to about 70 dB, about 1 dB to about 89 dB, about 1 dB to about 90 dB, about 1 dB to about 100 dB, about 2 dB to about 4 dB, about 2 dB to about 8 dB, about 2 dB to about 10 dB, about 2 dB to about 30 dB, about 2 dB to about 50 dB, about 2 dB to about 60 dB, about 2 dB to about 70 dB, about 2 dB to about 89 dB, about 2 dB to about 90 dB, about 2 dB to about 100 dB, about 4 dB to about 8 dB, about 4 dB to about 10 dB, about 4 dB to about 30 dB, about 4 dB to about 50 dB, about 4 dB to about 60 dB, about 4 dB to about 70 dB, about 4 dB to about 89 dB, about 4 dB to about 90 dB, about 4 dB to about 100 dB, about 8 dB to about 10 dB, about 8 dB to about 30 dB, about 8 dB to about 50 dB, about 8 dB to about 60 dB, about 8 dB to about 70 dB, about 8 dB to about 89 dB, about 8 dB to about 90 dB, about 8 dB to about 100 dB, about 10 dB to about 30 dB, about 10 dB to about 50 dB, about 10 dB to about 60 dB, about 10 dB to about 70 dB, about 10 dB to about 89 dB, about 10 dB to about 90 dB, about 10 dB to about 100 dB, about 30 dB to about 50 dB, about 30 dB to about 60 dB, about 30 dB to about 70 dB, about 30 dB to about 89 dB, about 30 dB to about 90 dB, about 30 dB to about 100 dB, about 50 dB to about 60 dB, about 50 dB to about 70 dB, about 50 dB to about 89 dB, about 50 dB to about 90 dB, about 50 dB to about 100 dB, about 60 dB to about 70 dB, about 60 dB to about 89 dB, about 60 dB to about 90 dB, about 60 dB to about 100 dB, about 70 dB to about 89 dB, about 70 dB to about 90 dB, about 70 dB to about 100 dB, about 89

dB to about 90 dB, about 89 dB to about 100 dB, or about 90 dB to about 100 dB. In some cases, the signal to noise ratio may be about 1 dB, about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, about 90 dB, or about 100 dB. In some cases, the signal to noise ratio may be at least about 1 dB, about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, or about 90 dB. In some cases, the signal to noise ratio may be at most about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, about 90 dB, or about 100 dB.

[0064] In some cases, the contrast may be about 1 decibels (dB) to about 100 dB. In some cases, the signal to noise ratio may be about 1 dB to about 2 dB, about 1 dB to about 4 dB, about 1 dB to about 8 dB, about 1 dB to about 10 dB, about 1 dB to about 30 dB, about 1 dB to about 50 dB, about 1 dB to about 60 dB, about 1 dB to about 70 dB, about 1 dB to about 89 dB, about 1 dB to about 90 dB, about 1 dB to about 100 dB, about 2 dB to about 4 dB, about 2 dB to about 8 dB, about 2 dB to about 10 dB, about 2 dB to about 30 dB, about 2 dB to about 50 dB, about 2 dB to about 60 dB, about 2 dB to about 70 dB, about 2 dB to about 89 dB, about 2 dB to about 90 dB, about 2 dB to about 100 dB, about 4 dB to about 8 dB, about 4 dB to about 10 dB, about 4 dB to about 30 dB, about 4 dB to about 50 dB, about 4 dB to about 60 dB, about 4 dB to about 70 dB, about 4 dB to about 89 dB, about 4 dB to about 90 dB, about 4 dB to about 100 dB, about 8 dB to about 10 dB, about 8 dB to about 30 dB, about 8 dB to about 50 dB, about 8 dB to about 60 dB, about 8 dB to about 70 dB, about 8 dB to about 89 dB, about 8 dB to about 90 dB, about 8 dB to about 100 dB, about 10 dB to about 30 dB, about 10 dB to about 50 dB, about 10 dB to about 60 dB, about 10 dB to about 70 dB, about 10 dB to about 89 dB, about 10 dB to about 90 dB, about 10 dB to about 100 dB, about 30 dB to about 50 dB, about 30 dB to about 60 dB, about 30 dB to about 70 dB, about 30 dB to about 89 dB, about 30 dB to about 90 dB, about 30 dB to about 100 dB, about 50 dB to about 60 dB, about 50 dB to about 70 dB, about 50 dB to about 89 dB, about 50 dB to about 90 dB, about 50 dB to about 100 dB, about 60 dB to about 70 dB, about 60 dB to about 89 dB, about 60 dB to about 90 dB, about 60 dB to about 100 dB, about 70 dB to about 89 dB, about 70 dB to about 90 dB, about 70 dB to about 100 dB, about 89 dB to about 90 dB, about 89 dB to about 100 dB, or about 90 dB to about 100 dB. In some cases, the contrast may be about 1 dB, about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, about 90 dB, or about 100 dB. In some cases, the contrast may be at least about 1 dB, about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, or about 90 dB. In some cases, the contrast may be at most about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, about 90 dB, or about 100 dB.

[0065] In some instances, the ultrasonic transducer **310** may comprise linear array, phase array, or any combination thereof ultrasonic transducer.

[0066] In some cases, the ultrasonic transducer may comprise about 1 element to about 2,048 elements. In some cases, the ultrasonic transducer may comprise about 1 element to about 2 elements, about 1 element to about 4 elements, about 1 element to about 8 elements, about 1 element to about 16 elements, about 1 element to about 32 elements, about 1 element to about 64 elements, about 1 element to about 128 elements, about 1 element to about 256 elements, about 1 element to about 512 elements, about 1 element to about 1,025 elements, about 1 element to about 2,048 elements, about 2 elements to about 4 elements, about 2 elements to about 8 elements, about 2 elements to about 16 elements, about 2 elements to about 32 elements, about 2 elements to about 64 elements, about 2 elements to about 128 elements, about 2 elements to about 256 elements, about 2 elements to about 512 elements, about 2 elements to about 1,025 elements, about 2 elements to about 2,048 elements, about 4 elements to about 8 elements, about 4 elements to about 16 elements, about 4 elements to about 32 elements, about 4 elements to about 64 elements, about 4 elements to about 128 elements, about 4 elements to about 256 elements, about 4 elements to about 512 elements, about 4 elements to about 1,025 elements, about 4 elements to about 2,048 elements, about 8 elements to about 16 elements, about 8 elements to about 32 elements, about 8 elements to about 64 elements, about 8 elements to about 128 elements, about 8 elements to about 256 elements, about 8 elements to about 512 elements, about 8 elements to about 1,025 elements, about 8 elements to about 2,048 elements, about 16 elements to about 32 elements, about 16 elements to about 64 elements, about 16 elements to about 128 elements, about 16 elements to about 256 elements, about 16 elements to about 512 elements, about 16 elements to about 1,025 elements, about 16 elements to about 2,048 elements, about 32 elements to about 64 elements, about 32 elements to about 128 elements, about 32 elements to about 256 elements, about 32 elements to about 512 elements, about 32 elements to about 1,025 elements, about 32 elements to about 2,048 elements, about 64 elements to about 128 elements, about 64 elements to about 256 elements, about 64 elements to about 512 elements, about 64 elements to about 1,025 elements, about 64 elements to about 2,048 elements, about 128 elements to about 256 elements, about 128 elements to about 512 elements, about 128 elements to about 1,025 elements, about 128 elements to about 2,048 elements, about 256 elements to about 512 elements, about 256 elements to about 1,025 elements, about 256 elements to about 2,048 elements, about 512 elements to about 1,025 elements, about 512 elements to about 2,048 elements, or about 1,025 elements to about 2,048 elements. In some cases, the ultrasonic transducer may comprise about 1 element, about 2 elements, about 4 elements, about 8 elements, about 16 elements, about 32 elements, about 64 elements, about 128

elements, about 256 elements, about 512 elements, about 1,025 elements, or about 2,048 elements. In some cases, the ultrasonic transducer may comprise at least about 1 element, about 2 elements, about 4 elements, about 8 elements, about 16 elements, about 32 elements, about 64 elements, about 128 elements, about 256 elements, about 512 elements, or about 1,025 elements. In some cases, the ultrasonic transducer may comprise at most about 2 elements, about 4 elements, about 8 elements, about 16 elements, about 32 elements, about 64 elements, about 128 elements, about 256 elements, about 512 elements, about 1,025 elements, or about 2,048 elements.

[0067] In some instances, the center frequency of the ultrasonic transducer may comprise about 1 megahertz (MHz) to about 40 MHz. In some instances, the center frequency of the transducer may comprise about 1 MHz to about 5 MHz, about 1 MHz to about 10 MHz, about 1 MHz to about 20 MHz, about 1 MHz to about 25 MHz, about 1 MHz to about 30 MHz, about 1 MHz to about 35 MHz, about 1 MHz to about 40 MHz, about 5 MHz to about 10 MHz, about 5 MHz to about 20 MHz, about 5 MHz to about 25 MHz, about 5 MHz to about 30 MHz, about 5 MHz to about 35 MHz, about 5 MHz to about 40 MHz, about 10 MHz to about 20 MHz, about 10 MHz to about 25 MHz, about 10 MHz to about 30 MHz, about 10 MHz to about 35 MHz, about 10 MHz to about 40 MHz, about 20 MHz to about 25 MHz, about 20 MHz to about 30 MHz, about 20 MHz to about 35 MHz, about 20 MHz to about 40 MHz, about 25 MHz to about 30 MHz, about 25 MHz to about 35 MHz, about 25 MHz to about 40 MHz, about 30 MHz to about 35 MHz, about 30 MHz to about 40 MHz, or about 35 MHz to about 40 MHz. In some instances, the center frequency of the ultrasonic transducer may comprise about 1 MHz, about 5 MHz, about 10 MHz, about 20 MHz, about 25 MHz, about 30 MHz, about 35 MHz, or about 40 MHz. In some instances, the center frequency of the ultrasonic transducer may comprise at least about 1 MHz, about 5 MHz, about 10 MHz, about 20 MHz, about 25 MHz, about 30 MHz, or about 35 MHz. In some instances, the center frequency of the ultrasonic transducer may comprise at most about 5 MHz, about 10 MHz, about 20 MHz, about 25 MHz, about 30 MHz, about 35 MHz, or about 40 MHz.

[0068] In some cases, the light source may comprise one or more light sources described elsewhere herein. In some instances, the at least one light source may comprise one or more fibers. In some cases, the at least one light source may comprise a fiber bundle **304**. In some instances, the fiber bundle may be in optical communication with the one or more light sources of the imaging module **100**. In some cases, the optical communication may comprise a Subminiature version A (SMA) connector.

[0069] In some cases, the fiber bundle **304** may comprise about 1 fiber to about 100 fibers. In some cases, the fiber bundle **304** may comprise about 1 fiber to about 2 fibers, about 1 fiber to

about 4 fibers, about 1 fiber to about 8 fibers, about 1 fiber to about 10 fibers, about 1 fiber to about 30 fibers, about 1 fiber to about 50 fibers, about 1 fiber to about 60 fibers, about 1 fiber to about 70 fibers, about 1 fiber to about 89 fibers, about 1 fiber to about 90 fibers, about 1 fiber to about 100 fibers, about 2 fibers to about 4 fibers, about 2 fibers to about 8 fibers, about 2 fibers to about 10 fibers, about 2 fibers to about 30 fibers, about 2 fibers to about 50 fibers, about 2 fibers to about 60 fibers, about 2 fibers to about 70 fibers, about 2 fibers to about 89 fibers, about 2 fibers to about 90 fibers, about 2 fibers to about 100 fibers, about 4 fibers to about 8 fibers, about 4 fibers to about 10 fibers, about 4 fibers to about 30 fibers, about 4 fibers to about 50 fibers, about 4 fibers to about 60 fibers, about 4 fibers to about 70 fibers, about 4 fibers to about 89 fibers, about 4 fibers to about 90 fibers, about 4 fibers to about 100 fibers, about 8 fibers to about 10 fibers, about 8 fibers to about 30 fibers, about 8 fibers to about 50 fibers, about 8 fibers to about 60 fibers, about 8 fibers to about 70 fibers, about 8 fibers to about 89 fibers, about 8 fibers to about 90 fibers, about 8 fibers to about 100 fibers, about 10 fibers to about 30 fibers, about 10 fibers to about 50 fibers, about 10 fibers to about 60 fibers, about 10 fibers to about 70 fibers, about 10 fibers to about 89 fibers, about 10 fibers to about 90 fibers, about 10 fibers to about 100 fibers, about 30 fibers to about 50 fibers, about 30 fibers to about 60 fibers, about 30 fibers to about 70 fibers, about 30 fibers to about 89 fibers, about 30 fibers to about 90 fibers, about 30 fibers to about 100 fibers, about 50 fibers to about 60 fibers, about 50 fibers to about 70 fibers, about 50 fibers to about 89 fibers, about 50 fibers to about 90 fibers, about 50 fibers to about 100 fibers, about 60 fibers to about 70 fibers, about 60 fibers to about 89 fibers, about 60 fibers to about 90 fibers, about 60 fibers to about 100 fibers, about 70 fibers to about 89 fibers, about 70 fibers to about 90 fibers, about 70 fibers to about 100 fibers, about 89 fibers to about 90 fibers, about 89 fibers to about 100 fibers, or about 90 fibers to about 100 fibers. In some cases, the fiber bundle **304** may comprise about 1 fiber, about 2 fibers, about 4 fibers, about 8 fibers, about 10 fibers, about 30 fibers, about 50 fibers, about 60 fibers, about 70 fibers, about 89 fibers, about 90 fibers, or about 100 fibers. In some cases, the fiber bundle **304** may comprise at least about 1 fiber, about 2 fibers, about 4 fibers, about 8 fibers, about 10 fibers, about 30 fibers, about 50 fibers, about 60 fibers, about 70 fibers, about 89 fibers, or about 90 fibers. In some cases, the fiber bundle **304** may comprise at most about 2 fibers, about 4 fibers, about 8 fibers, about 10 fibers, about 30 fibers, about 50 fibers, about 60 fibers, about 70 fibers, about 89 fibers, about 90 fibers, or about 100 fibers.

[0070] In some cases, the fiber bundle **304** may be in optical communication with one or more optical elements (**306**, **312**). In some instances, the one or more optical elements may comprise a plano-convex lens **306**, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror **312**, or any combination thereof.

[0071] In some cases, the dielectric mirror **312** may be positioned closer to the distal tip of the device compared to the ultrasonic transducer **310**, as seen in **FIG. 3B**. In some instances, the angle of the dielectric mirror **312** with respect to the optical axis of the one or more optical elements **306** may comprise an angle of less than about 45 degrees.

[0072] In some cases, the ultrasonic transducer **310** may be positioned closer to the distal tip of the device compared to the dielectric mirror **312**, as seen in **FIG. 3C**. In some instances, the angle of the dielectric mirror **312** with respect to the optical axis of the one or more optical elements **306** may comprise an angle of at least about 45 degrees. In some cases, the angle of the dielectric mirror **312** with respect to the optical axis of the one or more optical elements **306** may be configured such that the light emission **316** directed from the one or more optical elements **306** by the dielectric mirror **312** intersects the field of view of the ultrasonic transducer **310**. In some cases, when the light emission **316** intersects the field of view of the ultrasonic transducer **310** the ultrasonic transducer may detect the one or more pressure waves **318** within one or more tissues of the subject's oral cavity **314**.

[0073] In some instances, the interface between the one or more optical components and the fiber bundle **304** may comprise an index matching material configured to transmit optical energy from one or more fibers of the fiber bundle **304** to the one or more tissues of a subject's oral cavity. In some cases, the one or more fibers of the fiber bundle **304** may be cleaved at an angle with respect to the optical axis of the fiber. In some cases, the angle may comprise up to 8 degrees. In some instances, the angle cleaved fibers of the fiber bundle may prevent damage to end of the fiber bundle transmitting light energy to the one or more optical elements **306** described elsewhere herein. The index matching material may comprise an index matching gel, liquid, adhesive, or any combination thereof.

[0074] In some cases, the one or fibers of the fiber bundle **304** may comprise a fiber core diameter of about 20 micrometers (μm) to about 1,000 μm . In some cases, the one or fibers of the fiber bundle **304** may comprise a fiber core diameter of about 20 μm to about 50 μm , about 20 μm to about 100 μm , about 20 μm to about 200 μm , about 20 μm to about 300 μm , about 20 μm to about 400 μm , about 20 μm to about 500 μm , about 20 μm to about 600 μm , about 20 μm to about 800 μm , about 20 μm to about 1,000 μm , about 50 μm to about 100 μm , about 50 μm to about 200 μm , about 50 μm to about 300 μm , about 50 μm to about 400 μm , about 50 μm to about 500 μm , about 50 μm to about 600 μm , about 50 μm to about 800 μm , about 50 μm to about 1,000 μm , about 100 μm to about 200 μm , about 100 μm to about 300 μm , about 100 μm to about 400 μm , about 100 μm to about 500 μm , about 100 μm to about 600 μm , about 100 μm to about 800 μm , about 100 μm to about 1,000 μm , about 200 μm to about 300 μm , about 200 μm to about 400 μm , about 200 μm to about 500 μm , about 200 μm to about 600 μm , about 200

μm to about 800 μm, about 200 μm to about 1,000 μm, about 300 μm to about 400 μm, about 300 μm to about 500 μm, about 300 μm to about 600 μm, about 300 μm to about 800 μm, about 300 μm to about 1,000 μm, about 400 μm to about 500 μm, about 400 μm to about 600 μm, about 400 μm to about 800 μm, about 400 μm to about 1,000 μm, about 500 μm to about 600 μm, about 500 μm to about 800 μm, about 500 μm to about 1,000 μm, about 600 μm to about 800 μm, about 600 μm to about 1,000 μm, or about 800 μm to about 1,000 μm. In some cases, the one or fibers of the fiber bundle 304 may comprise a fiber core diameter of about 20 μm, about 50 μm, about 100 μm, about 200 μm, about 300 μm, about 400 μm, about 500 μm, about 600 μm, about 800 μm, or about 1,000 μm. In some cases, the one or fibers of the fiber bundle 304 may comprise a fiber core diameter of at least about 20 μm, about 50 μm, about 100 μm, about 200 μm, about 300 μm, about 400 μm, about 500 μm, about 600 μm, or about 800 μm. In some cases, the one or fibers of the fiber bundle 304 may comprise a fiber core diameter of at most about 50 μm, about 100 μm, about 200 μm, about 300 μm, about 400 μm, about 500 μm, about 600 μm, about 800 μm, or about 1,000 μm.

[0075] In some cases, the intraoral imaging device 104 may comprise one or more sensors 308 configured to sense light reflected off of tissue within a subject's mouth, as seen in **FIGS. 3A-3C**. In some instances, the one or more sensors 308 may comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof. In some cases, one of the one or more light sources, described elsewhere herein may be configured to provide visible illumination for visualization of one or more tissues within the oral cavity of a subject by the one or more sensors 308. In some cases, the one or more sensors 308 may be configured to generate a three-dimensional topography of tissues within a subject's mouth.

[0076] In some instances, the intraoral imaging device 104 may comprise a rigid biocompatible exterior 300. In some cases, the rigid biocompatible exterior 300 may be constructed from stainless steel, biocompatible plastics, or any combination thereof. The rigid biocompatible exterior 300 may comprise user interaction surfaces 302, where the user interaction surfaces may comprise a button 704, slider, toggle switch, or any combination thereof interface. In some cases, the user interaction surface may control, select, or modify an aspect of the imaging module or methods of imaging described elsewhere herein.

[0077] In some cases, the intraoral imaging device may comprise a wireless intraoral device 700, as shown in **FIG. 7**. The wireless intraoral device may comprise: a tip 724, where the tip comprises at least one light source 720 and at least one ultrasound transducer 722; and a processor (708, 714, 712) in electrical communication with the at least one light source 720 and the at least one ultrasound transducer 722, where the processor is located on a body 702 of the wireless intraoral imaging device. In some instances, the at least one ultrasound transducer 722

may comprise an array ultrasound transducer comprised of a plurality of ultrasound transducer elements. In some cases, the at least one light source **720** may comprise an array of light source elements. In some cases, the wireless intraoral device **700** and/or device tip **724** may be sized, as described elsewhere herein, to allow for whole oral cavity imaging. In some cases, the wireless intraoral device **700** may comprise a sensor **718**, where the sensor **718** may comprise a light-based sensor (e.g., a CCD and/or CMOS camera, described elsewhere herein), gyroscopic sensor, accelerometer sensor, magnetometer sensor, global positioning sensor (GPS), or any combination thereof sensor(s). In some instances, the body **702** of the wireless intraoral imaging device may be manufactured from medical grade stainless steel, plastic, or any combination thereof, as described elsewhere herein. The wireless intraoral device may comprise a button **704**, slider, toggle switch, or any combination thereof interface on the body **702** of the wireless intraoral device. In some cases, the user interaction with the button **704** may control, select, or modify an aspect of the imaging module or methods of imaging described elsewhere herein e.g., change the at least one ultrasound transducer operating mode (no flash angle, flash angles, and wide beam), change a parameter(s) and/or characteristic(s) of the at least one ultrasound transducer and/or the at least one light source, begin imaging, stop imaging, select between various modes of imaging e.g., (photoacoustic, ultrasound, or a combination of photoacoustic and ultrasound imaging), or any combination thereof.

[0078] In some cases, the at least one light source **720** may comprise, for example, a center emission wavelength of 730nm, 850nm, or any combination thereof. In some instances, the at least one light source **720** may emit a range of wavelength. In some cases, the range of wavelengths may comprise of about 400 nanometers (nm) to about 1,700 nm. In some cases, the light emission of the one or more light sources may comprise a wavelength range of about 400 nm to about 500 nm, about 400 nm to about 600 nm, about 400 nm to about 700 nm, about 400 nm to about 800 nm, about 400 nm to about 900 nm, about 400 nm to about 1,000 nm, about 400 nm to about 1,200 nm, about 400 nm to about 1,500 nm, about 400 nm to about 1,700 nm, about 500 nm to about 600 nm, about 500 nm to about 700 nm, about 500 nm to about 800 nm, about 500 nm to about 900 nm, about 500 nm to about 1,000 nm, about 500 nm to about 1,200 nm, about 500 nm to about 1,500 nm, about 500 nm to about 1,700 nm, about 600 nm to about 700 nm, about 600 nm to about 800 nm, about 600 nm to about 900 nm, about 600 nm to about 1,000 nm, about 600 nm to about 1,200 nm, about 600 nm to about 1,500 nm, about 600 nm to about 1,700 nm, about 700 nm to about 800 nm, about 700 nm to about 900 nm, about 700 nm to about 1,000 nm, about 700 nm to about 1,200 nm, about 700 nm to about 1,500 nm, about 700 nm to about 1,700 nm, about 800 nm to about 900 nm, about 800 nm to about 1,000 nm, about 800 nm to about 1,200 nm, about 800 nm to about 1,500 nm, about 800 nm to about 1,700 nm,

about 900 nm to about 1,000 nm, about 900 nm to about 1,200 nm, about 900 nm to about 1,500 nm, about 900 nm to about 1,700 nm, about 1,000 nm to about 1,200 nm, about 1,000 nm to about 1,500 nm, about 1,000 nm to about 1,700 nm, about 1,200 nm to about 1,500 nm, about 1,200 nm to about 1,700 nm, or about 1,500 nm to about 1,700 nm. In some cases, the range of wavelengths may comprise at least about 400 nm, about 500 nm, about 600 nm, about 700 nm, about 800 nm, about 900 nm, about 1,000 nm, about 1,200 nm, about 1,500 nm, or about 1,700 nm. In some cases, the range of wavelengths may comprise at most about 500 nm, about 600 nm, about 700 nm, about 800 nm, about 900 nm, about 1,000 nm, about 1,200 nm, about 1,500 nm, or about 1,700 nm.

[0079] In some cases, the at least one light source may comprise a pulse energy e.g., of at least 400 μ J. In some instances, the pulse energy of the at least one light source may be about 0.01 millijoule (mJ) to about 40 mJ. In some instances, the pulse energy of the at least one light source may be about 0.01 mJ to about 0.1 mJ, about 0.01 mJ to about 0.5 mJ, about 0.01 mJ to about 1 mJ, about 0.01 mJ to about 10 mJ, about 0.01 mJ to about 20 mJ, about 0.01 mJ to about 30 mJ, about 0.01 mJ to about 40 mJ, about 0.1 mJ to about 0.5 mJ, about 0.1 mJ to about 1 mJ, about 0.1 mJ to about 10 mJ, about 0.1 mJ to about 20 mJ, about 0.1 mJ to about 30 mJ, about 0.1 mJ to about 40 mJ, about 0.5 mJ to about 1 mJ, about 0.5 mJ to about 10 mJ, about 0.5 mJ to about 20 mJ, about 0.5 mJ to about 30 mJ, about 0.5 mJ to about 40 mJ, about 1 mJ to about 10 mJ, about 1 mJ to about 20 mJ, about 1 mJ to about 30 mJ, about 1 mJ to about 40 mJ, about 10 mJ to about 20 mJ, about 10 mJ to about 30 mJ, about 10 mJ to about 40 mJ, about 20 mJ to about 30 mJ, about 20 mJ to about 40 mJ, or about 30 mJ to about 40 mJ. In some instances, the pulse energy of at least one light source may be about 0.01 mJ, about 0.1 mJ, about 0.5 mJ, about 1 mJ, about 10 mJ, about 20 mJ, about 30 mJ, or about 40 mJ. In some instances, the pulse energy of the at least one light source may be at least about 0.01 mJ, about 0.1 mJ, about 0.5 mJ, about 1 mJ, about 10 mJ, about 20 mJ, or about 30 mJ. In some instances, the pulse energy of the at least one light source may be at most about 0.1 mJ, about 0.5 mJ, about 1 mJ, about 10 mJ, about 20 mJ, about 30 mJ, or about 40 mJ.

[0080] In some instances, the at least one light source **720** may comprise about beam divergence angle from the optical axis of the at least one light source. In some instances, the beam divergence angle may comprise an angle of about 0 degrees to about 180 degrees from the optical axis of the at least one light source. In some instances, the beam divergence angle may comprise an angle of about 0 degrees to about 10 degrees, about 0 degrees to about 20 degrees, about 0 degrees to about 40 degrees, about 0 degrees to about 60 degrees, about 0 degrees to about 80 degrees, about 0 degrees to about 100 degrees, about 0 degrees to about 120 degrees, about 0 degrees to about 140 degrees, about 0 degrees to about 160 degrees, about 0 degrees to

about 180 degrees, about 10 degrees to about 20 degrees, about 10 degrees to about 40 degrees, about 10 degrees to about 60 degrees, about 10 degrees to about 80 degrees, about 10 degrees to about 100 degrees, about 10 degrees to about 120 degrees, about 10 degrees to about 140 degrees, about 10 degrees to about 160 degrees, about 10 degrees to about 180 degrees, about 20 degrees to about 40 degrees, about 20 degrees to about 60 degrees, about 20 degrees to about 80 degrees, about 20 degrees to about 100 degrees, about 20 degrees to about 120 degrees, about 20 degrees to about 140 degrees, about 20 degrees to about 160 degrees, about 20 degrees to about 180 degrees, about 40 degrees to about 60 degrees, about 40 degrees to about 80 degrees, about 40 degrees to about 100 degrees, about 40 degrees to about 120 degrees, about 40 degrees to about 140 degrees, about 40 degrees to about 160 degrees, about 40 degrees to about 180 degrees, about 60 degrees to about 80 degrees, about 60 degrees to about 100 degrees, about 60 degrees to about 120 degrees, about 60 degrees to about 140 degrees, about 60 degrees to about 160 degrees, about 60 degrees to about 180 degrees, about 80 degrees to about 100 degrees, about 80 degrees to about 120 degrees, about 80 degrees to about 140 degrees, about 80 degrees to about 160 degrees, about 80 degrees to about 180 degrees, about 100 degrees to about 120 degrees, about 100 degrees to about 140 degrees, about 100 degrees to about 160 degrees, about 100 degrees to about 180 degrees, about 120 degrees to about 140 degrees, about 120 degrees to about 160 degrees, about 120 degrees to about 180 degrees, about 140 degrees to about 160 degrees, about 140 degrees to about 180 degrees, or about 160 degrees to about 180 degrees from the optical axis of the at least one light source. In some instances, the beam divergence angle may comprise an angle of about 0 degrees, about 10 degrees, about 20 degrees, about 40 degrees, about 60 degrees, about 80 degrees, about 100 degrees, about 120 degrees, about 140 degrees, about 160 degrees, or about 180 degrees from the optical axis of the at least one light source. In some instances, the beam divergence angle may comprise an angle of at least about 0 degrees, about 10 degrees, about 20 degrees, about 40 degrees, about 60 degrees, about 80 degrees, about 100 degrees, about 120 degrees, about 140 degrees, or about 160 degrees, or about 180 degrees from the optical axis of the at least one light source. In some instances, the beam divergence angle may comprise an angle of at most about 10 degrees, about 20 degrees, about 40 degrees, about 60 degrees, about 80 degrees, about 100 degrees, about 120 degrees, about 140 degrees, about 160 degrees, or about 180 degrees from the optical axis of the at least one light source.

[0081] In some cases, the array of light source elements may comprise an array of light emitting diodes, fiber optics, etc., described elsewhere herein. In some cases, the at least one light source **720** may comprise an array of at least 1, at least 2, at least 3, or at least 4 light sources. In some cases, the array of light source elements may comprise one or more arrays of light source

elements. In some instances, the one or more arrays of light source elements may comprise light source elements that emit different center wavelengths (e.g., a light source array emitting a first wavelength and a second light source array emitting a second wavelength, where the first and second wavelength differ). In some instances, the tip **724** of the wireless intraoral device may comprise a recess, perforations, or holes where the at least one light source may be coupled to the tip. In some cases, the tip **724** may wholly or partially encapsulate the at least one light source **720**. In some cases, a panel of fused silica, glass, or other optically transparent window may be mounted in contact with the outer surface of the at least one light source **720** such that the surface of the at least one light source is planar with respect to a planar surface of the wireless intraoral imaging device tip **724**. In some instances, the panel may be coupled to the at least one light source by UV curable epoxy, index matching liquid and/or gel, or any combination thereof. In some instances, the at least one light source output fluence may comprise up to about $5\text{mJ}/\text{cm}^2$. In some instances, the at least one light source **720** may be mechanically and/or thermally coupled to a heatsink **716**. The heatsink **716** may be configured to redistribute heat generated by the at least one light source **720**. In some instances, the heatsink may be fluidly and/or thermally coupled to a fan, where the fan may provide a cooling convective flow of a liquid over the heatsink to draw away the heat and/or thermal energy of the heatsink away from the at least one light source. In some cases, the heated fluid thermally coupled to the heatsink may be expelled from the wireless intraoral device **700** out of the body of the wireless intraoral device by a vent. In some cases, the vent may comprise a plurality of openings in fluid communication with the atmosphere outside the wireless intraoral device. The plurality of opens may comprise a plurality of slits or other geometric features. The heatsink **716** may enable the at least one light source to maintain constant light source operating parameters e.g., a constant level of output power, pulse width (and/or response), repetition rate, or any combination thereof. By maintaining constant light source operating parameters, a better-than-expected result of at least about 3dB SNR may be maintained, as described elsewhere herein.

[0082] In some cases, the at least one ultrasound transducer **722** may comprise a plurality of ultrasound transducers. The plurality of ultrasound transducers may comprise an array ultrasound transducer comprising at least two ultrasound transducers. In some instances, the array ultrasound transducer may comprise, for example 128 ultrasound transducers (i.e., ultrasound elements). In some cases, the ultrasonic transducer may comprise about 1 element to about 2,048 elements. In some cases, the ultrasonic transducer may comprise about 1 element to about 2 elements, about 1 element to about 4 elements, about 1 element to about 8 elements, about 1 element to about 16 elements, about 1 element to about 32 elements, about 1 element to about 64 elements, about 1 element to about 128 elements, about 1 element to about 256

elements, about 1 element to about 512 elements, about 1 element to about 1,025 elements, about 1 element to about 2,048 elements, about 2 elements to about 4 elements, about 2 elements to about 8 elements, about 2 elements to about 16 elements, about 2 elements to about 32 elements, about 2 elements to about 64 elements, about 2 elements to about 128 elements, about 2 elements to about 256 elements, about 2 elements to about 512 elements, about 2 elements to about 1,025 elements, about 2 elements to about 2,048 elements, about 4 elements to about 8 elements, about 4 elements to about 16 elements, about 4 elements to about 32 elements, about 4 elements to about 64 elements, about 4 elements to about 128 elements, about 4 elements to about 256 elements, about 4 elements to about 512 elements, about 4 elements to about 1,025 elements, about 4 elements to about 2,048 elements, about 8 elements to about 16 elements, about 8 elements to about 32 elements, about 8 elements to about 64 elements, about 8 elements to about 128 elements, about 8 elements to about 256 elements, about 8 elements to about 512 elements, about 8 elements to about 1,025 elements, about 8 elements to about 2,048 elements, about 16 elements to about 32 elements, about 16 elements to about 64 elements, about 16 elements to about 128 elements, about 16 elements to about 256 elements, about 16 elements to about 512 elements, about 16 elements to about 1,025 elements, about 16 elements to about 2,048 elements, about 32 elements to about 64 elements, about 32 elements to about 128 elements, about 32 elements to about 256 elements, about 32 elements to about 512 elements, about 32 elements to about 1,025 elements, about 32 elements to about 2,048 elements, about 64 elements to about 128 elements, about 64 elements to about 256 elements, about 64 elements to about 512 elements, about 64 elements to about 1,025 elements, about 64 elements to about 2,048 elements, about 128 elements to about 256 elements, about 128 elements to about 512 elements, about 128 elements to about 1,025 elements, about 128 elements to about 2,048 elements, about 256 elements to about 512 elements, about 256 elements to about 1,025 elements, about 256 elements to about 2,048 elements, about 512 elements to about 1,025 elements, about 512 elements to about 2,048 elements, or about 1,025 elements to about 2,048 elements. In some cases, the ultrasonic transducer may comprise about 1 element, about 2 elements, about 4 elements, about 8 elements, about 16 elements, about 32 elements, about 64 elements, about 128 elements, about 256 elements, about 512 elements, about 1,025 elements, or about 2,048 elements. In some cases, the ultrasonic transducer may comprise at least about 1 element, about 2 elements, about 4 elements, about 8 elements, about 16 elements, about 32 elements, about 64 elements, about 128 elements, about 256 elements, about 512 elements, or about 1,025 elements. In some cases, the ultrasonic transducer may comprise at most about 2 elements, about 4 elements, about 8 elements, about 16 elements, about 32 elements, about 64

elements, about 128 elements, about 256 elements, about 512 elements, about 1,025 elements, or about 2,048 elements.

[0083] In some instances, the center frequency of the at least one ultrasound transducer may comprise up about a center frequency of, e.g., 20MHz. In some instances, the center frequency of the ultrasonic transducer may comprise about 1 megahertz (MHz) to about 40 MHz. In some instances, the center frequency of the transducer may comprise about 1 MHz to about 5 MHz, about 1 MHz to about 10 MHz, about 1 MHz to about 20 MHz, about 1 MHz to about 25 MHz, about 1 MHz to about 30 MHz, about 1 MHz to about 35 MHz, about 1 MHz to about 40 MHz, about 5 MHz to about 10 MHz, about 5 MHz to about 20 MHz, about 5 MHz to about 25 MHz, about 5 MHz to about 30 MHz, about 5 MHz to about 35 MHz, about 5 MHz to about 40 MHz, about 10 MHz to about 20 MHz, about 10 MHz to about 25 MHz, about 10 MHz to about 30 MHz, about 10 MHz to about 35 MHz, about 10 MHz to about 40 MHz, about 20 MHz to about 25 MHz, about 20 MHz to about 30 MHz, about 20 MHz to about 35 MHz, about 20 MHz to about 40 MHz, about 25 MHz to about 30 MHz, about 25 MHz to about 35 MHz, about 25 MHz to about 40 MHz, about 30 MHz to about 35 MHz, about 30 MHz to about 40 MHz, or about 35 MHz to about 40 MHz. In some instances, the center frequency of the ultrasonic transducer may comprise about 1 MHz, about 5 MHz, about 10 MHz, about 20 MHz, about 25 MHz, about 30 MHz, about 35 MHz, or about 40 MHz. In some instances, the center frequency of the ultrasonic transducer may comprise at least about 1 MHz, about 5 MHz, about 10 MHz, about 20 MHz, about 25 MHz, about 30 MHz, or about 35 MHz. In some instances, the center frequency of the ultrasonic transducer may comprise at most about 5 MHz, about 10 MHz, about 20 MHz, about 25 MHz, about 30 MHz, about 35 MHz, or about 40 MHz.

[0084] The array ultrasound transducer may comprise a length of about 1 cm to about 4 cm. The array ultrasound transducer may comprise a length of about 1 cm to about 2 cm, about 1 cm to about 3 cm, about 1 cm to about 4 cm, about 2 cm to about 3 cm, about 2 cm to about 4 cm, or about 3 cm to about 4 cm. The array ultrasound transducer may comprise a length of about 1 cm, about 2 cm, about 3 cm, or about 4 cm. The array ultrasound transducer may comprise a length of at least about 1 cm, about 2 cm, or about 3 cm. The array ultrasound transducer may comprise a length of at most about 2 cm, about 3 cm, or about 4 cm. The array ultrasound transducer pitch element size may comprise a pitch of e.g., up to about 80 μ m. In some cases, the array ultrasound transducer pitch element size may be a fraction thereof the length of the array ultrasound transducer, described elsewhere herein. In some instances, the at least one ultrasound transducer may be operated in one or more modes, where the one or more modes may comprise no flash angle, flash angles, and wide beam. In some instances, the at least one ultrasound transducer may comprise an ultrasound transducer operating in linear, convex, and phase array modes.

[0085] The size of the device tip **724** may comprise e.g., a height of 15 mm and a width of 10mm. In some cases, the height of the device tip **724** may comprise about 1 mm to about 40 mm. In some cases, the height of the device tip **724** may comprise about 1 mm to about 5 mm, about 1 mm to about 10 mm, about 1 mm to about 15 mm, about 1 mm to about 20 mm, about 1 mm to about 25 mm, about 1 mm to about 30 mm, about 1 mm to about 35 mm, about 1 mm to about 40 mm, about 5 mm to about 10 mm, about 5 mm to about 15 mm, about 5 mm to about 20 mm, about 5 mm to about 25 mm, about 5 mm to about 30 mm, about 5 mm to about 35 mm, about 5 mm to about 40 mm, about 10 mm to about 15 mm, about 10 mm to about 20 mm, about 10 mm to about 25 mm, about 10 mm to about 30 mm, about 10 mm to about 35 mm, about 10 mm to about 40 mm, about 15 mm to about 20 mm, about 15 mm to about 25 mm, about 15 mm to about 30 mm, about 15 mm to about 35 mm, about 15 mm to about 40 mm, about 20 mm to about 25 mm, about 20 mm to about 30 mm, about 20 mm to about 35 mm, about 20 mm to about 40 mm, about 25 mm to about 30 mm, about 25 mm to about 35 mm, about 25 mm to about 40 mm, about 30 mm to about 35 mm, about 30 mm to about 40 mm, or about 35 mm to about 40 mm. In some cases, the height of the device tip **724** may comprise about 1 mm, about 5 mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, about 35 mm, or about 40 mm. In some cases, the height of the device tip **724** may comprise at least about 1 mm, about 5 mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, or about 35 mm. In some cases, the height of the device tip **724** may comprise at most about 5 mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, about 35 mm, or about 40 mm.

[0086] In some cases, the width of the device tip **724** may comprise about 1 mm to about 40 mm. In some cases, the width of the device tip **724** may comprise about 1 mm to about 5 mm, about 1 mm to about 10 mm, about 1 mm to about 15 mm, about 1 mm to about 20 mm, about 1 mm to about 25 mm, about 1 mm to about 30 mm, about 1 mm to about 35 mm, about 1 mm to about 40 mm, about 5 mm to about 10 mm, about 5 mm to about 15 mm, about 5 mm to about 20 mm, about 5 mm to about 25 mm, about 5 mm to about 30 mm, about 5 mm to about 35 mm, about 5 mm to about 40 mm, about 10 mm to about 15 mm, about 10 mm to about 20 mm, about 10 mm to about 25 mm, about 10 mm to about 30 mm, about 10 mm to about 35 mm, about 10 mm to about 40 mm, about 15 mm to about 20 mm, about 15 mm to about 25 mm, about 15 mm to about 30 mm, about 15 mm to about 35 mm, about 15 mm to about 40 mm, about 20 mm to about 25 mm, about 20 mm to about 30 mm, about 20 mm to about 35 mm, about 20 mm to about 40 mm, about 25 mm to about 30 mm, about 25 mm to about 35 mm, about 25 mm to about 40 mm, about 30 mm to about 35 mm, about 30 mm to about 40 mm, or about 35 mm to about 40 mm. In some cases, the width of the device tip **724** may comprise about 1 mm, about 5 mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, about 35 mm, or

about 40 mm. In some cases, the width of the device tip **724** may comprise at least about 1 mm, about 5 mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, or about 35 mm. In some cases, the width of the device tip **724** may comprise at most about 5 mm, about 10 mm, about 15 mm, about 20 mm, about 25 mm, about 30 mm, about 35 mm, or about 40 mm.

[0087] In some cases, whole oral cavity imaging may comprise imaging of posterior molar teeth of a human and/or non-human mammal subject, described elsewhere herein. In some cases, the wireless intraoral device may comprise a size (width, height, depth, etc.) configured to image the buccal and lingual surfaces of one or more subjects' teeth.

[0088] In some cases, the wireless intraoral device **700** may comprise a battery **710** in electrical communication with all components of the wireless intraoral device (e.g., at least one transducer, at least one light source, processor, etc.), described elsewhere herein, configured to power all components. In some instances, the battery may comprise a lithium-ion polymer battery, where the lithium-ion polymer battery is rechargeable via a charge dock or charging station **706**. In some cases, the charge dock or charging station **706**, may be in electrical communication with a conventional electrical AC socket and/or a system, described elsewhere herein. In some cases, the charging dock or charging station **706** may comprise an indicator, where the presence of the indicator will notify a user and/or medical personnel that the wireless intraoral device **700** is charged and ready for use, requires further charging, has encountered an error, and needs servicing, or any combination thereof indicators. In some cases, the indicator may comprise a light-based indicator, where the light-based indicator may emit a particular wavelength or color of light to indicate various states. In some cases, the indicator may comprise a text-based indicator shown directly on the charging station **706** or system or personal user device wirelessly in communication with the charging station **706** and/or the wireless intraoral device **700**.

[0089] In some cases, the processor(s) (**708**, **714**, **712**) of the wireless intraoral device may comprise a wireless communication processor **708**, light source driver **712**, data acquisition processor **714**, or any combination thereof. The wireless communication processor **708** may comprise a processor in electrical communication with one or more wireless transmission circuits (e.g., WIFI, Bluetooth, X-bee, or any combination thereof wireless communication platforms). The wireless transmission circuits and the wireless communication processor **708** may be configured to transmit data to a system (e.g., system with a user interface and/or one or more user interface devices, described elsewhere herein) over e.g., an ad-hoc WIFI connection, Bluetooth, radiofrequency communication, or any combination thereof. The system may comprise a system as described elsewhere herein. The system may be a personal computer, server computer, mobile computer, laptop computer, desktop computer, or any combination

thereof, configured to further process, display, and/or allow for data manipulation by one or more users. The wireless communication processor **708** may be configured to send and/or receive one or more packets of data from the system and/or other remote systems configured to communicate with the device over one or more wireless communication methods, as described elsewhere herein. The one or more packets of data may comprise user commands (e.g., start acquisition, stop acquisition, acquire data for a set period, etc.), user settings e.g., operating center frequency of the ultrasound transducer, light source parameters (e.g., light source pulse width, pulse repetition rate, output power, etc.), or any combination thereof, described elsewhere herein. In some cases, the one or more packets of data may comprise one or more images (e.g., ultrasound, photoacoustic, visible light or a combination or overlay thereof). In some instances, the wireless communication processor **708** may be in electrical communication with the data acquisition processor **714**, the light source driver **708**, to set and/or read processor parameters (e.g., data acquisition rate, pulse width, light source repetition rate, etc.) based on the one or more packets of data transmitted and received by the wireless communication processor **708**. The wireless communication processor **708** may receive power from a battery **710**, to conduct the various functions described elsewhere herein. In some instances, the battery **710** comprises a rechargeable battery (e.g., lithium-ion polymer battery).

[0090] The processor (**708**, **714**, **712**) of the wireless intraoral device **700**, may comprise a data acquisition processor **714** in electrical communication with the at least one ultrasound transducer **722**, light source driver **712**, at least one light source **720**, sensor **718**, wireless communication processor **708**, battery **710**, or any combination thereof. In some cases, the data acquisition processor **714**, may provide a driving ultrasound excitation signal, described elsewhere herein, to cause the at least one ultrasound transducer **722** to emit one or more pressure waves. In some instances, the data acquisition processor **714**, may detect one or more echo pressure waves from the at least one ultrasound transducer **722**. In some cases, the data acquisition processor **714** may provide a pulse signal to the at least one ultrasound transducer **722** to cause the at least one ultrasound transducer **722** to emit one or more pressure waves. The data acquisition processor **714** may comprise a field programmable gate array (FPGA), parallel processor (with virtual threads), arm processor, or any combination thereof. The FPGA may comprise e.g., up to 16 channels of detection of e.g., ultrasound echo signals. For example, the FPGA-based data acquisition may comprise 16 transmitter channels and 32 receiver channels electrically coupled to the at least one ultrasound transducer.

[0091] The FPGA may comprise about 1 receiver channel to about 2,048 receiver channels. The FPGA may comprise about 1 receiver channel to about 2 receiver channels, about 1 receiver channel to about 4 receiver channels, about 1 receiver channel to about 8 receiver channels,

[illegible]

about 128 receiver channels to about 2,048 receiver channels, about 256 receiver channels to about 512 receiver channels, about 256 receiver channels to about 1,024 receiver channels, about 256 receiver channels to about 2,048 receiver channels, about 512 receiver channels to about 1,024 receiver channels, about 512 receiver channels to about 2,048 receiver channels, or about 1,024 receiver channels to about 2,048 receiver channels. The FPGA may comprise about 1 receiver channel, about 2 receiver channels, about 4 receiver channels, about 8 receiver channels, about 16 receiver channels, about 32 receiver channels, about 64 receiver channels, about 128 receiver channels, about 256 receiver channels, about 512 receiver channels, about 1,024 receiver channels, or about 2,048 receiver channels. The FPGA may comprise at least about 1 receiver channel, about 2 receiver channels, about 4 receiver channels, about 8 receiver channels, about 16 receiver channels, about 32 receiver channels, about 64 receiver channels, about 128 receiver channels, about 256 receiver channels, about 512 receiver channels, or about 1,024 receiver channels. The FPGA may comprise at most about 2 receiver channels, about 4 receiver channels, about 8 receiver channels, about 16 receiver channels, about 32 receiver channels, about 64 receiver channels, about 128 receiver channels, about 256 receiver channels, about 512 receiver channels, about 1,024 receiver channels, or about 2,048 receiver channels.

[0092] The FPGA may comprise about 1 transmitter channel to about 2,048 transmitter channels. The FPGA may comprise about 1 transmitter channel to about 2 transmitter channels, about 1 transmitter channel to about 4 transmitter channels, about 1 transmitter channel to about 8 transmitter channels, about 1 transmitter channel to about 16 transmitter channels, about 1 transmitter channel to about 32 transmitter channels, about 1 transmitter channel to about 64 transmitter channels, about 1 transmitter channel to about 128 transmitter channels, about 1 transmitter channel to about 256 transmitter channels, about 1 transmitter channel to about 512 transmitter channels, about 1 transmitter channel to about 1,024 transmitter channels, about 1 transmitter channel to about 2,048 transmitter channels, about 2 transmitter channels to about 4 transmitter channels, about 2 transmitter channels to about 8 transmitter channels, about 2 transmitter channels to about 16 transmitter channels, about 2 transmitter channels to about 32 transmitter channels, about 2 transmitter channels to about 64 transmitter channels, about 2 transmitter channels to about 128 transmitter channels, about 2 transmitter channels to about 256 transmitter channels, about 2 transmitter channels to about 512 transmitter channels, about 2 transmitter channels to about 1,024 transmitter channels, about 2 transmitter channels to about 2,048 transmitter channels, about 4 transmitter channels to about 8 transmitter channels, about 4 transmitter channels to about 16 transmitter channels, about 4 transmitter channels to about 32 transmitter channels, about 4 transmitter channels to about 64 transmitter channels, about 4 transmitter channels to about 128 transmitter channels, about 4 transmitter channels to about 256

transmitter channels, about 4 transmitter channels to about 512 transmitter channels, about 4 transmitter channels to about 1,024 transmitter channels, about 4 transmitter channels to about 2,048 transmitter channels, about 8 transmitter channels to about 16 transmitter channels, about 8 transmitter channels to about 32 transmitter channels, about 8 transmitter channels to about 64 transmitter channels, about 8 transmitter channels to about 128 transmitter channels, about 8 transmitter channels to about 256 transmitter channels, about 8 transmitter channels to about 512 transmitter channels, about 8 transmitter channels to about 1,024 transmitter channels, about 8 transmitter channels to about 2,048 transmitter channels, about 16 transmitter channels to about 32 transmitter channels, about 16 transmitter channels to about 64 transmitter channels, about 16 transmitter channels to about 128 transmitter channels, about 16 transmitter channels to about 256 transmitter channels, about 16 transmitter channels to about 512 transmitter channels, about 16 transmitter channels to about 1,024 transmitter channels, about 16 transmitter channels to about 2,048 transmitter channels, about 32 transmitter channels to about 64 transmitter channels, about 32 transmitter channels to about 128 transmitter channels, about 32 transmitter channels to about 256 transmitter channels, about 32 transmitter channels to about 512 transmitter channels, about 32 transmitter channels to about 1,024 transmitter channels, about 32 transmitter channels to about 2,048 transmitter channels, about 64 transmitter channels to about 128 transmitter channels, about 64 transmitter channels to about 256 transmitter channels, about 64 transmitter channels to about 512 transmitter channels, about 64 transmitter channels to about 1,024 transmitter channels, about 64 transmitter channels to about 2,048 transmitter channels, about 128 transmitter channels to about 256 transmitter channels, about 128 transmitter channels to about 512 transmitter channels, about 128 transmitter channels to about 1,024 transmitter channels, about 128 transmitter channels to about 2,048 transmitter channels, about 256 transmitter channels to about 512 transmitter channels, about 256 transmitter channels to about 1,024 transmitter channels, about 256 transmitter channels to about 2,048 transmitter channels, about 512 transmitter channels to about 1,024 transmitter channels, about 512 transmitter channels to about 2,048 transmitter channels, or about 1,024 transmitter channels to about 2,048 transmitter channels. The FPGA may comprise about 1 transmitter channel, about 2 transmitter channels, about 4 transmitter channels, about 8 transmitter channels, about 16 transmitter channels, about 32 transmitter channels, about 64 transmitter channels, about 128 transmitter channels, about 256 transmitter channels, about 512 transmitter channels, about 1,024 transmitter channels, or about 2,048 transmitter channels. The FPGA may comprise at least about 1 transmitter channel, about 2 transmitter channels, about 4 transmitter channels, about 8 transmitter channels, about 16 transmitter channels, about 32 transmitter channels, about 64 transmitter channels, about 128 transmitter channels, about 256 transmitter channels, about 512

transmitter channels, or about 1,024 transmitter channels. The FPGA may comprise at most about 2 transmitter channels, about 4 transmitter channels, about 8 transmitter channels, about 16 transmitter channels, about 32 transmitter channels, about 64 transmitter channels, about 128 transmitter channels, about 256 transmitter channels, about 512 transmitter channels, about 1,024 transmitter channels, or about 2,048 transmitter channels.

[0093] For example, after a clock cycle of transmitting and receiving signals, 16 transmitter channels with send ultrasound pulses and receive ultrasound echo signals. In some instances, a multiplexing approach may be implemented such that after up to about 8 clock cycles, all the elements (e.g., 128-elements of an array ultrasound transducer) will send and receive signals. The FPGA-based data acquisition may further provide master timing and triggers for the various other processors and components (e.g., at one ultrasound transducer and/or at least one light source). For example, after each LED pulse, photoacoustic signals may be acquired from 32 receiver ultrasound transducer elements. After about 4 clock cycles, all the ultrasound transducer element's (e.g., 128-elements of an array ultrasound transducer) one or more ultrasound echo signals will be acquired and stored. In some instances, the data acquisition processor **714** may provide a trigger signal to the light source driver **712** to synchronize one or more pulses of emitted light by the at least one light source **720** with the detection and/or emission of ultrasound pressure waves by the at least one ultrasound transducer **722**. In some cases, the data acquisition processor **714** may receive signals from the sensor **718** in a synchronous or unsynchronous manner with respect to a method and/or operation or series of operations, as described elsewhere herein.

[0094] The processor (**708**, **714**, **712**) of the wireless intraoral device **700**, may comprise a light source driver **712** in electrical communication with the data acquisition processor **714**, at least one light source **720**, wireless communication processor **708**, battery **710**, or any combination thereof. In some instances, the light source driver **712** may be configured to drive the at least one light source **720** in a pulsed or continuous wave emission mode. In some instances, the light source driver **712** may generate a variable pulse width to drive the emission of light of the at least one light source **720**. In some instances, the variable pulse width may comprise e.g., 25 nanoseconds (ns) to about 50 ns. In some cases, the variable pulse width may be about 1 nanosecond (ns) to about 1,000 ns. In some cases, the variable pulse width may be about 1 ns to about 50 ns, about 1 ns to about 100 ns, about 1 ns to about 150 ns, about 1 ns to about 200 ns, about 1 ns to about 350 ns, about 1 ns to about 500 ns, about 1 ns to about 700 ns, about 1 ns to about 900 ns, about 1 ns to about 1,000 ns, about 50 ns to about 100 ns, about 50 ns to about 150 ns, about 50 ns to about 200 ns, about 50 ns to about 350 ns, about 50 ns to about 500 ns, about 50 ns to about 700 ns, about 50 ns to about 900 ns, about 50 ns to about 1,000 ns, about 100 ns

to about 150 ns, about 100 ns to about 200 ns, about 100 ns to about 350 ns, about 100 ns to about 500 ns, about 100 ns to about 700 ns, about 100 ns to about 900 ns, about 100 ns to about 1,000 ns, about 150 ns to about 200 ns, about 150 ns to about 350 ns, about 150 ns to about 500 ns, about 150 ns to about 700 ns, about 150 ns to about 900 ns, about 150 ns to about 1,000 ns, about 200 ns to about 350 ns, about 200 ns to about 500 ns, about 200 ns to about 700 ns, about 200 ns to about 900 ns, about 200 ns to about 1,000 ns, about 350 ns to about 500 ns, about 350 ns to about 700 ns, about 350 ns to about 900 ns, about 350 ns to about 1,000 ns, about 500 ns to about 700 ns, about 500 ns to about 900 ns, about 500 ns to about 1,000 ns, about 700 ns to about 900 ns, about 700 ns to about 1,000 ns, or about 900 ns to about 1,000 ns. In some cases, the variable pulse width may be about 1 ns, about 50 ns, about 100 ns, about 150 ns, about 200 ns, about 350 ns, about 500 ns, about 700 ns, about 900 ns, or about 1,000 ns. In some cases, the variable pulse width may be at least about 1 ns, about 50 ns, about 100 ns, about 150 ns, about 200 ns, about 350 ns, about 500 ns, about 700 ns, or about 900 ns. In some cases, the variable pulse width may be at most about 50 ns, about 100 ns, about 150 ns, about 200 ns, about 350 ns, about 500 ns, about 700 ns, about 900 ns, or about 1,000 ns.

Tip Mechanical Coupling Structures

[0095] The intraoral imaging device may comprise a tip structure configured to provide a single to noise ratio of at least 3B when collecting data, described elsewhere herein. In some cases, the tip structure may be configured to expand upon pressing a coupling interface of the intraoral imaging device tip onto a surface of an oral tissue. In some instances, the pressure applied between the coupling interface of the intraoral imaging device tip between the oral surface may improve the impedance coupling between the at least one ultrasound transducer of the intraoral imaging device. In some cases, the coupling interface may comprise at least one spring mechanically coupled to the coupling interface, where the at least one spring is configured to expand when the coupling interface is pressed on the surface of the oral tissue. In some instances, the coupling interface may comprise a shape memory material (e.g., shape memory metal (e.g., nitinol) or plastic).

Computer Systems and Machine Learning Models

[0096] In some embodiments, the systems disclosed herein may comprise a computer system suitable for implementing machine learning models configured to analyze ultrasound and/or photoacoustic data collected by the imaging system described elsewhere herein. In some cases, one or more ultrasound and/or photoacoustic images may be generated from ultrasound and/or photoacoustic data collected. In some cases, the machine learning models may analyze, extract,

condense, reduce, predict, classify, or any combination thereof operations conducted on ultrasound and/or photoacoustic data and/or images.

[0097] In some cases, one or more features may be identified and classified from one or more regions of interest of the ultrasound, photoacoustic, or combination thereof image data, described elsewhere herein, and as shown in **FIGS. 8A-8B**. **FIG. 8A** shows an example ultrasound image **816** acquired by the devices and/or systems described elsewhere herein with an overlay of one or more regions of interest (**800, 802, 804, 806, 808, 810, 812, or 814**). The one or more regions of interest may be set by a user (e.g., dentist, dental hygienist, etc.) or by one or more predictive models and/or machine learning algorithms. The one or more regions of interest may comprise the alveolar bone crest (ABC shortened to “AC”) **800**, gingiva surface **802**, gingiva mucosa **804**, gingival margin (GM) **806**, tooth buccal surface **808**, dentin **810**, cementoenamel junction **812**, periodontal ligament (PDL) **814**, or any combination thereof. One or more statistical features of the image data within the one or more regions of interest may be determined and utilized to classify and to predict regions of interest of unclassified ultrasound, photoacoustic, or a combination thereof image data, as shown graphically in **FIG. 8B**. The one or more statistical features may comprise mean, variance, standard deviation, skewness, median, entropy, kurtosis, or any combination thereof of the image data with the one or more regions of interest. In some cases, the one or more statistical features may comprise texture features of the gray level co-occurrence matrix (GLCM) in one or more directions of the detected ultrasound signals. The texture features may comprise homogeneity, contrast, energy, entropy, correlation, or any combination thereof. In some cases, the one or more statistical features comprise texture features of the gray level run length matrix (GLRLM) in one or more directions. The more directions may comprise 0 degrees, 45 degrees, 90 degrees, 135 degrees, or any combination thereof. In some cases, the texture features of the GLRLM comprise short run emphasis, long run emphasis, gray-level non-uniformity, run percentage, run length nonuniformity, low gray-level run emphasis, high gray-level run emphasis, or any combination thereof.

[0098] In some cases, the one or more regions of interest and features related to classification of the one or more regions of interest may be used to segment and quantify anatomical structures of the periodontal oral tissue. The segmented and quantified anatomical structures of the periodontal oral tissue may then be provided as features to a second machine learning model and/or predictive model configured to determine one or more oral health metrics, as described elsewhere herein.

[0099] In some embodiments, the systems disclosed herein may implement a machine learning algorithm configured to determine one or more oral health metrics. In some cases, the one or more oral health metrics may comprise gingival pocket depth, inflammation of the gingiva,

infection of the gingiva, blood flow through the gingiva, or any combination thereof. The machine learning model may comprise a classification module that may take the features collected/extracted from a signal preprocessing step and classify the features. In some cases, the features may be extracted without a signal preprocessing step.

[0100] In some cases, machine learning algorithms may need to extract and draw relationships between features as conventional statistical techniques may not be sufficient. In some cases, machine learning algorithms may be used in conjunction with conventional statistical techniques. In some cases, conventional statistical techniques may provide the machine learning algorithm with preprocessed features.

[0101] In some embodiments, the plurality of features may be classified into any number of categories. One or more ultrasound and/or photoacoustic images generated by the systems described elsewhere herein may be classified as healthy or diseased. In some cases, the disease may be periodontal disease, gingivitis, or any combination thereof. Individual categories may also be divided into sub-categories.

[0102] In some embodiments, a human may select, and discard features prior/during machine learning classification. In some cases, a computer may select and discard features. In some cases, the features may be discarded based on a threshold value.

[0103] In some embodiments, any number of features may be classified by the machine learning algorithm. The machine learning algorithm may classify at least 10 features. In some cases, the plurality of features may include between about 10 features to 200 features. In some cases, the plurality of features may include between about 10 features to 100 features. In some cases, the plurality of features may include between about 10 features to 50 features. In some embodiments, the machine learning algorithm may be, for example, an unsupervised learning algorithm, supervised learning algorithm, or a combination thereof. The unsupervised learning algorithm may be, for example, clustering, hierarchical clustering, k-means, mixture models, DBSCAN, OPTICS algorithm, anomaly detection, local outlier factor, neural networks, autoencoders, deep belief nets, hebbian learning, generative adversarial networks, self-organizing map, expectation-maximization algorithm (EM), method of moments, blind signal separation techniques, principal component analysis, independent component analysis, non-negative matrix factorization, singular value decomposition, or a combination thereof. The supervised learning algorithm may be, for example, support vector machines, linear regression, logistic regression, linear discriminant analysis, decision trees, k-nearest neighbor algorithm, neural networks, similarity learning, or a combination thereof. In some embodiments, the machine learning algorithm may comprise a deep neural network (DNN). The deep neural network may comprise a convolutional neural network (CNN). The CNN may be, for example,

U-Net, ImageNet, LeNet-5, AlexNet, ZFNet, GoogleNet, VGGNet, ResNet18 or ResNet, etc. Other neural networks may be, for example, deep feed forward neural network, recurrent neural network, LSTM (Long Short Term Memory), GRU (Gated Recurrent Unit), Auto Encoder, variational autoencoder, adversarial autoencoder, denoising auto encoder, sparse auto encoder, Boltzmann machine, RBM (Restricted BM), deep belief network, generative adversarial network (GAN), deep residual network, capsule network, or attention/transformer networks, etc.

[0104] In some instances, the machine learning model may comprise clustering, scalar vector machines, kernel SVM, linear discriminant analysis, Quadratic discriminant analysis, neighborhood component analysis, manifold learning, convolutional neural networks, reinforcement learning, random forest, Naive Bayes, gaussian mixtures, Hidden Markov model, Monte Carlo, restrict Boltzmann machine, linear regression, or any combination thereof.

[0105] In some cases, the machine learning algorithm may include ensemble learning algorithms such as bagging, boosting, and stacking. The machine learning algorithm may be individually applied to the plurality of features extracted.

[0106] In some embodiments, the systems may apply one or more machine learning algorithms.

[0107] In some embodiments, the machine learning algorithm may have a variety of parameters. The variety of parameters may be, for example, learning rate, minibatch size, number of epochs to train for, momentum, learning weight decay, or neural network layers etc.

[0108] In some embodiments, the learning rate may be between about 0.00001 to 0.1.

[0109] In some embodiments, the minibatch size may be at between about 16 to 128.

[0110] In some embodiments, the neural network may comprise neural network layers. The neural network may have at least about 2 to 1000 or more neural network layers.

[0111] In some embodiments, the number of epochs to train for may be at least about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 150, 200, 250, 500, 1000, 10000, or more.

[0112] In some embodiments, the momentum may be at least about 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 or more. In some embodiments, the momentum may be at most about 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, or less.

[0113] In some embodiments, learning weight decay may be at least about 0.00001, 0.0001, 0.001, 0.002, 0.003, 0.004, 0.005, 0.006, 0.007, 0.008, 0.009, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, or more. In some embodiments, the learning weight decay may be at most about 0.1, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03, 0.02, 0.01, 0.009, 0.008, 0.007, 0.006, 0.005, 0.004, 0.003, 0.002, 0.001, 0.0001, 0.00001, or less.

[0114] In some embodiments, the machine learning algorithm may use a loss function. The loss function may be, for example, regression losses, mean absolute error, mean bias error, hinge loss, Adam optimizer and/or cross entropy.

[0115] In some embodiments, the parameters of the machine learning algorithm may be adjusted with the aid of a human and/or computer system.

[0116] In some embodiments, the machine learning algorithm may prioritize certain features. The machine learning algorithm may prioritize features that may be more relevant for detecting periodontal disease. The feature may be more relevant for detecting periodontal disease if the feature is classified more often than another feature. In some cases, the features may be prioritized using a weighting system. In some cases, the features may be prioritized on probability statistics based on the frequency and/or quantity of occurrence of the feature. The machine learning algorithm may prioritize features with the aid of a human and/or computer system.

[0117] In some embodiments, one or more of the features may be used with machine learning or conventional statistical techniques to determine if a segment is likely to contain artifacts. The identified artifacts may be a result of optical misalignment, movement of sample during image acquisition, laser power instability, laser pulse frequency jitter, movement, subject movement, or any combination thereof. In some cases, movement sensors or other sensors may be used as an additional input to the artifact rejection module. In some cases, the identified artifacts can be rejected from being used in periodontal disease classification.

[0118] In some cases, the machine learning algorithm may prioritize certain features to reduce calculation costs, save processing power, save processing time, increase reliability, or decrease random access memory usage, etc.

[0119] In some cases, the imaging module 100 may comprise a computer system 604 configured to process ultrasound and/or photoacoustic data and/or images. The computer system 604, as seen in FIG. 5, may comprise a central processing unit (CPU, also “processor” and “computer processor” herein) 610, which may be a single core or multi core processor, or a plurality of processor for parallel processing. The computer system 604 may further comprise memory or memory locations 608 (e.g., random-access memory, read-only memory, flash memory), electronic storage unit 606 (e.g., hard disk), communications interface 614 (e.g., network adapter) for communicating with one or more other devices, and peripheral devices 612, such as cache, other memory, data storage and/or electronic display adapters. The memory 608, storage unit 606, interface 614, and peripheral devices (e.g., mouse, keyboard, etc.) 612 may be in communication with the CPU 610 through a communication bus (solid lines), such as a motherboard. The storage unit 606 may be a data storage unit (or a data repository) for storing

data. The computer system **604** may be operatively coupled to a computer network (“network”) **616** with the aid of the communication interface **614**. The network **616** may be the Internet, an internet and/or extranet, or an intranet and/or extranet that is in communication with the Internet. The network **616** may, in some cases, be a telecommunication and/or data network. The network **616** may include one or more computer servers, which may enable distributed computing, such as cloud computing. The network **616**, in some cases with the aid of the computer system **604**, may implement a peer-to-peer network, which may enable devices coupled to the computer system **604** to behave as a client or a server.

[0120] The CPU **610** may execute a sequence of machine-readable instructions, which may be embodied in a program or software. The instructions may be directed to the CPU **610**, which may subsequently program or otherwise configured the CPU **610** to acquire data and/or process data produced by the imaging system described elsewhere herein.

[0121] In some embodiments, the computer system **604** central processing unit **610** may execute machine executable or machine-readable code that may be provided in the form of software to transfer data generated by the imaging system to a network and/or cloud **616** for further processing, classification, data clustering, or any combination thereof. In some instances, the data may comprise individual image pixel data where an image is comprised of one or more pixels. In some cases, the pixel data may comprise ultrasound and/or photoacoustic data obtained by the imaging system, described elsewhere herein.

[0122] In some embodiments, the CPU **610** may be part of a circuit, such as an integrated circuit. One or more other components of the system **604** may be included in the circuit. In some cases, the circuit is an application specific integrated circuit (ASIC).

[0123] The storage unit **606** may store files, such as drivers, libraries, and saved programs. The storage unit **606** may store acquired ultrasound and/or photoacoustic data, ultrasound and/or photoacoustic images, or any combination thereof data. In some cases, the files, ultrasound and/or photoacoustic data and/or images may be stored in the cloud, a dental office PC or any combination thereof. In some cases, the dental office PC may comprise a desktop computer, a laptop computer, or any combination thereof. The computer system **604**, in some cases may include one or more additional data storage units that are external to the computer system **604**, such as located on a remote server that is in communication with the computer system **604** through an intranet or the internet.

[0124] Methods as described herein may be implemented by way of machine (e.g., computer processor) executable code stored on non-transitory electronic storage medium of the computer device **604**, such as, for example, on the memory **608** or electronic storage unit **606**. The machine executable or machine-readable code may be provided in the form of software. During

use, the code may be executed by the processor **610**. In some instances, the code may be retrieved from the storage unit **606** and stored on the memory **608** for ready access by the processor **610**. In some instances, the electronic storage unit **606** may be precluded, and machine-executable instructions are stored on memory **608**.

[0125] The code may be pre-compiled and configured for use with a machine having a processor adapted to execute the code or may be compiled during runtime. The code may be supplied in a programming language that may be selected to enable the code to be executed in a pre-compiled or as-compiled fashion.

[0126] Aspects of the systems and methods provided herein, such as the computer system **604**, may be embodied in programming. Various aspects of the technology may be thought of a “product” or “articles of manufacture” typically in the form of a machine (or processor) executable code and/or associated data that is carried on or embodied in a type of machine readable medium. Machine-executable code may be stored on an electronic storage unit, such as memory (e.g., read-only memory, random-access memory, flash memory) or a hard disk. “Storage” type media may include any or all of the tangible memory of a computer, processor the like, or associated modules thereof, such as various semiconductor memories, tape drives, disk drives and the like, which may provide non-transitory storage at any time for the software program. All or portions of the software may at times be communicated through the Internet or various other telecommunication networks. Such communications, for example, may enable loading of the software from one computer or processor into another, for example, from a management server or host computer into the computer platform of an application server. Thus, another type of media that may bear the software elements includes optical, electrical, and electromagnetic waves, such as used across physical interfaces between local devices, through wired and optical landline networks and over various air-links. The physical elements that carry such waves, such as wired or wireless links, optical links, or the like, also may be considered as media bearing the software. As used herein, unless restricted to non-transitory, tangible “storage” media, term such as computer or machine “readable medium” refer to any medium that participates in providing instructions to a processor for execution.

[0127] Hence, a machine readable medium, such as computer-executable code, may take many forms, including but not limited to, a tangible storage medium, a carrier wave medium or physical transmission medium. Non-volatile storage media may include, for example, optical or magnetic disks, such as any of the storage devices in any computer(s) or the like, such as may be used to implement the databases, etc. Volatile storage media may include dynamic memory, such as main memory of such a computer platform. Tangible transmission media includes coaxial cables; copper wire and fiber optics, including the wires that comprise a bus within a

computer device. Carrier-wave transmission media may take the form of electric or electromagnetic signals, or acoustic or light waves such as those generated during radio frequency (RF) and infrared (IR) data communications. Common forms of computer-readable media therefor include for example: a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, DVD or DVD-ROM, any other optical medium, punch cards paper tape, any other physical storage medium with pattern of holes, a RAM, a ROM, a PROM and EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave transporting data or instructions, cables or links transporting such a carrier wave, or any other medium from which a computer may read programming code and/or data. Many of these forms of computer readable media may be involved in carrying one or more sequences of one or more instruction to a processor for execution.

[0128] The computer system may include or be in communication with an electronic display **108** that comprises a user interface (UI) **630** for viewing ultrasound and/or photoacoustic data, ultrasound and/or photoacoustic images, or any combination thereof.

User Interface

[0129] Aspects of the systems of disclosure provided herein may comprise a user interface (UI). The UI **630** may comprise an image display such as a flat-screen panel or a touch-screen display **108**. The UI **630** may permit visualization of the data acquired from the one or more tissues of a subject's mouth. The user-interface may provide actionable information for health care personnel to guide diagnosis of periodontal disease. In some cases, the user-interface **630** may display visible light video or visible light still images of the tissue being imaged. In some cases, the user-interface may comprise a view indicating segmented oral health metrics, described elsewhere herein.

[0130] In some embodiments, the user-interface **630** may comprise functional buttons, switches, editable dialogue boxes, slides, radio buttons, or any combination thereof. In some instances, the user-interface may comprise one or more displays that allow the user to configure device parameters e.g., scanning speed, resolution, or any combination thereof. The user-interface may comprise functional buttons that may toggle between varying overlay signal processing false color maps that may indicate to a user a region of the tissue of a subject's mouth that may be diseased. In some cases, the disease may comprise periodontal disease. In some cases, the user-interface may comprise functional buttons that enable scanning, stop scanning, emergency stop scanning, pause scanning, resume scanning, or any combination thereof.

[0131] In some embodiments, the user-interface **630** may comprise a touch screen interface permitting a user to tap on the screen to select operations. Alternatively, the user-interface **630** may be manipulated or interacted with a keyboard and/or mouse.

Methods

[0132] Aspects of the disclosure provided herein may comprise a method for determine one or more health metrics of a subject's oral cavity from one or more detected ultrasound signals and/or photoacoustic signals (**400, 600**), as seen in **FIG. 4** and **6**.

[0133] In some instances, the method of determining one or more health metrics from photoacoustic data **400** of a subject's oral cavity may comprise the steps of: (a) providing at least one light source incident on one or more tissues of the oral cavity **401**; (b) generating one or more pressure waves through the interaction of the at least one light source or ultrasonic transducer and the one or more tissues of the oral cavity **402**; (c) detecting the one or more pressure waves with the ultrasonic transducer thereby generating one or more detected ultrasound signals with a signal to noise ratio of at least 3dB **403**; and (d) determining one or more health metrics of the oral cavity from the one or more detected ultrasound signals **404**.

[0134] In some cases, the method of determining one or more health metrics from ultrasound data of a subject's oral cavity **600** may comprise the steps of: (a) generating one or more pressure waves through the interaction of the at least one ultrasonic transducer and one or more tissues of the oral cavity **601**; (b) detecting the one or more pressure waves with the ultrasonic transducer thereby generating one or more detected ultrasound signals with a signal to noise ratio of at least 3dB **602**; and (c) determining one or more health metrics of the oral cavity from the one or more detected ultrasound signals **603**.

[0135] In some cases, the signal to noise ratio may be about 1 decibels (dB) to about 100 dB. In some cases, the signal to noise ratio may be about 1 dB to about 2 dB, about 1 dB to about 4 dB, about 1 dB to about 8 dB, about 1 dB to about 10 dB, about 1 dB to about 30 dB, about 1 dB to about 50 dB, about 1 dB to about 60 dB, about 1 dB to about 70 dB, about 1 dB to about 89 dB, about 1 dB to about 90 dB, about 1 dB to about 100 dB, about 2 dB to about 4 dB, about 2 dB to about 8 dB, about 2 dB to about 10 dB, about 2 dB to about 30 dB, about 2 dB to about 50 dB, about 2 dB to about 60 dB, about 2 dB to about 70 dB, about 2 dB to about 89 dB, about 2 dB to about 90 dB, about 2 dB to about 100 dB, about 4 dB to about 8 dB, about 4 dB to about 10 dB, about 4 dB to about 30 dB, about 4 dB to about 50 dB, about 4 dB to about 60 dB, about 4 dB to about 70 dB, about 4 dB to about 89 dB, about 4 dB to about 90 dB, about 4 dB to about 100 dB, about 8 dB to about 10 dB, about 8 dB to about 30 dB, about 8 dB to about 50 dB, about 8 dB to about 60 dB, about 8 dB to about 70 dB, about 8 dB to about 89 dB, about 8 dB to about 90 dB,

about 8 dB to about 100 dB, about 10 dB to about 30 dB, about 10 dB to about 50 dB, about 10 dB to about 60 dB, about 10 dB to about 70 dB, about 10 dB to about 89 dB, about 10 dB to about 90 dB, about 10 dB to about 100 dB, about 30 dB to about 50 dB, about 30 dB to about 60 dB, about 30 dB to about 70 dB, about 30 dB to about 89 dB, about 30 dB to about 90 dB, about 30 dB to about 100 dB, about 50 dB to about 60 dB, about 50 dB to about 70 dB, about 50 dB to about 89 dB, about 50 dB to about 90 dB, about 50 dB to about 100 dB, about 60 dB to about 70 dB, about 60 dB to about 89 dB, about 60 dB to about 90 dB, about 60 dB to about 100 dB, about 70 dB to about 89 dB, about 70 dB to about 90 dB, about 70 dB to about 100 dB, about 89 dB to about 90 dB, about 89 dB to about 100 dB, or about 90 dB to about 100 dB. In some cases, the signal to noise ratio may be about 1 dB, about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, about 90 dB, or about 100 dB. In some cases, the signal to noise ratio may be at least about 1 dB, about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, or about 90 dB. In some cases, the signal to noise ratio may be at most about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, about 90 dB, or about 100 dB.

[0136] In some cases, the contrast may be about 1 decibels (dB) to about 100 dB. In some cases, the signal to noise ratio may be about 1 dB to about 2 dB, about 1 dB to about 4 dB, about 1 dB to about 8 dB, about 1 dB to about 10 dB, about 1 dB to about 30 dB, about 1 dB to about 50 dB, about 1 dB to about 60 dB, about 1 dB to about 70 dB, about 1 dB to about 89 dB, about 1 dB to about 90 dB, about 1 dB to about 100 dB, about 2 dB to about 4 dB, about 2 dB to about 8 dB, about 2 dB to about 10 dB, about 2 dB to about 30 dB, about 2 dB to about 50 dB, about 2 dB to about 60 dB, about 2 dB to about 70 dB, about 2 dB to about 89 dB, about 2 dB to about 90 dB, about 2 dB to about 100 dB, about 4 dB to about 8 dB, about 4 dB to about 10 dB, about 4 dB to about 30 dB, about 4 dB to about 50 dB, about 4 dB to about 60 dB, about 4 dB to about 70 dB, about 4 dB to about 89 dB, about 4 dB to about 90 dB, about 4 dB to about 100 dB, about 8 dB to about 10 dB, about 8 dB to about 30 dB, about 8 dB to about 50 dB, about 8 dB to about 60 dB, about 8 dB to about 70 dB, about 8 dB to about 89 dB, about 8 dB to about 90 dB, about 8 dB to about 100 dB, about 10 dB to about 30 dB, about 10 dB to about 50 dB, about 10 dB to about 60 dB, about 10 dB to about 70 dB, about 10 dB to about 89 dB, about 10 dB to about 90 dB, about 10 dB to about 100 dB, about 30 dB to about 50 dB, about 30 dB to about 60 dB, about 30 dB to about 70 dB, about 30 dB to about 89 dB, about 30 dB to about 90 dB, about 30 dB to about 100 dB, about 50 dB to about 60 dB, about 50 dB to about 70 dB, about 50 dB to about 89 dB, about 50 dB to about 90 dB, about 50 dB to about 100 dB, about 60 dB to about 70 dB, about 60 dB to about 89 dB, about 60 dB to about 90 dB, about 60 dB to about 100 dB,

about 70 dB to about 89 dB, about 70 dB to about 90 dB, about 70 dB to about 100 dB, about 89 dB to about 90 dB, about 89 dB to about 100 dB, or about 90 dB to about 100 dB. In some cases, the contrast may be about 1 dB, about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, about 90 dB, or about 100 dB. In some cases, the contrast may be at least about 1 dB, about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, or about 90 dB. In some cases, the contrast may be at most about 2 dB, about 4 dB, about 8 dB, about 10 dB, about 30 dB, about 50 dB, about 60 dB, about 70 dB, about 89 dB, about 90 dB, or about 100 dB.

[0137] In some cases, the one or more light sources may comprise one a fiber bundle **304**.

[0138] In some cases, the fiber bundle **304** may comprise about 1 fiber to about 100 fibers. In some cases, the fiber bundle **304** may comprise about 1 fiber to about 2 fibers, about 1 fiber to about 4 fibers, about 1 fiber to about 8 fibers, about 1 fiber to about 10 fibers, about 1 fiber to about 30 fibers, about 1 fiber to about 50 fibers, about 1 fiber to about 60 fibers, about 1 fiber to about 70 fibers, about 1 fiber to about 89 fibers, about 1 fiber to about 90 fibers, about 1 fiber to about 100 fibers, about 2 fibers to about 4 fibers, about 2 fibers to about 8 fibers, about 2 fibers to about 10 fibers, about 2 fibers to about 30 fibers, about 2 fibers to about 50 fibers, about 2 fibers to about 60 fibers, about 2 fibers to about 70 fibers, about 2 fibers to about 89 fibers, about 2 fibers to about 90 fibers, about 2 fibers to about 100 fibers, about 4 fibers to about 8 fibers, about 4 fibers to about 10 fibers, about 4 fibers to about 30 fibers, about 4 fibers to about 50 fibers, about 4 fibers to about 60 fibers, about 4 fibers to about 70 fibers, about 4 fibers to about 89 fibers, about 4 fibers to about 90 fibers, about 4 fibers to about 100 fibers, about 8 fibers to about 10 fibers, about 8 fibers to about 30 fibers, about 8 fibers to about 50 fibers, about 8 fibers to about 60 fibers, about 8 fibers to about 70 fibers, about 8 fibers to about 89 fibers, about 8 fibers to about 90 fibers, about 8 fibers to about 100 fibers, about 10 fibers to about 30 fibers, about 10 fibers to about 50 fibers, about 10 fibers to about 60 fibers, about 10 fibers to about 70 fibers, about 10 fibers to about 89 fibers, about 10 fibers to about 90 fibers, about 10 fibers to about 100 fibers, about 30 fibers to about 50 fibers, about 30 fibers to about 60 fibers, about 30 fibers to about 70 fibers, about 30 fibers to about 89 fibers, about 30 fibers to about 90 fibers, about 30 fibers to about 100 fibers, about 50 fibers to about 60 fibers, about 50 fibers to about 70 fibers, about 50 fibers to about 89 fibers, about 50 fibers to about 90 fibers, about 50 fibers to about 100 fibers, about 60 fibers to about 70 fibers, about 60 fibers to about 89 fibers, about 60 fibers to about 90 fibers, about 60 fibers to about 100 fibers, about 70 fibers to about 89 fibers, about 70 fibers to about 90 fibers, about 70 fibers to about 100 fibers, about 89 fibers to about 90 fibers, about 89 fibers to about 100 fibers, or about 90 fibers to about 100 fibers. In some cases, the fiber bundle **304** may comprise about 1 fiber, about 2 fibers, about 4

fibers, about 8 fibers, about 10 fibers, about 30 fibers, about 50 fibers, about 60 fibers, about 70 fibers, about 89 fibers, about 90 fibers, or about 100 fibers. In some cases, the fiber bundle **304** may comprise at least about 1 fiber, about 2 fibers, about 4 fibers, about 8 fibers, about 10 fibers, about 30 fibers, about 50 fibers, about 60 fibers, about 70 fibers, about 89 fibers, or about 90 fibers. In some cases, the fiber bundle **304** may comprise at most about 2 fibers, about 4 fibers, about 8 fibers, about 10 fibers, about 30 fibers, about 50 fibers, about 60 fibers, about 70 fibers, about 89 fibers, about 90 fibers, or about 100 fibers.

[0139] In some cases, the at least one light source may comprise a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, incoherent laser, Mode-locked laser, p, surface emitting diode, super luminescent diode, or any combination thereof.

[0140] In some cases, the at least one light source may comprise a pulse width described elsewhere herein. In some instances, the at least one light source may comprise a light emission wavelength range described elsewhere herein. In some instances, the at least one light source may comprise a pulse repetition rate described elsewhere herein. In some cases, the at least one light source may comprise a peak output power described elsewhere herein. In some instances, the at least one light source may comprise a pulse energy described elsewhere herein.

[0141] In some instances, the one or more fibers may be in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within a subject's oral cavity. In some cases, the index matching material may comprise an index matching gel, liquid, adhesive, or any combination thereof. In some cases, the one or more fibers may comprise a fiber core diameter described elsewhere herein.

[0142] In some instances, the at least one light source may be in optical communication with one or more optical elements. In some instances, the one or more optical elements may comprise a plano-convex lens **306**, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror **312**, or any combination thereof.

[0143] In some instances, the method for determining one or more health metrics of one or more tissues of a subject's oral cavity from one or more detected ultrasound signals may comprise detecting light reflected off of tissue within a subject's oral cavity with one or more sensors. In some cases, the one or more sensors may comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof sensor. In some cases, the one or more health metrics may comprise gingival pocket depth, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, or any combination thereof.

[0144] In some cases, determining may comprise subjecting one or more ultrasound and/or photoacoustic images generated by the one or more ultrasound signals to a processing algorithm.

In some instances, analyzing may be completed on a local processor, cloud-based processor, or any combination thereof. In some cases, the one or more health metrics may be used to suggest a therapeutic, treatment, procedure, or any combination thereof intervention to the subject. In some cases, the methods provided herein may be completed on the systems described elsewhere herein.

[0145] Although the above steps show each of the methods or sets of operations in accordance with embodiments, a person of ordinary skill in the art will recognize many variations based on the teaching described herein. The steps may be completed in a different order. Steps may be added or omitted. Some of the steps may comprise sub-steps. Many of the steps may be repeated as often as beneficial.

[0146] One or more of the steps of each of the methods or sets of operations may be performed with circuitry as described herein, for example, one or more of the processor or logic circuitry such as programmable array logic for a field programmable gate array. The circuitry may be programmed to provide one or more of the steps of each of the methods or sets of operations, and the program may comprise program instructions stored on a computer readable memory or programmed steps of the logic circuitry such as the programmable array logic or the field programmable gate array, for example.

[0147] While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. It is not intended that the invention be limited by the specific examples provided within the specification. While the invention has been described with reference to the aforementioned specification, the descriptions and illustrations of the embodiments herein are not meant to be construed in a limiting sense. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. Furthermore, it shall be understood that all aspects of the invention are not limited to the specific depictions, configurations or relative proportions set forth herein which depend upon a variety of conditions and variables. It should be understood that alternatives and/or combinations of embodiments described herein may be employed in practicing the invention. It is therefore contemplated that the invention shall also cover any such alternatives, modifications, variations, combinations, or equivalents. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

DEFINITIONS

[0148] Unless defined otherwise, all terms of art, notations and other technical and scientific terms or terminology used herein are intended to have the same meaning as is commonly understood by one of ordinary skill in the art to which the claimed subject matter pertains. In some cases, terms with commonly understood meanings are defined herein for clarity and/or for ready reference, and the inclusion of such definitions herein should not necessarily be construed to represent a substantial difference over what is generally understood in the art.

[0149] Throughout this application, various embodiments may be presented in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the disclosure. Accordingly, the description of a range should be considered to have specifically disclosed all the possible subranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed subranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

[0150] As used in the specification and claims, the singular forms “a”, “an” and “the” include plural references unless the context clearly dictates otherwise. For example, the term “a sample” includes a plurality of samples, including mixtures thereof.

[0151] The terms “determining,” “measuring,” “evaluating,” “assessing,” “assaying,” and “analyzing” are often used interchangeably herein to refer to forms of measurement. The terms include determining if an element is present or not (for example, detection). These terms can include quantitative, qualitative, or quantitative and qualitative determinations. Assessing can be relative or absolute. “Detecting the presence of” can include determining the amount of something present in addition to determining whether it is present or absent depending on the context.

[0152] The terms “subject,” “individual,” “patient”, or “subject” are often used interchangeably herein. A “subject” can be a biological entity containing expressed genetic materials. The biological entity can be a plant, animal, or microorganism, including, for example, bacteria, viruses, fungi, and protozoa. The subject can be tissues, cells and their progeny of a biological entity obtained *in vivo* or cultured *in vitro*. The subject can be a mammal. The mammal can be a human. The subject may be diagnosed or suspected of being at high risk for a disease. In some cases, the subject is not necessarily diagnosed or suspected of being at high risk for the disease.

[0153] The term “*in vivo*” is used to describe an event that takes place in a subject’s body.

[0154] The term “*ex vivo*” is used to describe an event that takes place outside of a subject’s body. An *ex vivo* assay is not performed on a subject. Rather, it is performed upon a sample separate from a subject. An example of an *ex vivo* assay performed on a sample is an “*in vitro*” assay.

[0155] The term “*in vitro*” is used to describe an event that takes places contained in a container for holding laboratory reagent such that it is separated from the biological source from which the material is obtained. *In vitro* assays can encompass cell-based assays in which living or dead cells are employed. *In vitro* assays can also encompass a cell-free assay in which no intact cells are employed.

[0156] As used herein, the term “about” a number refers to that number plus or minus 10% of that number. The term “about” a range refers to that range minus 10% of its lowest value and plus 10% of its greatest value.

[0157] Use of absolute or sequential terms, for example, “will,” “will not,” “shall,” “shall not,” “must,” “must not,” “first,” “initially,” “next,” “subsequently,” “before,” “after,” “lastly,” and “finally,” are not meant to limit scope of the present embodiments disclosed herein but as exemplary.

[0158] Any systems, methods, software, compositions, and platforms described herein are modular and not limited to sequential steps. Accordingly, terms such as “first” and “second” do not necessarily imply priority, order of importance, or order of acts.

[0159] As used herein, the terms “treatment” or “treating” are used in reference to a pharmaceutical or other intervention regimen for obtaining beneficial or desired results in the recipient. Beneficial or desired results include but are not limited to a therapeutic benefit and/or a prophylactic benefit. A therapeutic benefit may refer to eradication or amelioration of symptoms or of an underlying disorder being treated. Also, a therapeutic benefit can be achieved with the eradication or amelioration of one or more of the physiological symptoms associated with the underlying disorder such that an improvement is observed in the subject, notwithstanding that the subject may still be afflicted with the underlying disorder. A prophylactic effect includes delaying, preventing, or eliminating the appearance of a disease or condition, delaying, or eliminating the onset of symptoms of a disease or condition, slowing, halting, or reversing the progression of a disease or condition, or any combination thereof. For prophylactic benefit, a subject at risk of developing a particular disease, or to a subject reporting one or more of the physiological symptoms of a disease may undergo treatment, even though a diagnosis of this disease may not have been made.

EMBODIMENTS

[0160] Numbered **embodiment 1** comprises an intraoral imaging device comprising: a scan head configured to be placed inside a subject's mouth, the scan head comprising at least one ultrasonic transducer configured to detect one or more pressure waves with a signal to noise ratio of at least 3dB and at least one light source, wherein the at least one light source or the at least one ultrasonic transducer is configured to generate the one or more pressure waves within one or more tissues of the subject's mouth. Numbered **embodiment 2** comprises the device of **embodiment 1**, wherein the at least one light source comprises one or more fibers. Numbered **embodiment 3** comprises the device of **embodiment 1**, wherein the at least one light source comprises a fiber bundle. Numbered **embodiment 4** comprises the device of **embodiment 3**, wherein the fiber bundle comprises at least 1 fiber. Numbered **embodiment 5** comprises the device of **embodiment 3**, wherein the fiber bundle comprises at least 2 fibers. Numbered **embodiment 6** comprises the device of **embodiment 3**, wherein the fiber bundle comprises at least 4 fibers. Numbered **embodiment 7** comprises the device of **embodiment 3**, wherein the fiber bundle comprises at least 6 fibers. Numbered **embodiment 8** comprises the device of **embodiment 3**, wherein the fiber bundle comprises at least 8 fibers. Numbered **embodiment 9** comprises the device of **embodiment 3**, wherein the fiber bundle comprises at least 10 fibers. Numbered **embodiment 10** comprises the device of **embodiment 3**, wherein the fiber bundle comprises at least 12 fibers. Numbered **embodiment 11** comprises the device of **embodiment 3**, wherein the fiber bundle comprises at least 14 fibers. Numbered **embodiment 12** comprises the device of **embodiment 3**, wherein the fiber bundle comprises at least 16 fibers. Numbered **embodiment 13** comprises the device of **embodiment 3**, wherein the fiber bundle comprises at least 19 fibers. Numbered **embodiment 14** comprises the device of **embodiment 1**, wherein the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, vertical cavity scanning electron laser (VCSEL), VCSEL array, or any combination thereof. Numbered **embodiment 15** comprises the device of **embodiment 1**, wherein the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns). Numbered **embodiment 16** comprises the device of **embodiment 1**, wherein the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm. Numbered **embodiment 17** comprises the device of **embodiment 1**, wherein the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 (Hz). Numbered **embodiment 18** comprises the device of **embodiment 1**, wherein the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW). Numbered **embodiment 19** comprises the device of **embodiment 1**, wherein the at least one light source comprises a pulse energy of about 0.01

milli Joule(mJ) to about 40 mJ. Numbered **embodiment 20** comprises the device of **embodiment 2**, wherein the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth. Numbered **embodiment 21** comprises the device of **embodiment 2**, wherein the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm . Numbered **embodiment 22** comprises the device of **embodiment 20**, wherein the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof. Numbered **embodiment 23** comprises the device of **embodiment 1**, further comprising one or more optical elements in optical communication with the at least one light source. Numbered **embodiment 24** comprises the device of **embodiment 23**, wherein the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof. Numbered **embodiment 25** comprises the device of **embodiment 1**, further comprising one or more sensors configured to sense light reflected off of tissue within the subject's mouth. Numbered **embodiment 26** comprises the device of **embodiment 25**, wherein the one or more sensors comprise a charge coupled device (CCD, complementary metal oxide semiconductor (CMOS), or any combination thereof sensor. Numbered **embodiment 27** comprises the device of **embodiment 1**, wherein the one or more tissues comprise gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, or any combination thereof tissue. Numbered **embodiment 28** comprises the device of **embodiment 1**, wherein the one or more pressure waves are converted into one or more ultrasonic images, wherein the ultrasonic images comprise one or more oral health metrics. Numbered **embodiment 29** comprises the device of **embodiment 28**, wherein the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof. Numbered **embodiment 30** comprises the device of **embodiment 1**, further comprising a pulser in electrical communication with the at least one ultrasonic transducer.

[0161] Numbered **embodiment 31** comprises a method of determining one or more health metrics of a subject's oral cavity, comprising: providing at least one light source and at least one ultrasonic transducer incident on one or more tissues of the subject's oral cavity; generating one or more pressure waves through the interaction of the at least one light source or the at least one ultrasonic transducer and the one or more tissues of the oral cavity; detecting the one or more pressure waves with the at least one ultrasonic transducer thereby generating one or more detected ultrasound signals with a signal to noise ratio of at least 3dB; and determining one or

more health metrics of the oral cavity from the one or more detected ultrasound signals.

Numbered **embodiment 32** comprises the method of **embodiment 31**, wherein the at least one light source comprises one or more fibers. Numbered **embodiment 33** comprises the method of **embodiment 31**, wherein the at least one light source comprises a fiber bundle. Numbered **embodiment 34** comprises the method of **embodiment 33**, wherein the fiber bundle comprises at least 1 fiber. Number **embodiment 35** comprises the method of **embodiment 33**, wherein the fiber bundle comprises at least 2 fibers. Numbered **embodiment 36** comprises the method of **embodiment 33**, wherein the fiber bundle comprises at least 4 fibers. Numbered **embodiment 37** comprises the method of **embodiment 33**, wherein the fiber bundle comprises at least 6 fibers. Numbered **embodiment 38** comprises the method of **embodiment 33**, wherein the fiber bundle comprises at least 8 fibers. Numbered **embodiment 39** comprises the method of **embodiment 33**, wherein the fiber bundle comprises at least 10 fibers. Numbered **embodiment 40** comprises the method of **embodiment 33**, wherein the fiber bundle comprises at least 12 fibers. Numbered **embodiment 41** comprises the method of **embodiment 33**, wherein the fiber bundle comprises at least 14 fibers. Numbered **embodiment 42** comprises the method of **embodiment 33**, wherein the fiber bundle comprises at least 16 fibers. Numbered **embodiment 43** comprises the method of **embodiment 33**, wherein the fiber bundle comprises at least 19 fibers. Numbered **embodiment 44** comprises the method of **embodiment 31**, wherein the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, vertical cavity scanning electron laser (VCSEL), VCSEL array, or any combination thereof. Numbered **embodiment 45** comprises the method of **embodiment 31**, wherein the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns). Numbered **embodiment 46** comprises the method of **embodiment 31**, wherein the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm. Numbered **embodiment 47** comprises the method of **embodiment 31**, wherein the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 (Hz). Numbered **embodiment 48** comprises the method of **embodiment 31**, wherein the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW). Numbered **embodiment 49** comprises the method of **embodiment 31**, wherein the at least one light source comprises a pulse energy of about 0.01 milli Joule(mJ) to about 40 mJ. Numbered **embodiment 50** comprises the method of **embodiment 32**, wherein the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth. Numbered **embodiment 51** comprises the method of

embodiment 32, wherein the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm . Numbered **embodiment 52** comprises the method of **embodiment 50**, wherein the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof. Numbered **embodiment 53** comprises the method of **embodiment 31**, wherein the at least one light source is in optical communication with one or more optical elements. Numbered **embodiment 54** comprises the method of **embodiment 53**, wherein the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof. Numbered **embodiment 55** comprises the method of **embodiment 31**, further comprising detecting light reflected off of tissue within the subject's mouth with one or more sensors. Numbered **embodiment 56** comprises the method of **embodiment 55**, wherein the one or more sensors comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof sensor. Numbered **embodiment 57** comprises the method of **embodiment 31**, wherein the one or more tissues of the oral cavity comprise gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, or any combination thereof tissue. Numbered **embodiment 58** comprises the method of **embodiment 31**, wherein the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof. Numbered **embodiment 59** comprises the method of **embodiment 31**, wherein determining comprises applying a processing algorithm to one or more images generated by the one or more ultrasound signals to a processing algorithm. Numbered **embodiment 60** comprises the method of **embodiment 31**, wherein determining is completed on a local processor, cloud-based processor, or any combination thereof. Numbered **embodiment 61** comprises the method of **embodiment 31**, wherein the one or more health metrics are used to suggest a therapeutic, treatment, procedure, or any combination thereof to the subject. Numbered **embodiment 62** comprises the method of **embodiment 59**, wherein the processing algorithm comprises a trained predictive model, wherein the trained predictive model is trained with one or more statistical features of one or more regions of interest of the one or more images and an annotated label of the one or more regions of interest. Numbered **embodiment 63** comprises the method of **embodiment 62**, wherein the one or more statistical features comprise mean, variance, standard deviation, skewness, median, entropy, kurtosis, or any combination thereof. Numbered **embodiment 64** comprises the method of **embodiment 62**, wherein the one or more statistical features comprise texture features of the gray level co-occurrence matrix (GLCM) in one or more directions of the

detected ultrasound signals. Numbered **embodiment 65** comprises the method of **embodiment 64**, wherein the texture features comprise homogeneity, contrast, energy, entropy, correlation, or any combination thereof. Numbered **embodiment 66** comprises the method of **embodiment 62**, wherein the statistical features comprise texture features of the gray level run length matrix (GLRLM) in one or more directions. Numbered **embodiment 67** comprises the method of **embodiment 66**, wherein the texture features of the GLRLM comprise short run emphasis, long run emphasis, gray-level non-uniformity, run percentage, run length nonuniformity, low gray-level run emphasis, high gray-level run emphasis, or any combination thereof. Numbered **embodiment 68** comprises the method of **embodiment 64**, wherein the one or more directions comprise 0 degrees, 45 degrees, 90 degrees, 135 degrees, or any combination thereof. Numbered **embodiment 69** comprises the method of **embodiment 62**, wherein the trained predictive model comprises a machine learning model, a neural network, a convolutional neural network, or any combination thereof. Numbered **embodiment 70** comprises the method of **embodiment 62**, wherein the one or more regions of interest comprises a width of at least two pixels and a height of at least two pixels. Numbered **embodiment 71** comprises the method of **embodiment 62**, wherein the trained predictive model comprises an accuracy of at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, or at least 99%.

[0162] Numbered **embodiment 72** comprises a wireless intraoral imaging device, comprising: a tip, wherein the tip comprises at least one light source and at least one ultrasonic transducer; and a processor in communication with the at one light source and the at least one ultrasonic transducer, wherein the processor is located on a body of the wireless intraoral imaging device, and wherein the processor is configured to process data obtained from the ultrasound transducer. Numbered **embodiment 73** comprises the device of **embodiment 72**, wherein the processor is configured to wirelessly transmit and receive information with a second processor of an external system. Numbered **embodiment 74** comprises the device of **embodiment 72**, further comprising a pulser receiver electrically coupled to the processor configured to process an ultrasound pressure wave echo detected by the at least one ultrasonic transducer. Numbered **embodiment 75** comprises the device of **embodiment 72**, wherein the processor comprises a field programmable gate array. Numbered **embodiment 76** comprises the device of **embodiment 72**, further comprising a processor configured to transmit the processed data obtained from the at least one ultrasonic transducer to a system for further processing, display, or any combination thereof. Numbered **embodiment 77** comprises the device of **embodiment 72**, further comprising a light source driver in electrical communication with the at least one light source and the processor. Numbered **embodiment 78** comprises the device of **embodiment**

72, further comprising a heat sink configured to distribute heat generated by the at least one light source. Numbered **embodiment 79** comprises the device of **embodiment 78**, further comprising a fan in fluid communication with the heat sink. Numbered **embodiment 80** comprises the device of **embodiment 72**, wherein the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof. Numbered **embodiment 81** comprises the device of **embodiment 72**, further comprising a sensor. Numbered **embodiment 82** comprises the device of **embodiment 81**, wherein the sensor comprises a gravitational sensor, a light base sensor, a gyroscope, a magnetometer, an accelerometer, or any combination thereof. Numbered **embodiment 83** comprises the device of **embodiment 72**, further comprising a battery, wherein the battery comprises a lithium-ion polymer battery. Numbered **embodiment 84** comprises the device of **embodiment 83**, wherein the battery comprises a rechargeable battery. Numbered **embodiment 85** comprises the device of **embodiment 72**, wherein the body is comprised of stainless steel or a plastic. Numbered **embodiment 86** comprises the device of **embodiment 72**, wherein the at least one light source comprises one or more fibers. Numbered **embodiment 87** comprises the device of **embodiment 72**, wherein the at least one light source comprises a fiber bundle. Numbered **embodiment 88** comprises the device of **embodiment 87**, wherein the fiber bundle comprises at least 1 fiber. Numbered **embodiment 89** comprises the device of **embodiment 87**, wherein the fiber bundle comprises at least 2 fibers. Numbered **embodiment 90** comprises the device of **embodiment 87**, wherein the fiber bundle comprises at least 4 fibers. Numbered **embodiment 91** comprises the device of **embodiment 87**, wherein the fiber bundle comprises at least 6 fibers. Numbered **embodiment 92** comprises the device of **embodiment 87**, wherein the fiber bundle comprises at least 8 fibers. Numbered **embodiment 93** comprises the device of **embodiment 87**, wherein the fiber bundle comprises at least 10 fibers. Numbered **embodiment 94** comprises the device of **embodiment 87**, wherein the fiber bundle comprises at least 12 fibers. Numbered **embodiment 95** comprises the device of **embodiment 87**, wherein the fiber bundle comprises at least 14 fibers. Numbered **embodiment 96** comprises the device of **embodiment 87**, wherein the fiber bundle comprises at least 16 fibers. Numbered **embodiment 97** comprises the device of **embodiment 87**, wherein the fiber bundle comprises at least 19 fibers. Numbered **embodiment 98** comprises the device of **embodiment 72**, wherein the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns). Numbered **embodiment 99** comprises the device of **embodiment 72**, wherein the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm. Numbered **embodiment 100** comprises the device of **embodiment 72**, wherein the at

least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 Hz. Numbered **embodiment 101** comprises the device of **embodiment 72**, wherein the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW). Numbered **embodiment 102** comprises the device of **embodiment 72**, wherein the at least one light source comprises a pulse energy of about 0.01 milli Joule(mJ) to about 40 mJ. Numbered **embodiment 103** comprises the device of **embodiment 86**, wherein the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth. Numbered **embodiment 104** comprises the device of **embodiment 86**, wherein the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm . Numbered **embodiment 105** comprises the device of **embodiment 103**, wherein the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof. Numbered **embodiment 106** comprises the device of **embodiment 72**, further comprising one or more optical elements in optical communication with the at least one light source. Numbered **embodiment 107** comprises the device of **embodiment 106**, wherein the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof. Numbered **embodiment 108** comprises the device of **embodiment 72**, further comprising one or more sensors configured to sense light reflected off of tissue within the subject's mouth. Numbered **embodiment 109** comprises the device of **embodiment 108**, wherein the one or more sensors comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof sensor. Numbered **embodiment 110** comprises the device of **embodiment 72**, wherein the data obtained from the at least one ultrasound transducer comprises ultrasound echo data of one or more pressure waves emitted by one or more tissues detected by the at least one ultrasound transducer. Numbered **embodiment 111** comprises the device of **embodiment 72**, wherein the one or more tissues comprise gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, tooth enamel, or any combination thereof tissue. Numbered **embodiment 112** comprises the device of **embodiment 110**, wherein the one or more pressure waves are converted into one or more ultrasonic images, wherein the ultrasonic images comprise one or more oral health metrics. Numbered **embodiment 113** comprises the device of **embodiment 112**, wherein the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination

thereof. Numbered **embodiment 114** comprises the device of **embodiment 72**, further comprising a pulser in electrical communication with the at least one ultrasonic transducer.

[0163] Numbered **embodiment 115** comprises a device for oral imaging, comprising: a probe, wherein the probe comprises: a tip, wherein the tip comprises at least one light source, at least one ultrasound transducer, and a coupling interface, wherein the coupling interface is configured to expand upon pressing the coupling interface onto a surface of an oral tissue, and wherein the coupling interface applies a pressure to the surface of the oral tissue. Numbered **embodiment 116** comprises the device of **embodiment 115**, wherein the oral tissue comprises gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, tooth enamel, or any combination thereof tissue. Numbered **embodiment 117** comprises the device of **embodiment 115**, wherein the at least one light source and the at least one ultrasound transducer are housed within the coupling interface. Numbered **embodiment 118** comprises the device of **embodiment 115**, wherein the pressure applied by the coupling interface to the surface of the oral tissue is configured to provide at least 3dB signal to noise of a detected ultrasound signal by the at least one ultrasound transducer. Numbered **embodiment 119** comprises the device of **embodiment 115**, wherein the pressure applied by the coupling interface to the surface of the oral tissue is applied normal to the surface of the oral tissue. Numbered **embodiment 120** comprises the device of **embodiment 115**, wherein the coupling interface comprises at least one spring mechanically coupled to the coupling interface, wherein the at least one spring is configured to expand when the coupling interface is pressed onto a surface of an oral tissue. Numbered **embodiment 121** comprises the device of **embodiment 115**, wherein the coupling interface comprises a shape memory material. Numbered **embodiment 122** comprises the device of **embodiment 121**, wherein the shape memory material comprises a shape memory metal, plastic, or any combination thereof. Numbered **embodiment 123** comprises the device of any of **embodiments 115-122**, wherein the probe comprises a handled probe. Numbered **embodiment 124** comprises the device of **embodiment 115**, wherein the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof. Numbered **embodiment 125** comprises the device of **embodiment 115**, wherein the at least one ultrasound transducer comprises a single element transducer or an array-based ultrasound transducer. Numbered **embodiment 126** comprises the device of **embodiment 115**, further comprising a processor electrically coupled to the at least one ultrasound transducer and the at least one light source, wherein the processor is configured to wirelessly transmit and receive information with a second processor of an external system. Numbered **embodiment 127**

comprises the device of **embodiment 126**, further comprising a pulser receiver electrically coupled to the processor configured to process an ultrasound pressure wave echo detected by the at least one ultrasonic transducer. Numbered **embodiment 128** comprises the device of **embodiment 126**, wherein the processor comprises a field programmable gate array. Numbered **embodiment 129** comprises the device of **embodiment 115**, further comprising a processor configured to transmit the processed data obtained from the at least one ultrasonic transducer to a system for further processing, display, or any combination thereof. Numbered **embodiment 130** comprises the device of **embodiment 115**, further comprising a light source driver in electrical communication with the at least one light source and the processor. Numbered **embodiment 131** comprises the device of **embodiment 115**, further comprising a heat sink configured to distribute heat generated by the at least one light source. Numbered **embodiment 132** comprises the device of **embodiment 131**, further comprising a fan in fluid communication with the heat sink. Numbered **embodiment 133** comprises the device of **embodiment 115**, wherein the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof. Numbered **embodiment 134** comprises the device of **embodiment 115**, further comprising a sensor. Numbered **embodiment 135** comprises the device of **embodiment 134**, wherein the sensor comprises a gravitational sensor, a light base sensor, a gyroscope, a magnetometer, an accelerometer, or any combination thereof. Numbered **embodiment 136** comprises the device of **embodiment 115**, further comprising a battery, wherein the battery comprises a lithium-ion polymer battery, and wherein the battery is configured to power the at least one ultrasound transducer, the at least one light source, or any combination thereof. Numbered **embodiment 137** comprises the device of **embodiment 136**, wherein the battery comprises a rechargeable battery. Numbered **embodiment 138** comprises the device of **embodiment 115**, wherein the probe comprises a body mechanically coupled to the tip, wherein the body, tip, or any combination thereof is comprised of stainless steel or a plastic material. Numbered **embodiment 139** comprises the device of **embodiment 115**, wherein the at least one light source comprises one or more fibers. Numbered **embodiment 140** comprises the device of **embodiment 115**, wherein the at least one light source comprises a fiber bundle. Numbered **embodiment 141** comprises the device of **embodiment 140**, wherein the fiber bundle comprises at least 1 fiber. Numbered **embodiment 142** comprises the device of **embodiment 140**, wherein the fiber bundle comprises at least 2 fibers. Numbered **embodiment 143** comprises the device of **embodiment 140**, wherein the fiber bundle comprises at least 4 fibers. Numbered **embodiment 144** comprises the device of **embodiment 140**, wherein the fiber bundle comprises at least 6

fibers. Numbered **embodiment 145** comprises the device of **embodiment 140**, wherein the fiber bundle comprises at least 8 fibers. Numbered **embodiment 146** comprises the device of **embodiment 140**, wherein the fiber bundle comprises at least 10 fibers. Numbered **embodiment 147** comprises the device of **embodiment 140**, wherein the fiber bundle comprises at least 12 fibers. Numbered **embodiment 148** comprises the device of **embodiment 140**, wherein the fiber bundle comprises at least 14 fibers. Numbered **embodiment 149** comprises the device of **embodiment 140**, wherein the fiber bundle comprises at least 16 fibers. Numbered **embodiment 150** comprises the device of **embodiment 140**, wherein the fiber bundle comprises at least 19 fibers. Numbered **embodiment 151** comprises the device of **embodiment 115**, wherein the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns). Numbered **embodiment 152** comprises the device of **embodiment 115**, wherein the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm. Numbered **embodiment 153** comprises the device of **embodiment 115**, wherein the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 Hz. Numbered **embodiment 154** comprises the device of **embodiment 115**, wherein the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW). Numbered **embodiment 155** comprises the device of **embodiment 115**, wherein the at least one light source comprises a pulse energy of about 0.01 milli Joule (mJ) to about 40 mJ. Numbered **embodiment 156** comprises the device of **embodiment 139**, wherein the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth. Numbered **embodiment 157** comprises the device of **embodiment 139**, wherein the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm . Numbered **embodiment 158** comprises the device of **embodiment 156**, wherein the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof. Numbered **embodiment 159** comprises the device of **embodiment 115**, further comprising one or more optical elements in optical communication with the at least one light source. Numbered **embodiment 160** comprises the device of **embodiment 159**, wherein the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof. Numbered **embodiment 161** comprises the device of **embodiment 115**, further comprising one or more sensors configured to sense light reflected off the oral tissue. Numbered **embodiment 162** comprises the device of **embodiment 161**, wherein the one or more sensors comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof sensor.

Numbered **embodiment 163** comprises the device of **embodiment 115**, wherein the at least one ultrasound transducer is configured to obtain data comprising ultrasound echo data of one or more pressure waves emitted by the oral tissue. Numbered **embodiment 164** comprises the device of **embodiment 163**, wherein the one or more pressure waves are converted into one or more ultrasonic images, wherein the ultrasonic images comprise one or more oral health metrics. Numbered **embodiment 165** comprises the device of **embodiment 164**, wherein the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof. Numbered **embodiment 166** comprises the device of **embodiment 115**, further comprising a pulser in electrical communication with the at least one ultrasonic transducer.

[0164] Numbered **embodiment 167** comprises a device for oral imaging, comprising: a probe, wherein the probe comprises: a tip, wherein the tip comprises a coupling interface, wherein the coupling interface is configured to expand upon pressing the coupling interface onto a surface of an oral tissue thereby providing a signal to noise ratio of at least 3dB when collecting data with the probe. Numbered **embodiment 168** comprises the device of **embodiment 167**, wherein the probe comprises a handheld probe. Numbered **embodiment 169** comprises the device of **embodiment 167**, wherein the oral tissue comprises gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, tooth enamel, or any combination thereof tissue. Numbered **embodiment 170** comprises the device of **embodiment 167**, wherein the tip comprises at least one ultrasound transducer housed within the tip. Numbered **embodiment 171** comprises the device of **embodiment 170**, wherein the data comprises ultrasound data collected from the oral tissue by the at least one ultrasound transducer. Numbered **embodiment 172** comprises the device of **embodiment 167**, wherein the pressure applied by the coupling interface to the surface of the oral tissue is applied normal to the surface of the oral tissue. Numbered **embodiment 173** comprises the device of **embodiment 167**, wherein the coupling interface comprises at least one spring mechanically coupled to the coupling interface, wherein the at least one spring is configured to expand when the coupling interface is pressed onto a surface of the oral tissue. Numbered **embodiment 174** comprises the device of **embodiment 167**, wherein the coupling interface comprises a shape memory material. Numbered **embodiment 175** comprises the device of **embodiment 174**, wherein the shape memory material comprises a shape memory metal, plastic, or any combination thereof. Numbered **embodiment 176** comprises the device of **embodiment 167**, wherein the tip further comprises at least one light source, at, at least one sensor, or any combination thereof. Numbered **embodiment 177** comprises the device of **embodiment 176**, wherein the at least one

light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof. Numbered **embodiment 178** comprises the device of **embodiment 170**, wherein the at least one ultrasound transducer comprises a single element transducer or an array-based ultrasound transducer. Numbered **embodiment 179** comprises the device of **embodiment 176**, wherein the at least one sensor comprises a gravitational sensor, a light base sensor, a gyroscope, a magnetometer, an accelerometer, or any combination thereof. Numbered **embodiment 180** comprises the device of **embodiment 179**, wherein the light base sensor comprises a charged coupled device (CCD) or a complementary metal oxide semiconductor sensor (CMOS). Numbered **embodiment 181** comprises the device of **embodiment 176**, wherein the probe further comprises a processor electrically coupled to the at least one ultrasound transducer, the at least one light source, or any combination thereof. Numbered **embodiment 182** comprises the device of **embodiment 181**, wherein the processor is configured to wirelessly transmit and receive information with a second processor of an external system. Numbered **embodiment 183** comprises the device of **embodiment 181**, wherein the probe further comprises a pulser receiver electrically coupled to the processor configured to process an ultrasound pressure wave echo detected by the at least one ultrasonic transducer. Numbered **embodiment 184** comprises the device of **embodiment 181**, wherein the processor comprises a field programmable gate array. Numbered **embodiment 185** comprises the device of **embodiment 170**, wherein the probe comprises a processor configured to transmit the processed data obtained from the at least one ultrasonic transducer to a system for further processing, display, or any combination thereof. Numbered **embodiment 186** comprises the device of **embodiment 176**, further comprising a light source driver in electrical communication with the at least one light source and the processor. Numbered **embodiment 187** comprises the device of **embodiment 186**, further comprising a heat sink configured to distribute heat generated by the at least one light source. Numbered **embodiment 188** comprises the device of **embodiment 187**, further comprising a fan in fluid communication with the heat sink. Numbered **embodiment 189** comprises the device of **embodiment 167**, wherein the probe comprises a battery, wherein the battery comprises a lithium-ion polymer battery. Numbered **embodiment 190** comprises the device of **embodiment 189**, wherein the battery comprises a rechargeable battery. Numbered **embodiment 191** comprises the device of **embodiment 167**, wherein the probe comprises a body, wherein the body is comprised of stainless steel or a plastic. Numbered **embodiment 192** comprises the device of **embodiment 176**, wherein the at least one light source comprises one or more fibers. Numbered **embodiment 193** comprises the device of **embodiment 176**, wherein the at least one light source comprises a

fiber bundle. Numbered **embodiment 194** comprises the device of **embodiment 193**, wherein the fiber bundle comprises at least 1 fiber. Numbered **embodiment 195** comprises the device of **embodiment 193**, wherein the fiber bundle comprises at least 2 fibers. Numbered **embodiment 196** comprises the device of **embodiment 193**, wherein the fiber bundle comprises at least 4 fibers. Numbered **embodiment 197** comprises the device of **embodiment 193**, wherein the fiber bundle comprises at least 6 fibers. Numbered **embodiment 198** comprises the device of **embodiment 193**, wherein the fiber bundle comprises at least 8 fibers. Numbered **embodiment 199** comprises the device of **embodiment 193**, wherein the fiber bundle comprises at least 10 fibers. Numbered **embodiment 200** comprises the device of **embodiment 193**, wherein the fiber bundle comprises at least 12 fibers. Numbered **embodiment 201** comprises the device of **embodiment 193**, wherein the fiber bundle comprises at least 14 fibers. Numbered **embodiment 202** comprises the device of **embodiment 193**, wherein the fiber bundle comprises at least 16 fibers. Numbered **embodiment 203** comprises the device of **embodiment 193**, wherein the fiber bundle comprises at least 19 fibers. Numbered **embodiment 204** comprises the device of **embodiment 176**, wherein the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns). Numbered **embodiment 205** comprises the device of **embodiment 176**, wherein the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm. Numbered **embodiment 206** comprises the device of **embodiment 176**, wherein the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 Hz. Numbered **embodiment 207** comprises the device of **embodiment 176**, wherein the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW). Numbered **embodiment 208** comprises the device of **embodiment 176**, wherein the at least one light source comprises a pulse energy of about 0.01 milli Joule(mJ) to about 40 mJ. Numbered **embodiment 209** comprises the device of **embodiment 192**, wherein the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth. Numbered **embodiment 210** comprises the device of **embodiment 192**, wherein the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm . Numbered **embodiment 211** comprises the device of **embodiment 209**, wherein the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof. Numbered **embodiment 212** comprises the device of **embodiment 176**, wherein the probe further comprises one or more optical elements optically coupled with the at least one light source. Numbered **embodiment 213** comprises the device of **embodiment 212**, wherein the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-

convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof. Numbered **embodiment 214** comprises the device of **embodiment 170**, wherein the data obtained by the probe comprises ultrasound echo data of one or more pressure waves emitted by one or more tissues obtained by the at least one ultrasound transducer. Numbered **embodiment 215** comprises the device of **embodiment 214**, wherein the one or more pressure waves are converted into one or more ultrasonic images, wherein the ultrasonic images comprise one or more oral health metrics. Numbered **embodiment 216** comprises the device of **embodiment 215**, wherein the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof. Numbered **embodiment 217** comprises the device of **embodiment 170**, further comprising a pulser in electrical communication with the at least one ultrasonic transducer.

EXAMPLES

Example 1: Characterization of an Ultrasound-Array Oral Imaging Probe

[0165] To address the shortcoming and/or inability of larger ultrasound probes to image deep and/or posterior oral tissues in hard-to-reach areas of the oral cavity, a compact form ultrasound-array oral probe was constructed and tested.

The ultrasound-array oral imaging probe (SS-19-128 for purposes of reference in the FIGs), described elsewhere herein, shown in **FIG. 9A**, incorporated a 128-element linear array with a center frequency of 19 megahertz (MHz) and an average -6 db bandwidth of 48.9%. The length of the ultrasound transducer active area was 10.24 millimeters (mm) with an element pitch size of 78 μm . The transducer was housed inside a handpiece of 1.8 centimeters (cm) by 1cm that permitted access to the entire oral cavity, particularly the molar teeth in the posterior region of the oral cavity that are understood to be affected readily by periodontitis. The ultrasound transducer was positioned within the housing in a manner such that the active area of the ultrasound transducer array was configured to obtain ultrasound echo data normal to the house (i.e., a side-viewing ultrasound probe) to facilitate positioning of the probe on the gingival and tooth surfaces of the oral cavity. The ultrasound transducer array was connected to a data acquisition (DAQ) system (i.e., one or more processors) via a UTA 260D adapter. The DAQ provide a 5.6V power supply and controlled electrical excitement time delay for the ultrasound transducer. The DAQ also sampled all radiofrequency data (i.e., ultrasound echo data) and processed ultrasound images from the sampled radiofrequency data. The ultrasound device and system supported frequency ranges from 2 to 42 MHz, 14-bit analog to digital converters with

programmable sample rates of up to 62.5MHz, and imaging rate of up to 100,000 frames/second. The C1 15-7 Philips transducer, and L22-14vX were used as comparison for form factor, as shown in **FIG. 9D** and their corresponding accessibility of various regions of the oral cavity, as shown in **FIG. 9C**.

Biological and Tissue Mimicking Samples

[0166] A tissue mimicking phantom constructed from polyacrylamide (PAA) was created to test the performance of the ultrasound-array oral imaging probe, as shown in **FIG. 11A**. The phantom included an array of light-wall polytetrafluoroethylene tubes were embedded in the tissue mimicking phantom varying depths of 5-35mm. The tubes were filled with water such that upon imaging with ultrasound would produce a hyperechoic signal due to a mismatch in mechanical impedance compared to the PAA body of the tissue mimicking phantom. PAA tissue mimicking phantoms were fabricated from a 400mL batch solution using a receipt of 12% weight/volume (w/v) acrylamide, 0.08% w/e APS, 0.2% TEMED, 0.7 milligram/milliliter (mg/mL) TiO₂, 0.00225% volume/volume (v/v) India ink, and 6 mg/mL glass beads. Phantoms took approximately five minutes to solidify and were allowed to cure for one hour with a maximum surface temperature of 46 degrees Celsius as measured by an infrared thermometer.

[0167] Ex-vivo swine (**FIGS. 13A-13C**) and in-vivo human (**FIGS. 12B-12H**) imaging was also conducted with the ultrasound-array oral imaging probe. Swine jaws were purchased and sliced with a bandsaw to size. The ex-vivo swine jaws were immobilized under water to facilitate with ultrasound coupling for imaging. Values of gingival thickness for 12 swine teeth were measured by the ultrasound-array oral imaging probe and 28-gauge needle with calipers (a gold standard), as shown in **FIGS. 13D and 13E**. For the gold standard needle measurement, the needle was inserted into the swine gingiva perpendicularly until contact was made with the tooth. A line was marked on the needle, and the distance between the marked line and the tip of the needle was measured with a 0.1mm precision caliper.

[0168] Human subject imaging involved imaging three healthy male subjects (with ages ranging between 25-40 years old) all characterized with good oral hygiene. The periodontal structure of all subjects was imaged. The ultrasound-array oral imaging probe, described elsewhere herein, was enclosed within a layer of parafilm with a thin amount of gel (i.e., index matching medium) between the transducer active surface and the parafilm. Coupling gel was also placed on the exterior of the parafilm wrapped device to facilitate coupling of the ultrasound emission and detection of ultrasound echoes between the subjects' oral tissue and the ultrasound-array oral imaging probe.

Imaging Procedures and Statistical Analysis

[0169] Three different modes of beamforming were used to process ultrasound images generated by the ultrasound-array oral imaging probe: no flash angle, flash angles, and wide beam, as shown in **FIG. 9E**. In the no flash angle model, all channels of the transducer were excited simultaneously to generate only one plane wave with no beam tilting that was then used to reconstruct a B-mode image from the ultrasound pulse-echo signal. In the flash angle mode (i.e., coherent compounding beamforming method), a time delay between ultrasound transducer element channels was applied by the DAQ system. Seven plane waves with different tilting angles were generated in a row that were averaged to reconstruct one image frame. In the wide beam mode, ultrasound transducer element channels were divided into a plurality of subgroups that were then sequentially utilized across all ultrasound transducer elements of the array for collection of pulse-echo signals. The reconstruction of ultrasound image from the wide beam model involved compensating the phase differences between the ultrasound transducer elements and adding together the pulse-echo signals from all channels (corresponding to each group of ultrasound-transducer elements of the array).

[0170] Bland-Altman and Pearson correlation statistical analysis were utilized when comparing the accuracy of gingival thickness measurements between the ultrasound-array oral imaging probe and the needle-based gold-standard measurement across the 12 swine teeth.

Oral Imaging System Setup and Device Parameter Comparison

[0171] The transducer-array oral imaging probe was found to access imaging all 32 human teeth and related oral tissue of the entire oral cavity, as shown in **FIG. 9C**, based at least in part on the size of the transducer-array oral imaging probe. It was found that the gums restrict the movement and maneuverability of larger transducers or transducers with front-facing configurations that are further detailed in the comparison in **Table 1**. The ultrasound transducer array oral imaging probe was configured to fit with a universal transducer adapter suitable for interfacing with the DAQ and/or processor, described elsewhere herein, as shown in **FIG. 9B**. The width of ultrasound transducer-array oral imaging probe at 18mm was found to be 1.83 to 1.94 times smaller compared with representative transducers (e.g., Zonare/Mindray L25-8, VisualSonics UHF70, Olympus V116, Vinno-X10 23L, or the Analogic L40-8/12, as shown in **Table 1**). The center frequency of the ultrasound transducer-array oral imaging probe was 19MHz, which was comparable to the 20MHz L22-vX (Verasonic) but two-times higher than the 9MHz CL15-7 (Philips).

Table 1: Comparison of Characteristics of Ultrasound Probes

Manufacturer- Transducer	Styl Sonic- SS-99-128	Mindray L25-8	VisualSonics- UHF70	Olympus- V116	Vinno X10- 23L	Analogic- L40-8/12	Philips CL15-7
Element number	128	NR	NR	1	128	128	128
Frequency (MHz)	19	24	70	20	23	20	9
Side or Forward Facing	Side	Side	Forward	Right Microdot	Forward	Forward	Forward
Size	10 mmx 18mm	12 mm x 18mm	~1 cm x 2 cm x 10 cm	6.4 mm by 9.7mm	NR	13mm x 4mm	~10 mm x23 mm
Axial Res (μm)	102.1 μm	64 μm	30 μm	NR	NR	NR	210
Lateral Res (μm)	142.9 μm	192 μm	65 μm	NR	NR	NR	196
Field of View (cm)	1	1.7	0.97	NR	NR	NR	NR
Penetration Depth (mm)	Greater than 30mm	15 mm	10 mm	NR	NR	16 mm	NR

Oral Imaging Probe Resolution and Penetration Depth Performance

[0172] Axial and lateral resolution in addition to penetration depth (i.e., imaging depth) of the transducer-array oral imaging probe was analyzed. Higher center frequency (e.g., center frequencies greater than 10 MHz) ultrasound transducers have better resolution but lower penetration depth as compared to low center frequency ultrasound transducers. Due to the importance of imaging oral features (e.g., CEJ, gingival thickness, etc.) to diagnose and monitor periodontitis, often sub-millimeter scale or higher precision measurements are required and are realized by ultrasound transducers with high center frequency.

[0173] Axial and lateral resolution were analyzed by imaging a known geometric structure embedded in a tissue mimicking phantom. The tissue mimicking phantom included two embedded 30 μm nichrome wires in water held at 5.5mm and 13.5mm from the surface of ultrasound transducer array probe and the surface of the water phantom, as shown in **FIG. 10A**. The axial (**FIG. 10C**) and lateral resolution (**FIG. 10D**) of the beam forming modes: no flash, flash angle, and wide beam, described elsewhere herein, were analyzed, and compared as shown in **FIGS. 10B-10D**. Axial resolution is dependent on center frequency and pulse cycle number, which parameters were set the same, and thus axial resolution was similar across three modes. Lateral resolution is related to beamwidth, which varied between the three modes. The axial resolution of the no flash and flash angle modes (**FIG. 10C**) were both found to be 102.1 μm , which was 9.2% higher than the wide beam mode (112.5 μm). It is understood that axial resolution is equal to the spatial pulse length (SPL)/2, and that SPL is proportional to wavelength and pulse cycle number. The wavelength and pulse cycle number were the same across the three modes in the analysis and thus the values axial resolution should have been identical but there was a 10% difference attributed to differences in position of the phantom relative to the array ultrasound transducer. The lateral resolution of the wire 5.5mm from the transducer was 142.9 μm in flash angle model, which is 36% lower than no flash mode (224.6 μm) and 58.8% lower than wide beam mode (347.1 μm), as shown in **FIG. 10D**. Under flash angle mode, the artifacts in the lateral

direction were compressed by averaging radiofrequency signals from plane waves within seven tilting angles. With consideration of resolving high-resolution features of the oral cavity, flash angle beamforming was used for subsequent imaging of human and non-human mammalian oral tissue.

[0174] The penetration depth of ultrasound transducer array probe was analyzed by imaging Polytetrafluorethylene tube targets embedded at varying depths within a tissue mimicking phantom, as shown in **FIG. 11A**. The signal-to-noise ratio (SNR) of the 30-mm deep tubes were 19 decibels (dB), 22dB, and 21 dB under no flash, flash angle, and wide beam modes, respectively, as shown in **FIGS. 11B and 11C**. The data show that the ultrasound transducer array probe can evaluate the entire gingiva (median gingival thickness = 1.1mm). The SNR vs. depth for the three beamforming modes was also further quantified, as shown in **FIG. 11C**.

Periodontal Human Subject Imaging

[0175] Three human subjects' teeth and corresponding oral tissue were imaged. Specifically, tooth and surround oral tissue (e.g., diagram shown in **FIG. 12A**) of tooth #30 and #32 of the first subject, tooth #8 and #19 of subject two, and tooth #5 and #14 of subject 3 was imaged with the ultrasound transducer array oral imaging probe, as shown in **FIGS. 12B-12H**. The imaging results indicate that the ultrasound transducer array oral imaging probe is capable of imaging molar with suitable image resolution to resolve oral tissue and teeth substructure, as shown in **FIGS. 12B-12H**. This is in part enabled by the small compact form factor of the ultrasound transducer array oral imaging probe, described elsewhere herein. Human tooth #8 images obtained by the ultrasound transducer array oral imaging probe and the convention CL 15-7 ultrasound transducer were also compared. The ultrasound transducer array oral imaging probe produces images with a twofold increase in resolution as compared to the CL 15-7 that agrees with 2.1 times higher center frequency of the ultrasound transducer array oral imaging probe as compared to the CL 15 (axial resolution of 200 μ m).

Gingival Thickness Measurement on Swine Jaws

[0176] The gingival thickness of swine jaws was measured 2 mm apical to the gingival margin with the ultrasound transducer array oral imaging probe (**FIGS. 13A-13C**) and with a needle. The gingival thickness values ranged from 1.0 to 1.6 mm as measured by both approaches. The Bland-Altman plot, as shown in **FIG. 13D** shows that the bias was 0.15mm, indicating that needle measurements provided slightly lower measured thickness values. Pearson correlation (**FIG. 13E**) shows that the correlation coefficient $r = 0.9235$ ($P < 0.0001$), indicating a high correlation agreement between the two measurements.

[0177] The results of the characterization of the ultrasound transducer array oral imaging probe and corresponding comparison to physical gold standard measurement show that the ultrasound transducer array oral imaging probe can access the entire oral cavity and appropriately visualize small scale oral tissue anatomy in real-time. The ultrasound array oral imaging probe's image quality was found to be comparable to the conventional bulky ultrasound transducers with the added benefit that the ultrasound array oral imaging probe was able to access the entirety of the oral cavity where the conventional bulky ultrasound transducers was not able to.

Example 2: Characterization of a Combined Photoacoustic and Ultrasound Oral Imaging Probe

[0178] Periodontitis, as described elsewhere herein is a common disease (particularly in the United States—nearly 50% of population with the disease) caused by subgingival bacteria that destroy supporting structures of teeth. Lengthening of the periodontal pocket and gingival inflammation are common features of periodontitis. Conventional approaches to diagnosing and monitoring of periodontitis including measuring periodontal pocket depth with metallic probes and visual inspection of discoloration of oral tissue. However, periodontal probing is limited in its diagnostic and disease monitoring capabilities because it involves a subjective determination of the extent of the pocket depth that may be confounded by the amount of force medical personnel use during probing. Additionally, periodontal probing is time-consuming and invasive often resulting a painful procedure where a metal probe is lodged between a subject's gingiva and tooth.

[0179] Photoacoustic and/or ultrasound imaging have been investigated as potential tools to objectively measure small scale anatomy of oral tissue e.g., the periodontal pocket depth as an indicator of periodontitis. However, conventional photoacoustic and/or ultrasound imaging probes are bulky and are thus limited in imaging posterior molar teeth and surrounding oral tissue typically affected in individuals with periodontitis. Thus, there exists an unmet need for a compact photoacoustic and/or ultrasound imaging probe that is addressed by the devices, systems, and methods described elsewhere herein.

[0180] A combined photoacoustic-ultrasound oral imaging probe, described elsewhere herein, was characterized (e.g., axial resolution, lateral resolution, signal to noise, beam power stability, etc.) and used for in-vivo human oral cavity imaging. The combined photoacoustic-ultrasound oral imaging probe is configured for in-vivo full-mouth oral cavity imaging particularly imaging of the periodontal pocket.

[0181] The photoacoustic-ultrasound oral imaging probe was comprised of a photoacoustic-ultrasound imaging transducer, a laser-diode module, an ultrasound DAQ. Photoacoustic

imaging requires optical excitation integrated with the detection of one or more pressure waves by an ultrasound transducer. The photoacoustic-ultrasound oral imaging probe integrated both the ultrasound transducer and a transparent window and mirror for light delivery for photoacoustic imaging. The ultrasound transducer was comprised of a high-frequency ultrasound transducer with a center frequency of 19MHz and average -6dB bandwidth of 48.9%. The transducer had 128 elements with element pitch of 78 μm . The photoacoustic-ultrasound oral imaging probe also comprised a laser-diode module comprising a pulsed laser diode, a function generator, coupling lens configured to couple the emission of the pulse laser diode to the oral tissue imaged, and a heat sink. The laser-diode module had dimensions of 35 cm (length) x 19 cm (width) x 28 cm (height and weighted approximately 5 kg. The pulse diode laser generated laser pulses with a 1kHz repetition rate at a center wavelength of 808 nm which were coupled into a fiber and delivered remotely to the oral tissue through the photoacoustic-ultrasound imaging probe. Since the imaging probe did not have any imbedded light sources or necessary thermal systems, the probe was able to fit into a compact form factor suitable for imaging across the entirety of the oral cavity. Alternative LED-based photoacoustic imaging systems require the LED arrays and heatsink to be assembled on and/or within the imaging probe body increasing the size of the imaging probe. The laser-diode module also provided a trigger in and out channel through a function generator board for synchronization with detection circuitry (i.e., the ultrasound transducer and associated DAQ, etc.). The pulse energy of the pulsed laser was 0.7 millijoule (mJ)/cm² with a pulse width of 100 nanoseconds (ns). An ultrasound data acquisition system was used to receive, process, and reconstruct the photoacoustic and/or ultrasound signals. The data acquisition system had 256 channels with a maximum sampling rate of 62.5MHz. The data acquisition system provided output triggers to a light source driver in electrical communication with the laser diode to synchronize light emission and ultrasound data acquisition.

[0182] The combined photoacoustic-ultrasound imaging probe was characterized for light homogeneity, light stability, penetration depth, lateral resolution, and axial resolution, as shown in **FIGS. 14A-14D**. A tissue-mimicking phantom was utilized to characterize the photoacoustic-ultrasound probe prior to ex-vivo swine oral tissue and/or in-vivo human oral tissue imaging. The tissue mimicking phantom was made of 20% intralipid solution. To evaluate light homogeneity, an array of pencil lead (10 mm wide, 5 lead pieces) of 0.2mm diameter was embedded into the intralipid solution 8 mm below the surface of the liquid tissue mimicking phantom and imaged with the photoacoustic-ultrasound imaging probe, as shown in **FIG. 14A**. Pencil lead is a strong light absorber leading to an accurate correlation between photoacoustic signal intensity and local light intensity (i.e., stronger photoacoustic signal indicates stronger

light focus). All five pencil leads are distinguishable in the 10-mm range in the photoacoustic image with similar intensity, as seen in **FIG. 14A**. **FIG. 14A** also shows that the photoacoustic intensity of the five pencil leads have only 11% relative standard deviation, indicating uniform illumination.

[0183] Light source emission stability was measured by monitoring the intensity of the emitted light source for a one-hour duration, as shown in **FIG. 14B**. The experimental setup was comprised of a photodetector was optically coupled to the emitted light of the photoacoustic-ultrasound imaging probe and electrically in communication with an oscilloscope, as shown in **FIG. 14B**. The measured light intensity dropped from 0.74 mJ/cm^2 to 0.58 mJ/cm^2 in the one-hour measurement window with 20% variation.

[0184] Imaging depth of the photoacoustic-ultrasound imaging probe was measured by imaging three polyethylene tubes filled with cuttlefish contrast agent ink ($20 \text{ }\mu\text{L}$) fixed at varying depths with a 3D printed holder. The tubes were placed into the tissue mimicking phantom at different depths (7 mm, 11 mm, 15 mm) from the surface of the phantom and the photoacoustic-ultrasound imaging probe. The first two tubes were distinguishable while the third is challenging to identify, as seen in **FIG. 14C**. **FIG. 14C** also shows that the signal-to-noise ratio (SNR) decreased with imaging depth which is expected due to light attenuation. These results demonstrated that the imaging probe and the system can image contrast agents as deep as 11 mm in tissues with more than 10-dB SNR. The pulse energy of the laser diodes of the imaging probe were sufficient for periodontal pocket imaging (less than 4 mm deep).

[0185] Resolution (e.g., axial, and lateral resolution) of the photoacoustic-ultrasound imaging probe were also determined by imaging a cross-section of a human hair ($100\text{-}\mu\text{m}$ diameter) and a $30 \text{ }\mu\text{m}$ nichrome wire. The full width half maximum (FWHM) of the lateral and axial amplitude distributions (obtained from imaging the human hair and nichrome wire with the photoacoustic-ultrasound imaging probe) were taken to be the axial and lateral resolution. The lateral and axial resolution of photoacoustic imaging mode of the photoacoustic-ultrasound imaging probe were $192 \text{ }\mu\text{m}$ and $352 \text{ }\mu\text{m}$, respectively, as shown in **FIG. 14D**. The lateral and axial resolution of the ultrasound imaging mode of the photoacoustic-ultrasound imaging probe was $142 \text{ }\mu\text{m}$ and $102 \text{ }\mu\text{m}$, respectively.

[0186] Ex-vivo swine and in-vivo human teeth and gingival tissues were imaged to analyze the performance of the photoacoustic-ultrasound imaging probe to resolve the periodontal oral tissue structure. One swine tooth and two human teeth were imaged ex vivo and in vivo, respectively. Swine teeth are a common model to human teeth because they have a similar structure. The photoacoustic-ultrasound imaging probe used in an ultrasound imaging mode was able to resolve teeth and surround oral tissue structures (e.g., gingival surface, tooth surface (occlusal

surface), gingival margin, alveolar bone, and/or alveolar bone crest (ABC)) in both the swine tooth (1st molar, **FIG. 15A**) and the human tooth (Cuspid tooth #6, **FIG. 15B**). The tooth surface was found to have stronger ultrasound intensity because it has a higher impedance than the other surrounding oral tissue. Moreover, the cemento-enamel junction (CEJ) is distinguishable in the human tooth (**FIG. 15B**). Resolving these structures and their positions are essential in the diagnosis and/or monitoring of periodontal disease. Moreover, the 1st molar of a human subject was imaged in-vivo with the photoacoustic-ultrasound imaging probe, as seen in **FIG. 15C**. The in-vivo image of the 1st molar of a human subject demonstrated that the photoacoustic-ultrasound imaging probe may operate in the posterior area of the oral cavity to image molars in vivo, which is a major limitation and challenge for conventional ultrasound transducers.

[0187] Dual-mode photoacoustic and ultrasound imaging was conducted with the photoacoustic-ultrasound imaging probe to resolve the periodontal pockets of both ex vivo and in vivo tissues. A cuttlefish ink solution was used as a photoacoustic contrast agent which highlighted the pocket areas. The ultrasound image in grayscale showed the tooth structure, while the photoacoustic image (shown in red scale) reveals the contrast agent and by association the periodontal pocket, as shown in **FIGS. 16A-16D, FIGS. 17A and 17B**, where the photoacoustic and ultrasound image data is overlaid in **FIGS. 16C, 16D, and 17B**. Two swine teeth (1st pre-molar and 1st molar) were imaged ex vivo (**FIGS. 16A-16D**) and a molar of a periodontal patient was imaged in vivo (**FIGS. 17A-17B**). **FIGS. 16A-16D** show ultrasound image data (**FIG. 16A and 16B**) of the two swine teeth before applying the contrast agent and after in the combined photoacoustic ultrasound image data (**FIGS. 16C and 16D**). Clearly, there is no photoacoustic signal in the periodontal pocket before applying contrast agents. The photoacoustic signal from the 1st pre-molar image was caused by a tooth stain as shown in the inset photo of **FIG. 16B**. After applying the contrast agent, the contrast agent is seen as a line below the gingival margin i.e., the periodontal pocket. This confirms that the photoacoustic-ultrasound imaging probe can detect the periodontal pocket ex vivo. By drawing a line between the gingival margin in the ultrasound image and the contrast end in the pocket in the photoacoustic image, the pocket depth was measured to be 2.3mm from the 1st molar and 4.0mm for the 1st pre-molar, close to a measured clinical periodontal probe pocket depth measurement of 2mm and 4mm, respectively.

[0188] The 1st molar #14 of a periodontal patient was also imaged in vivo with the photoacoustic-ultrasound imaging probe (**FIGS. 17A-17C**). The diseased patient was diagnosed with stage 2, grade B periodontitis. Tooth #14 was characterized via conventional probing and with the photoacoustic-ultrasound imaging probe. The probing pocket depth (PPD) depths were 4-3-5 mm (from distal to medial to mesial) on the buccal side and 4-3-6 mm on the lingual side. The clinical attachment level (CAL) buccal (from distal to medial to mesial) was 4-3-5mm, and

the CAL lingual was 4-3-6 mm. Similar to the swine teeth, the photoacoustic signal can be seen in the pocket after applying contrast agent (**FIG. 17B**). **FIG. 17C** also shows the line distribution of the photoacoustic signal across the pocket. As can be seen in **FIG. 17C**, the pocket area has a stronger photoacoustic intensity (red line) after applying the contrast agent as compared to without the contrast agent (blue line). The pocket depth was measured as 2.8 mm (medial, buccal side). The imaging assessment of the probing depth medially was within 7% of the value (3mm) as determined using a periodontal probe invasively. These such results demonstrated that the photoacoustic-ultrasound imaging probe can non-invasively and objectively determine the periodontal pocket depth of molars in vivo.

[0189] In addition to determining the periodontal pocket depth, gingival inflammation is also utilized to support a diagnosing and/or to monitor periodontal disease. It is expected that the inflamed tissue is well perfused and hence will exhibit more of a blood-based signal in comparison to healthy tissue. Such a difference was determined by detecting the hemoglobin photoacoustic signal in a swine tooth model with the photoacoustic-ultrasound imaging probe. Photoacoustic imaging of the well perfused tissue and the poorly perfused tissue, as seen in **FIG. 18A**, was conducted with resulting images in **FIGS. 18B and 18C**. As can be seen from the combined photoacoustic and ultrasound image data (**FIGS. 18B and 18C**), well perfused tissue has a much stronger photoacoustic signal close to the gingival surface than the poorly perfused tissue. The statistical analysis, shown in **FIG. 18D**, showed that the overall photoacoustic intensity of the well perfused tissue is around two times higher than the poorly perfused tissue.

[0190] From the results shown in **Example 2**, a combined photoacoustic-ultrasound imaging probe, as described elsewhere herein, was characterized, and evaluated in its ability to image and distinguish periodontal oral tissue (e.g., periodontal pocket depth, gingiva perfusion, small scale oral tissue anatomy, etc.).

Example 3: Imaging Oral Tissue with a Mechanically Coupled Interface of an Imaging Probe

[0191] An intraoral imaging probe comprising a mechanical coupling interface, as described elsewhere herein, is used to image an oral tissue (e.g., dentin, gingiva, etc., as described elsewhere herein). The mechanical coupling interface of the intraoral imaging probe is pressed against a subject's oral tissue and data is collected. When the mechanical coupling interface of the intraoral imaging probe is pressed against the oral tissue, the coupling interface provides coupling between the intraoral imaging probe and the oral tissue such that data with a signal-to-noise ratio and/or contrast of at least 3dB is collected. The data collected is ultrasound, photoacoustic, visible light photons, accelerometer, gyroscopic, magnetometer, or any

combination thereof data. In the example of ultrasound and/or photoacoustic data, the mechanical coupling interface of the imaging probe provides stabilization for the ultrasound transducer to detect one or more pressure waves with at least 3dB signal to noise and/or contrast resulting from the increased coupling e.g., reducing the mechanical impedance mismatch between e.g., ultrasound transducer and the oral tissue arising from air and/or fluid between a detecting surface of the ultrasound transducer and a surface of the oral tissue.

[0192] While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. It is not intended that the invention be limited by the specific examples provided within the specification. While the invention has been described with reference to the aforementioned specification, the descriptions and illustrations of the embodiments herein are not meant to be construed in a limiting sense. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. Furthermore, it shall be understood that all aspects of the invention are not limited to the specific depictions, configurations or relative proportions set forth herein which depend upon a variety of conditions and variables. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is therefore contemplated that the invention shall also cover any such alternatives, modifications, variations, or equivalents. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

CLAIMS**WHAT IS CLAIMED IS:**

1. An intraoral imaging device comprising:
a scan head configured to be placed inside a subject's mouth, the scan head comprising at least one ultrasonic transducer configured to detect one or more pressure waves with a signal to noise ratio of at least 3dB and at least one light source, wherein the at least one light source or the at least one ultrasonic transducer is configured to generate the one or more pressure waves within one or more tissues of the subject's mouth.
2. The device of claim 1, wherein the at least one light source comprises one or more fibers.
3. The device of claim 1, wherein the at least one light source comprises a fiber bundle.
4. The device of claim 3, wherein the fiber bundle comprises at least 1 fiber.
5. The device of claim 3, wherein the fiber bundle comprises at least 2 fibers.
6. The device of claim 3, wherein the fiber bundle comprises at least 4 fibers.
7. The device of claim 3, wherein the fiber bundle comprises at least 6 fibers.
8. The device of claim 3, wherein the fiber bundle comprises at least 8 fibers.
9. The device of claim 3, wherein the fiber bundle comprises at least 10 fibers.
10. The device of claim 3, wherein the fiber bundle comprises at least 12 fibers.
11. The device of claim 3, wherein the fiber bundle comprises at least 14 fibers.
12. The device of claim 3, wherein the fiber bundle comprises at least 16 fibers.
13. The device of claim 3, wherein the fiber bundle comprises at least 19 fibers.
14. The device of claim 1, wherein the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, vertical cavity scanning electron laser (VCSEL), VCSEL array, or any combination thereof.
15. The device of claim 1, wherein the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns).
16. The device of claim 1, wherein the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm.
17. The device of claim 1, wherein the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 (Hz).

18. The device of claim 1, wherein the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW).
19. The device of claim 1, wherein the at least one light source comprises a pulse energy of about 0.01 milli Joule(mJ) to about 40 mJ.
20. The device of claim 2, wherein the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth.
21. The device of claim 2, wherein the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm .
22. The device of claim 20, wherein the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof.
23. The device of claim 1, further comprising one or more optical elements in optical communication with the at least one light source.
24. The device of claim 23, wherein the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof.
25. The device of claim 1, further comprising one or more sensors configured to sense light reflected off of tissue within the subject's mouth.
26. The device of claim 25, wherein the one or more sensors comprise a charge coupled device (CCD, complementary metal oxide semiconductor (CMOS), or any combination thereof sensor.
27. The device of claim 1, wherein the one or more tissues comprise gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, or any combination thereof tissue.
28. The device of claim 1, wherein the one or more pressure waves are converted into one or more ultrasonic images, wherein the ultrasonic images comprise one or more oral health metrics.
29. The device of claim 28, wherein the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof.
30. The device of claim 1, further comprising a pulser in electrical communication with the at least one ultrasonic transducer.

31. A method of determining one or more health metrics of a subject's oral cavity, comprising:
- (a) providing at least one light source and at least one ultrasonic transducer incident on one or more tissues of the subject's oral cavity;
 - (b) generating one or more pressure waves through the interaction of the at least one light source or the at least one ultrasonic transducer and the one or more tissues of the oral cavity;
 - (c) detecting the one or more pressure waves with the at least one ultrasonic transducer thereby generating one or more detected ultrasound signals with a signal to noise ratio of at least 3dB; and
 - (d) determining one or more health metrics of the oral cavity from the one or more detected ultrasound signals.
32. The method of claim 31, wherein the at least one light source comprises one or more fibers.
33. The method of claim 31, wherein the at least one light source comprises a fiber bundle.
34. The method of claim 33, wherein the fiber bundle comprises at least 1 fiber.
35. The method of claim 33, wherein the fiber bundle comprises at least 2 fibers.
36. The method of claim 33, wherein the fiber bundle comprises at least 4 fibers.
37. The method of claim 33, wherein the fiber bundle comprises at least 6 fibers.
38. The method of claim 33, wherein the fiber bundle comprises at least 8 fibers.
39. The method of claim 33, wherein the fiber bundle comprises at least 10 fibers.
40. The method of claim 33, wherein the fiber bundle comprises at least 12 fibers.
41. The method of claim 33, wherein the fiber bundle comprises at least 14 fibers.
42. The method of claim 33, wherein the fiber bundle comprises at least 16 fibers.
43. The method of claim 33, wherein the fiber bundle comprises at least 19 fibers.
44. The method of claim 31, wherein the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, vertical cavity scanning electron laser (VCSEL), VCSEL array, or any combination thereof.
45. The method of claim 31, wherein the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns).

46. The method of claim 31, wherein the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm.
47. The method of claim 31, wherein the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 (Hz).
48. The method of claim 31, wherein the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW).
49. The method of claim 31, wherein the at least one light source comprises a pulse energy of about 0.01 milli Joule(mJ) to about 40 mJ.
50. The method of claim 32, wherein the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth.
51. The method of claim 32, wherein the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm .
52. The method of claim 50, wherein the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof.
53. The method of claim 31, wherein the at least one light source is in optical communication with one or more optical elements.
54. The method of claim 53, wherein the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof.
55. The method of claim 31, further comprising detecting light reflected off of tissue within the subject's mouth with one or more sensors.
56. The method of claim 55, wherein the one or more sensors comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof sensor.
57. The method of claim 31, wherein the one or more tissues of the oral cavity comprise gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, or any combination thereof tissue.
58. The method of claim 31, wherein the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof.

59. The method of claim 31, wherein determining comprises applying a processing algorithm to one or more images generated by the one or more ultrasound signals to a processing algorithm.
60. The method of claim 31, wherein determining is completed on a local processor, cloud-based processor, or any combination thereof.
61. The method of claim 31, wherein the one or more health metrics are used to suggest a therapeutic, treatment, procedure, or any combination thereof to the subject.
62. The method of claim 59, wherein the processing algorithm comprises a trained predictive model, wherein the trained predictive model is trained with one or more statistical features of one or more regions of interest of the one or more images and an annotated label of the one or more regions of interest.
63. The method of claim 62, wherein the one or more statistical features comprise mean, variance, standard deviation, skewness, median, entropy, kurtosis, or any combination thereof.
64. The method of claim 62, wherein the one or more statistical features comprise texture features of the gray level co-occurrence matrix (GLCM) in one or more directions of the detected ultrasound signals.
65. The method of claim 64, wherein the texture features comprise homogeneity, contrast, energy, entropy, correlation, or any combination thereof.
66. The method of claim 62, wherein the statistical features comprise texture features of the gray level run length matrix (GLRLM) in one or more directions.
67. The method of claim 66, wherein the texture features of the GLRLM comprise short run emphasis, long run emphasis, gray-level non-uniformity, run percentage, run length nonuniformity, low gray-level run emphasis, high gray-level run emphasis, or any combination thereof.
68. The method of claim 64, wherein the one or more directions comprise 0 degrees, 45 degrees, 90 degrees, 135 degrees, or any combination thereof.
69. The method of claim 62, wherein the trained predictive model comprises a machine learning model, a neural network, a convolutional neural network, or any combination thereof.
70. The method of claim 62, wherein the one or more regions of interest comprises a width of at least two pixels and a height of at least two pixels.
71. The method of claim 62, wherein the trained predictive model comprises an accuracy of at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 91%, at least

92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, or at least 99%.

72. A wireless intraoral imaging device, comprising:

a tip, wherein the tip comprises at least one light source and at least one ultrasonic transducer; and

a processor in communication with the at one light source and the at least one ultrasonic transducer, wherein the processor is located on a body of the wireless intraoral imaging device, and wherein the processor is configured to process data obtained from the ultrasound transducer.

73. The device of claim 72, wherein the processor is configured to wirelessly transmit and receive information with a second processor of an external system.

74. The device of claim 72, further comprising a pulser receiver electrically coupled to the processor configured to process an ultrasound pressure wave echo detected by the at least one ultrasonic transducer.

75. The device of claim 72, wherein the processor comprises a field programmable gate array.

76. The device of claim 72, further comprising a processor configured to transmit the processed data obtained from the at least one ultrasonic transducer to a system for further processing, display, or any combination thereof.

77. The device of claim 72, further comprising a light source driver in electrical communication with the at least one light source and the processor.

78. The device of claim 72, further comprising a heat sink configured to distribute heat generated by the at least one light source.

79. The device of claim 78, further comprising a fan in fluid communication with the heat sink.

80. The device of claim 72, wherein the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof.

81. The device of claim 72, further comprising a sensor.

82. The device of claim 81, wherein the sensor comprises a gravitational sensor, a light base sensor, a gyroscope, a magnetometer, an accelerometer, or any combination thereof.

83. The device of claim 72, further comprising a battery, wherein the battery comprises a lithium-ion polymer battery.

84. The device of claim 83, wherein the battery comprises a rechargeable battery.
85. The device of claim 72, wherein the body is comprised of stainless steel or a plastic.
86. The device of claim 72, wherein the at least one light source comprises one or more fibers.
87. The device of claim 72, wherein the at least one light source comprises a fiber bundle.
88. The device of claim 87, wherein the fiber bundle comprises at least 1 fiber.
89. The device of claim 87, wherein the fiber bundle comprises at least 2 fibers.
90. The device of claim 87, wherein the fiber bundle comprises at least 4 fibers.
91. The device of claim 87, wherein the fiber bundle comprises at least 6 fibers.
92. The device of claim 87, wherein the fiber bundle comprises at least 8 fibers.
93. The device of claim 87, wherein the fiber bundle comprises at least 10 fibers.
94. The device of claim 87, wherein the fiber bundle comprises at least 12 fibers.
95. The device of claim 87, wherein the fiber bundle comprises at least 14 fibers.
96. The device of claim 87, wherein the fiber bundle comprises at least 16 fibers.
97. The device of claim 87, wherein the fiber bundle comprises at least 19 fibers.
98. The device of claim 72, wherein the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns).
99. The device of claim 72, wherein the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm.
100. The device of claim 72, wherein the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 Hz.
101. The device of claim 72, wherein the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW).
102. The device of claim 72, wherein the at least one light source comprises a pulse energy of about 0.01 milli Joule(mJ) to about 40 mJ.
103. The device of claim 86, wherein the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth.

104. The device of claim 86, wherein the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm .
105. The device of claim 103, wherein the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof.
106. The device of claim 72, further comprising one or more optical elements in optical communication with the at least one light source.
107. The device of claim 106, wherein the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof.
108. The device of claim 72, further comprising one or more sensors configured to sense light reflected off of tissue within the subject's mouth.
109. The device of claim 108, wherein the one or more sensors comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof sensor.
110. The device of claim 72, wherein the data obtained from the at least one ultrasound transducer comprises ultrasound echo data of one or more pressure waves emitted by one or more tissues detected by the at least one ultrasound transducer.
111. The device of claim 72, wherein the one or more tissues comprise gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, tooth enamel, or any combination thereof tissue.
112. The device of claim 110, wherein the one or more pressure waves are converted into one or more ultrasonic images, wherein the ultrasonic images comprise one or more oral health metrics.
113. The device of claim 112, wherein the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof.
114. The device of claim 72, further comprising a pulser in electrical communication with the at least one ultrasonic transducer.
115. A device for oral imaging, comprising:

a probe, wherein the probe comprises:

a tip, wherein the tip comprises at least one light source, at least one ultrasound transducer, and a coupling interface, wherein the coupling interface is configured to

expand upon pressing the coupling interface onto a surface of an oral tissue, and wherein the coupling interface applies a pressure to the surface of the oral tissue.

116. The device of claim 115, wherein the oral tissue comprises gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, tooth enamel, or any combination thereof tissue.
117. The device of claim 115, wherein the at least one light source and the at least one ultrasound transducer are housed within the coupling interface.
118. The device of claim 115, wherein the pressure applied by the coupling interface to the surface of the oral tissue is configured to provide at least 3dB signal to noise of a detected ultrasound signal by the at least one ultrasound transducer.
119. The device of claim 115, wherein the pressure applied by the coupling interface to the surface of the oral tissue is applied normal to the surface of the oral tissue.
120. The device of claim 115, wherein the coupling interface comprises at least one spring mechanically coupled to the coupling interface, wherein the at least one spring is configured to expand when the coupling interface is pressed onto a surface of an oral tissue.
121. The device of claim 115, wherein the coupling interface comprises a shape memory material.
122. The device of claim 121, wherein the shape memory material comprises a shape memory metal, plastic, or any combination thereof.
123. The device of any one of claims 115-122, wherein the probe comprises a handled probe.
124. The device of claim 115, wherein the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof.
125. The device of claim 115, wherein the at least one ultrasound transducer comprises a single element transducer or an array-based ultrasound transducer.
126. The device of claim 115, further comprising a processor electrically coupled to the at least one ultrasound transducer and the at least one light source, wherein the processor is configured to wirelessly transmit and receive information with a second processor of an external system.
127. The device of claim 126, further comprising a pulser receiver electrically coupled to the processor configured to process an ultrasound pressure wave echo detected by the at least one ultrasonic transducer.

128. The device of claim 126, wherein the processor comprises a field programmable gate array.
129. The device of claim 115, further comprising a processor configured to transmit the processed data obtained from the at least one ultrasonic transducer to a system for further processing, display, or any combination thereof.
130. The device of claim 115, further comprising a light source driver in electrical communication with the at least one light source and the processor.
131. The device of claim 115, further comprising a heat sink configured to distribute heat generated by the at least one light source.
132. The device of claim 131, further comprising a fan in fluid communication with the heat sink.
133. The device of claim 115, wherein the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof.
134. The device of claim 115, further comprising a sensor.
135. The device of claim 134, wherein the sensor comprises a gravitational sensor, a light base sensor, a gyroscope, a magnetometer, an accelerometer, or any combination thereof.
136. The device of claim 115, further comprising a battery, wherein the battery comprises a lithium-ion polymer battery, and wherein the battery is configured to power the at least one ultrasound transducer, the at least one light source, or any combination thereof.
137. The device of claim 136, wherein the battery comprises a rechargeable battery.
138. The device of claim 115, wherein the probe comprises a body mechanically coupled to the tip, wherein the body, tip, or any combination thereof is comprised of stainless steel or a plastic material.
139. The device of claim 115, wherein the at least one light source comprises one or more fibers.
140. The device of claim 115, wherein the at least one light source comprises a fiber bundle.
141. The device of claim 140, wherein the fiber bundle comprises at least 1 fiber.
142. The device of claim 140, wherein the fiber bundle comprises at least 2 fibers.

143. The device of claim 140, wherein the fiber bundle comprises at least 4 fibers.
144. The device of claim 140, wherein the fiber bundle comprises at least 6 fibers.
145. The device of claim 140, wherein the fiber bundle comprises at least 8 fibers.
146. The device of claim 140, wherein the fiber bundle comprises at least 10 fibers.
147. The device of claim 140, wherein the fiber bundle comprises at least 12 fibers.
148. The device of claim 140, wherein the fiber bundle comprises at least 14 fibers.
149. The device of claim 140, wherein the fiber bundle comprises at least 16 fibers.
150. The device of claim 140, wherein the fiber bundle comprises at least 19 fibers.
151. The device of claim 115, wherein the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns).
152. The device of claim 115, wherein the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm.
153. The device of claim 115, wherein the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 Hz.
154. The device of claim 115, wherein the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW).
155. The device of claim 115, wherein the at least one light source comprises a pulse energy of about 0.01 milli Joule (mJ) to about 40 mJ.
156. The device of claim 139, wherein the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth.
157. The device of claim 139, wherein the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm .
158. The device of claim 156, wherein the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof.
159. The device of claim 115, further comprising one or more optical elements in optical communication with the at least one light source.
160. The device of claim 159, wherein the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof.

161. The device of claim 115, further comprising one or more sensors configured to sense light reflected off the oral tissue.
162. The device of claim 161, wherein the one or more sensors comprise a charge coupled device (CCD), complementary metal oxide semiconductor (CMOS), or any combination thereof sensor.
163. The device of claim 115, wherein the at least one ultrasound transducer is configured to obtain data comprising ultrasound echo data of one or more pressure waves emitted by the oral tissue.
164. The device of claim 163, wherein the one or more pressure waves are converted into one or more ultrasonic images, wherein the ultrasonic images comprise one or more oral health metrics.
165. The device of claim 164, wherein the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof.
166. The device of claim 115, further comprising a pulser in electrical communication with the at least one ultrasonic transducer.
167. A device for oral imaging, comprising:

a probe, wherein the probe comprises:

a tip, wherein the tip comprises a coupling interface, wherein the coupling interface is configured to expand upon pressing the coupling interface onto a surface of an oral tissue thereby providing a signal to noise ratio of at least 3dB when collecting data with the probe.
168. The device of claim 167, wherein the probe comprises a handheld probe.
169. The device of claim 167, wherein the oral tissue comprises gingiva, buccal mucosa, retromolar trigone, soft palate, hard palate, dorsal tongue, ventral tongue, floor of the mouth, labial mucosa, tooth enamel, or any combination thereof tissue.
170. The device of claim 167, wherein the tip comprises at least one ultrasound transducer housed within the tip.
171. The device of claim 170, wherein the data comprises ultrasound data collected from the oral tissue by the at least one ultrasound transducer.
172. The device of claim 167, wherein the pressure applied by the coupling interface to the surface of the oral tissue is applied normal to the surface of the oral tissue.
173. The device of claim 167, wherein the coupling interface comprises at least one spring mechanically coupled to the coupling interface, wherein the at least one spring is

configured to expand when the coupling interface is pressed onto a surface of the oral tissue.

174. The device of claim 167, wherein the coupling interface comprises a shape memory material.
175. The device of claim 174, wherein the shape memory material comprises a shape memory metal, plastic, or any combination thereof.
176. The device of claim 167, wherein the tip further comprises at least one light source, at, at least one sensor, or any combination thereof.
177. The device of claim 176, wherein the at least one light source comprises a laser, pulsed laser, Q-switched laser, pulsed laser diode, coherent laser, Mode-locked laser, incoherent laser, light emitting diode, surface emitting diode, super luminescent diode, VCSEL, VCSEL array, or any combination thereof.
178. The device of claim 170, wherein the at least one ultrasound transducer comprises a single element transducer or an array-based ultrasound transducer.
179. The device of claim 176, wherein the at least one sensor comprises a gravitational sensor, a light base sensor, a gyroscope, a magnetometer, an accelerometer, or any combination thereof.
180. The device of claim 179, wherein the light base sensor comprises a charged coupled device (CCD) or a complementary metal oxide semiconductor sensor (CMOS).
181. The device of claim 176, wherein the probe further comprises a processor electrically coupled to the at least one ultrasound transducer, the at least one light source, or any combination thereof.
182. The device of claim 181, wherein the processor is configured to wirelessly transmit and receive information with a second processor of an external system.
183. The device of claim 181, wherein the probe further comprises a pulser receiver electrically coupled to the processor configured to process an ultrasound pressure wave echo detected by the at least one ultrasonic transducer.
184. The device of claim 181, wherein the processor comprises a field programmable gate array.
185. The device of claim 170, wherein the probe comprises a processor configured to transmit the processed data obtained from the at least one ultrasonic transducer to a system for further processing, display, or any combination thereof.
186. The device of claim 176, further comprising a light source driver in electrical communication with the at least one light source and the processor.

187. The device of claim 186, further comprising a heat sink configured to distribute heat generated by the at least one light source.
188. The device of claim 187, further comprising a fan in fluid communication with the heat sink.
189. The device of claim 167, wherein the probe comprises a battery, wherein the battery comprises a lithium-ion polymer battery.
190. The device of claim 189, wherein the battery comprises a rechargeable battery.
191. The device of claim 167, wherein the probe comprises a body, wherein the body is comprised of stainless steel or a plastic.
192. The device of claim 176, wherein the at least one light source comprises one or more fibers.
193. The device of claim 176, wherein the at least one light source comprises a fiber bundle.
194. The device of claim 193, wherein the fiber bundle comprises at least 1 fiber.
195. The device of claim 193, wherein the fiber bundle comprises at least 2 fibers.
196. The device of claim 193, wherein the fiber bundle comprises at least 4 fibers.
197. The device of claim 193, wherein the fiber bundle comprises at least 6 fibers.
198. The device of claim 193, wherein the fiber bundle comprises at least 8 fibers.
199. The device of claim 193, wherein the fiber bundle comprises at least 10 fibers.
200. The device of claim 193, wherein the fiber bundle comprises at least 12 fibers.
201. The device of claim 193, wherein the fiber bundle comprises at least 14 fibers.
202. The device of claim 193, wherein the fiber bundle comprises at least 16 fibers.
203. The device of claim 193, wherein the fiber bundle comprises at least 19 fibers.
204. The device of claim 176, wherein the at least one light source comprises a pulse width from about 1 nanosecond (ns) to about 1000 (ns).
205. The device of claim 176, wherein the at least one light source comprises a light emission wavelength range of about 400 nanometers (nm) to about 1700nm.
206. The device of claim 176, wherein the at least one light source comprises a pulse repetition rate of about 1 hertz (Hz) to about 10,000,000 Hz.

207. The device of claim 176, wherein the at least one light source comprises a peak power output of about 10 watts (W) to about 40 megawatts (MW).
208. The device of claim 176, wherein the at least one light source comprises a pulse energy of about 0.01 milli Joule(mJ) to about 40 mJ.
209. The device of claim 192, wherein the one or more fibers are in optical communication with an index matching material configured to transmit optical energy from the one or more fibers to the one or more tissues within the subject's mouth.
210. The device of claim 192, wherein the one or more fibers comprise a fiber core diameter of about 20 micrometers (μm) to about 1000 μm .
211. The device of claim 209, wherein the index matching material comprises an index matching gel, liquid, adhesive, or any combination thereof.
212. The device of claim 176, wherein the probe further comprises one or more optical elements optically coupled with the at least one light source.
213. The device of claim 212, wherein the one or more optical elements comprise a plano-convex lens, a plano-convex cylindrical lens, a bi-convex lens, a plano-concave cylindrical lens, a bi-concave lens, a mirror, a dielectric mirror, or any combination thereof.
214. The device of claim 170, wherein the data obtained by the probe comprises ultrasound echo data of one or more pressure waves emitted by one or more tissues obtained by the at least one ultrasound transducer.
215. The device of claim 214, wherein the one or more pressure waves are converted into one or more ultrasonic images, wherein the ultrasonic images comprise one or more oral health metrics.
216. The device of claim 215, wherein the one or more oral health metrics comprise gingival pocket depth, clinical attachment loss, inflammation of the gingiva, infection of the gingiva, blood flow through the gingiva, phenotype of periodontal tissues, bone loss, or any combination thereof.
217. The device of claim 170, further comprising a pulser in electrical communication with the at least one ultrasonic transducer.

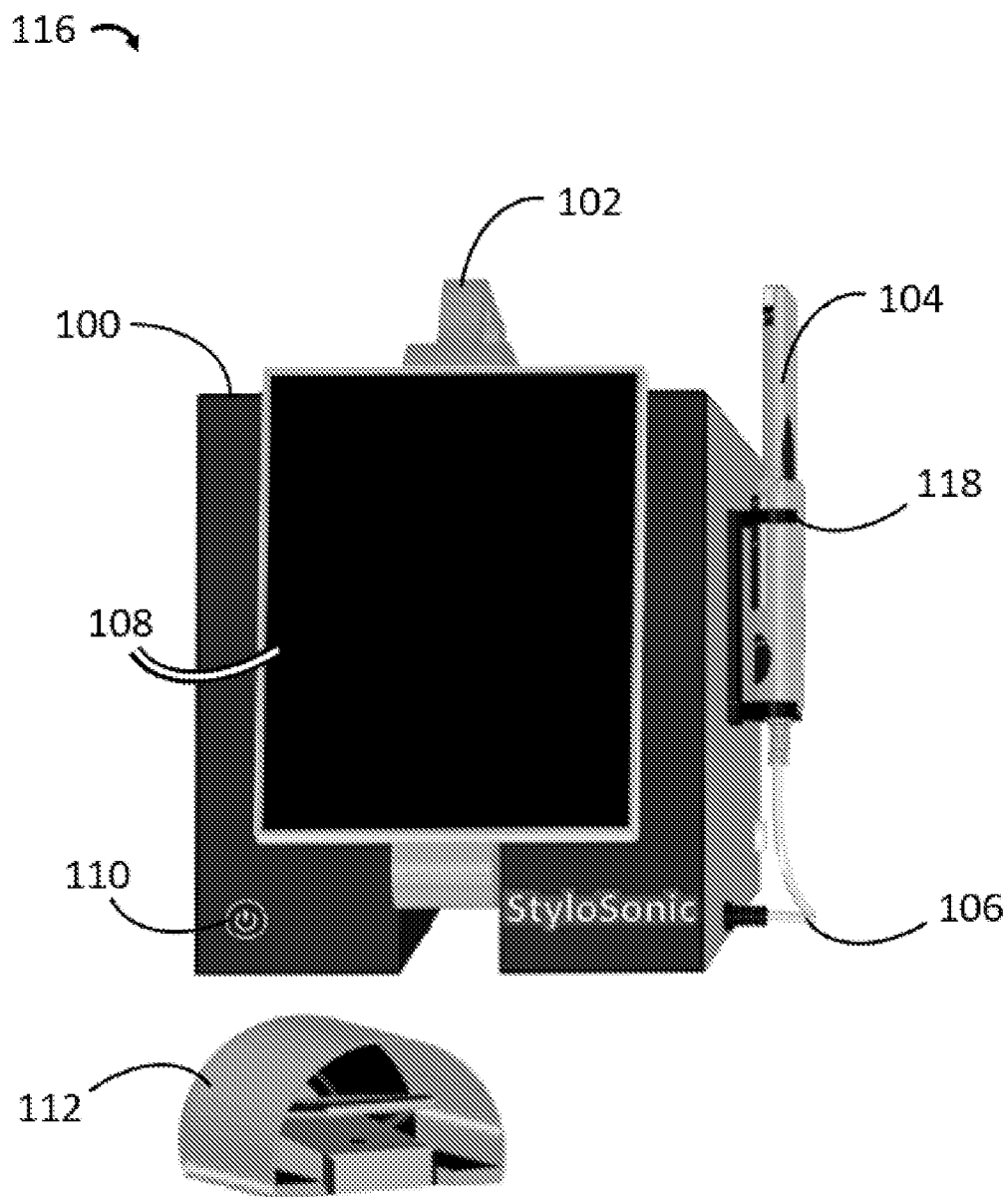


FIG. 1

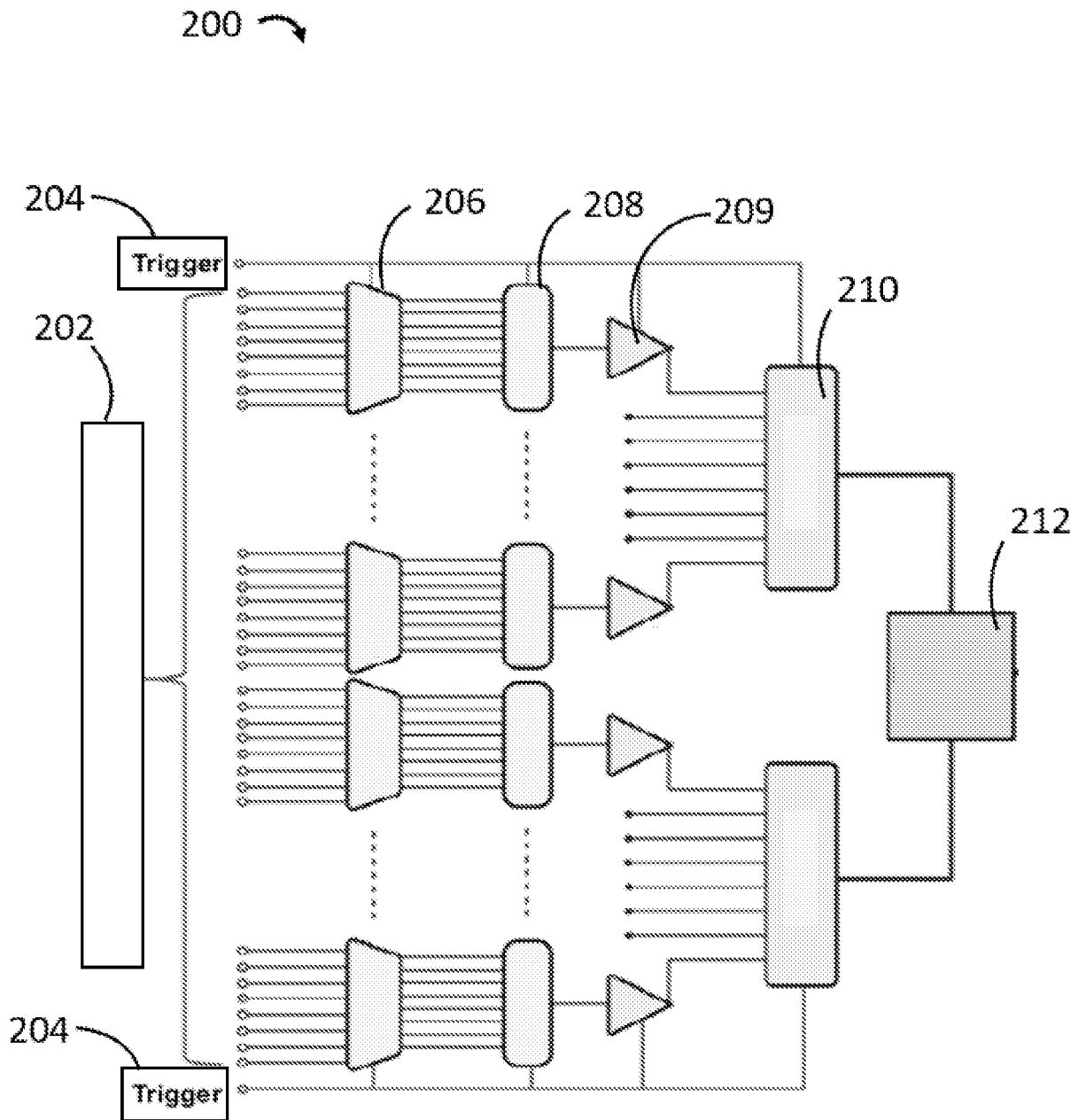
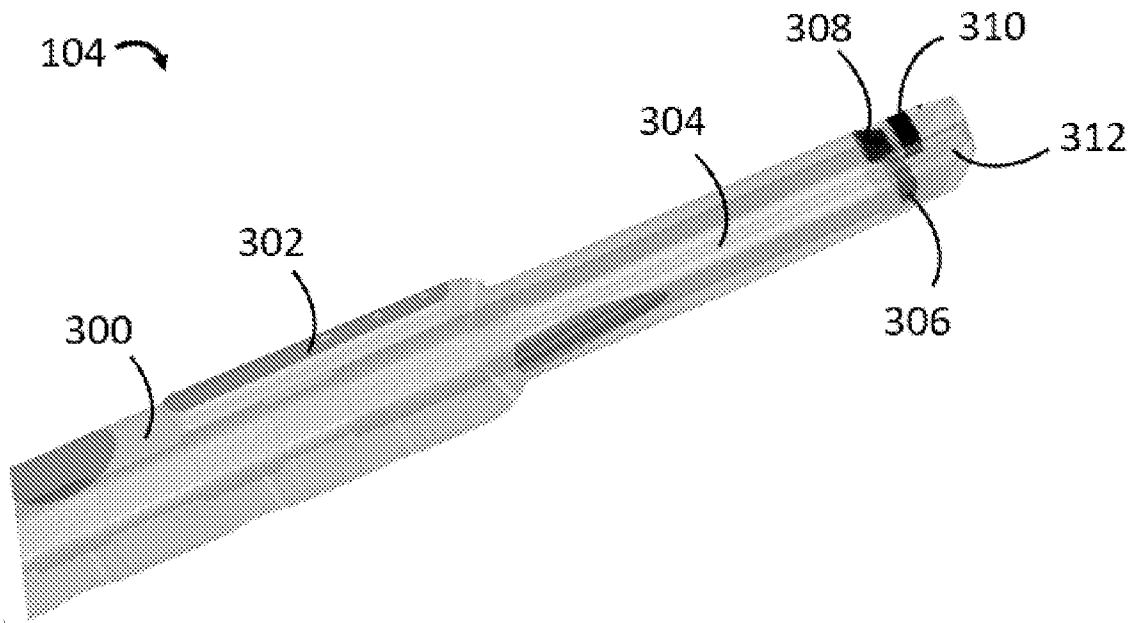


FIG. 2

**FIG. 3A**

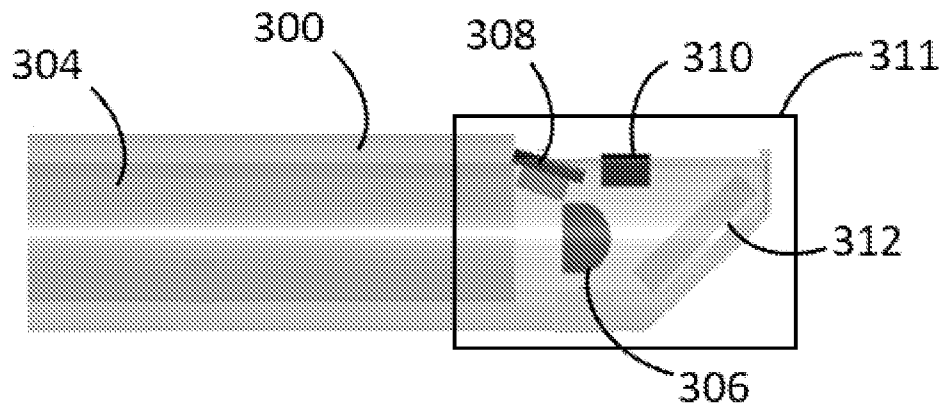


FIG. 3B

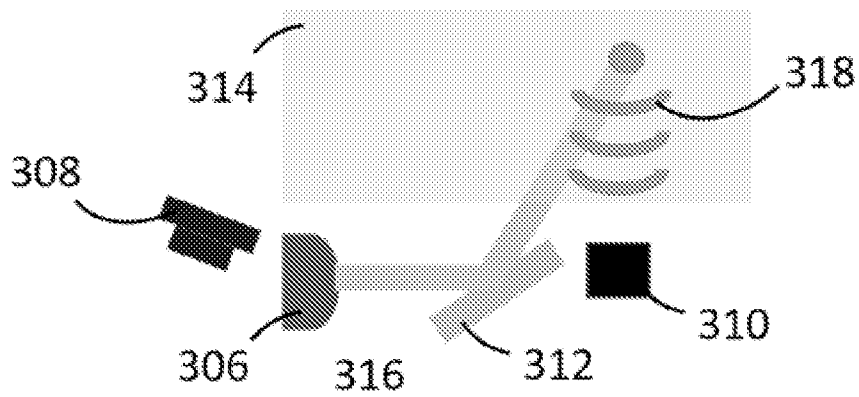
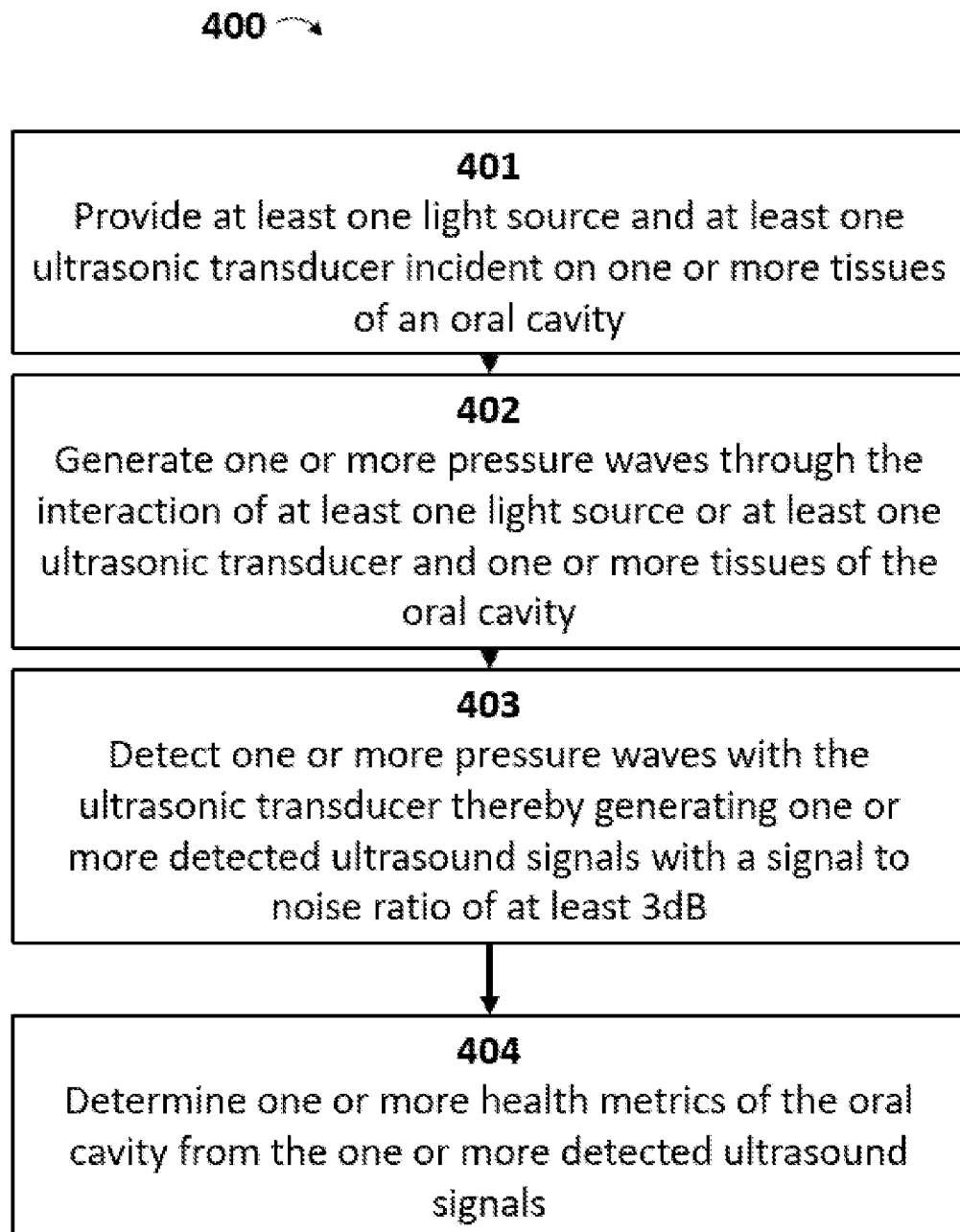


FIG. 3C

**FIG. 4**

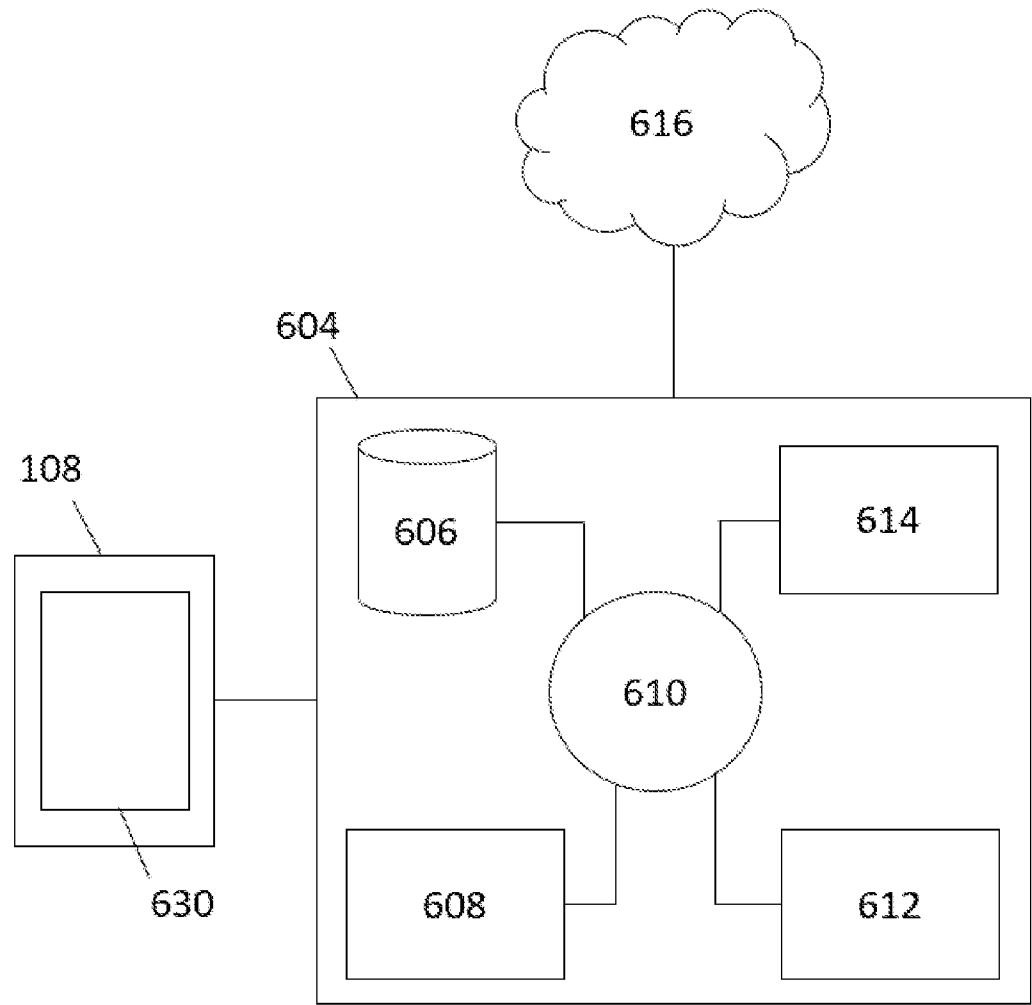
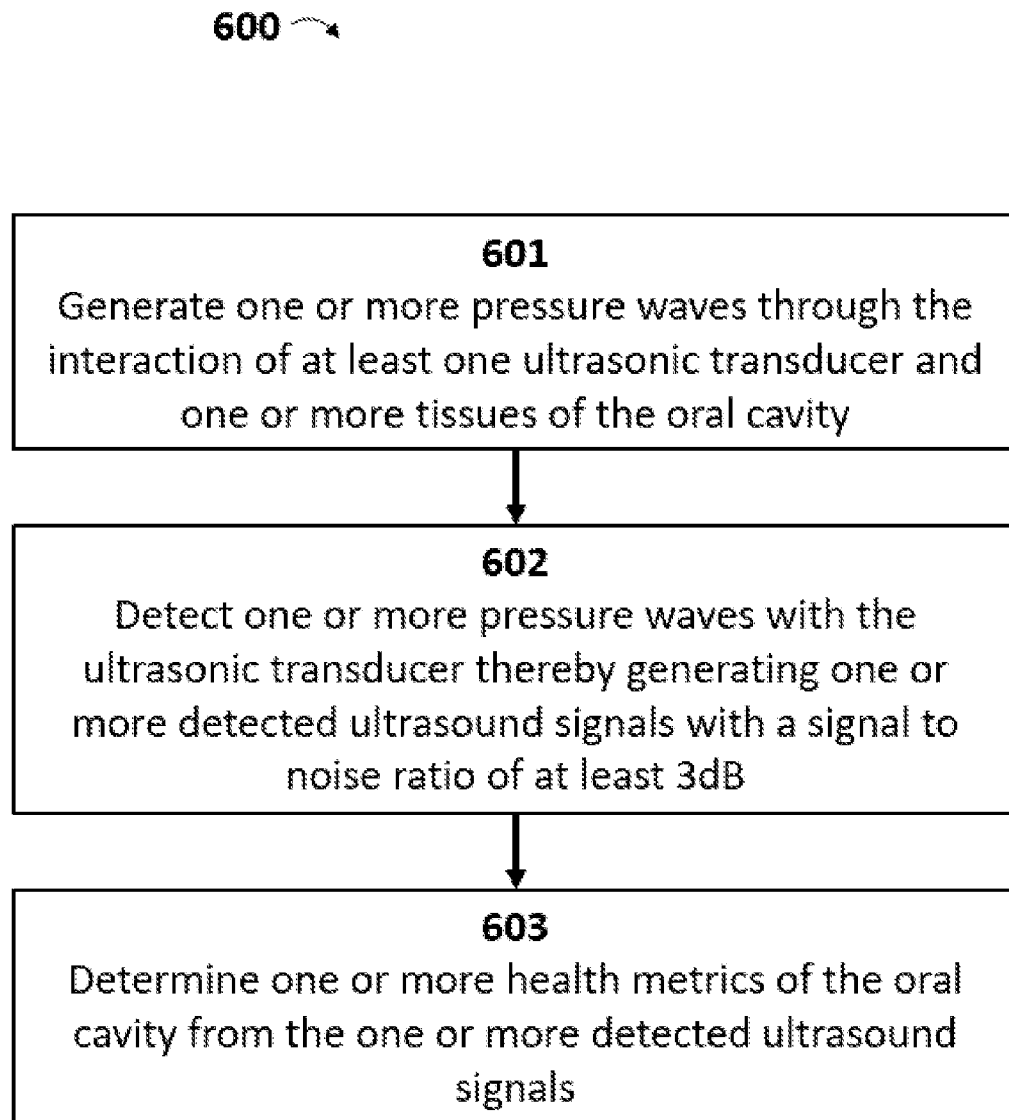


FIG. 5

**FIG. 6**

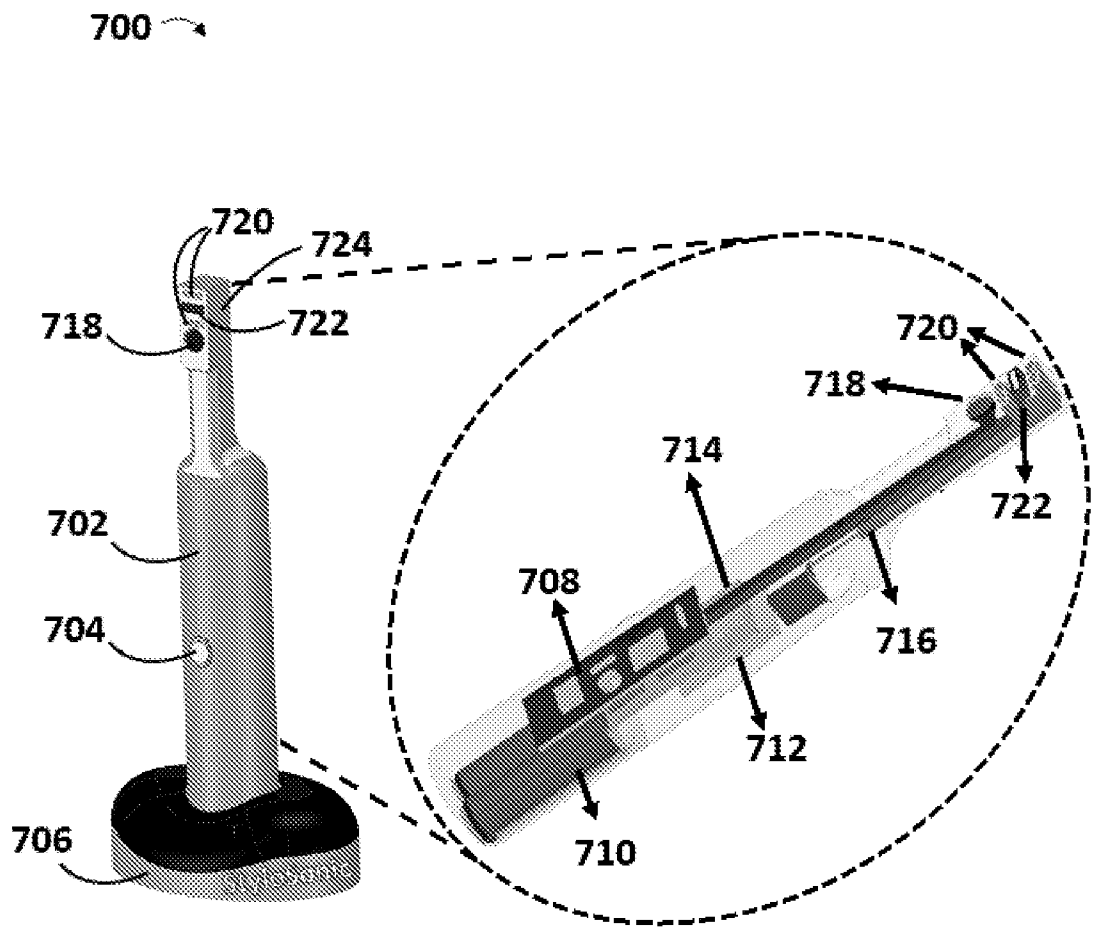


FIG. 7

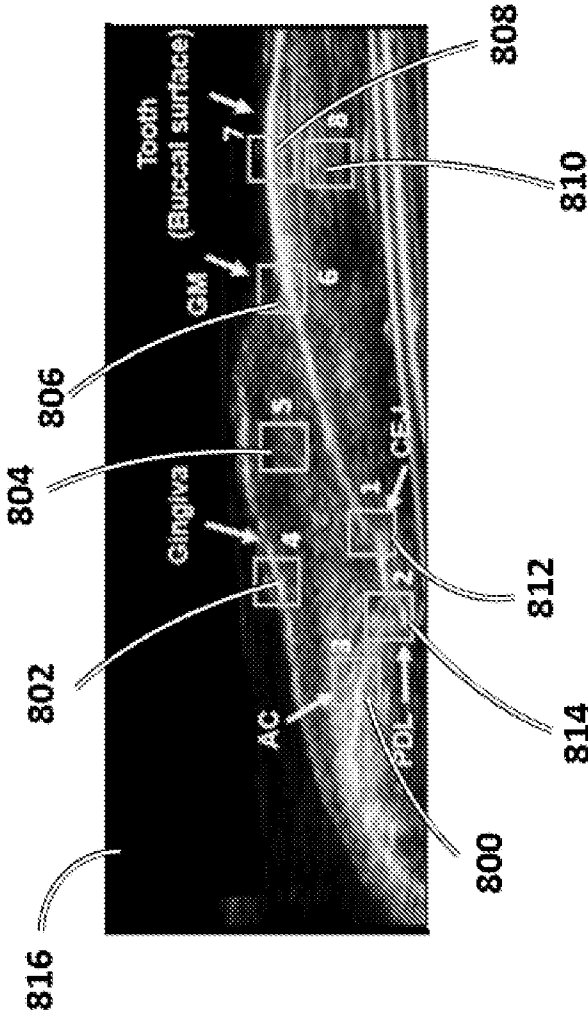


FIG. 8A

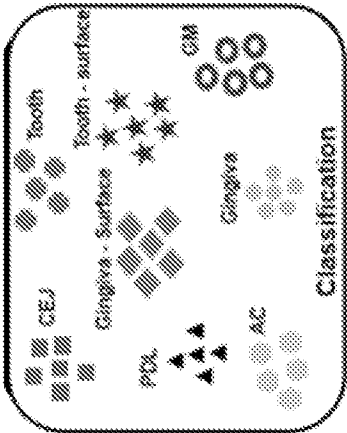


FIG. 8B

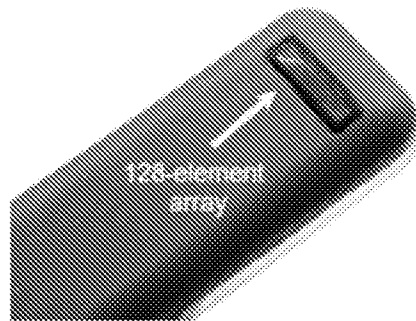


FIG. 9A

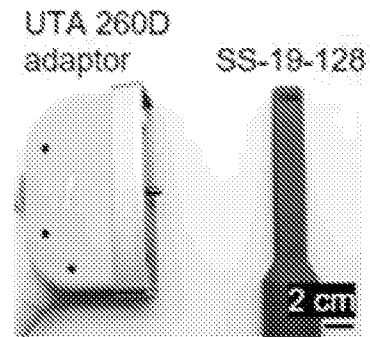


FIG. 9B

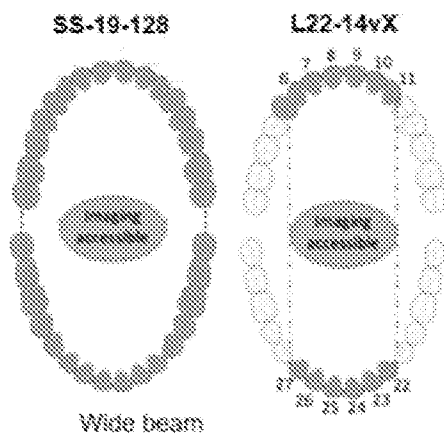


FIG. 9C

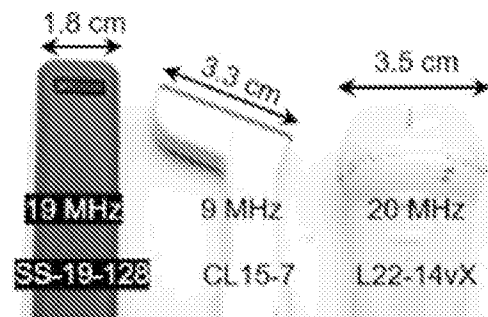


FIG. 9D

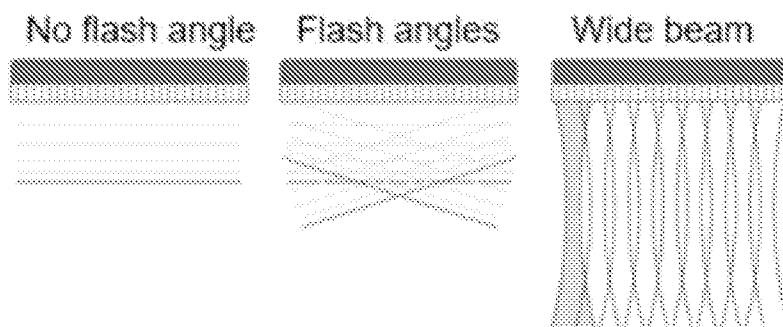


FIG. 9E

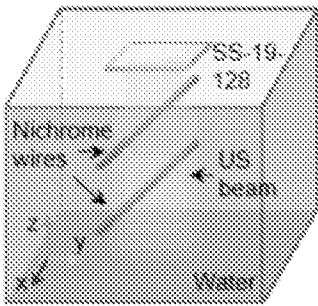


FIG. 10A

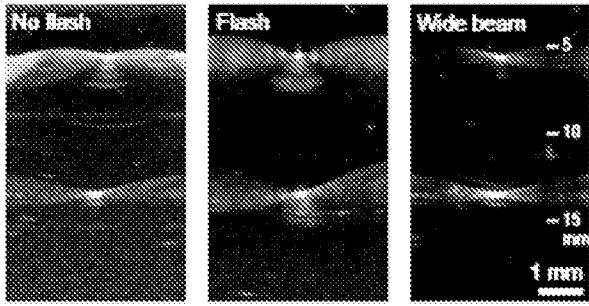


FIG. 10B

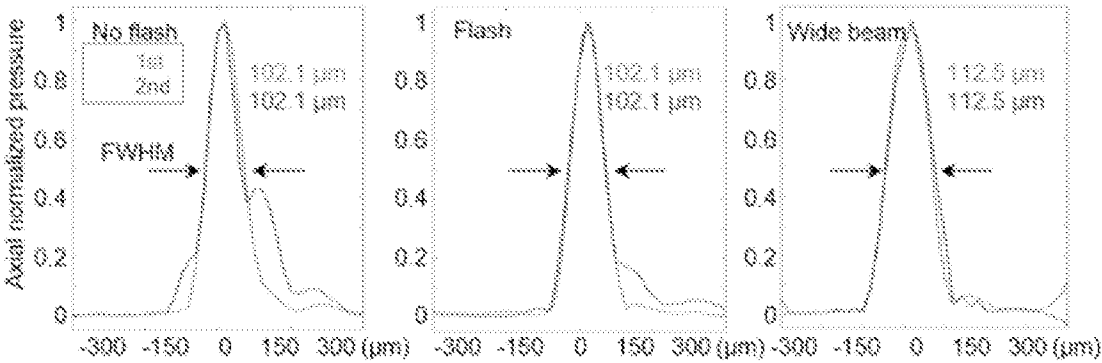


FIG. 10C

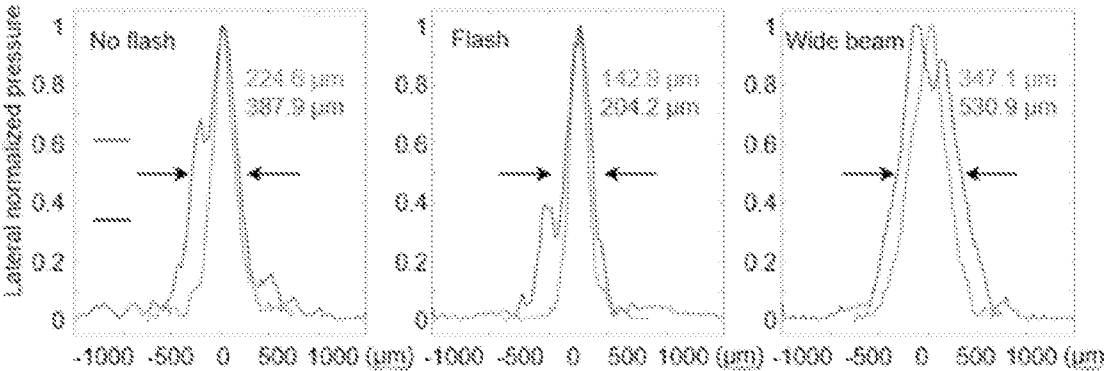


FIG. 10D

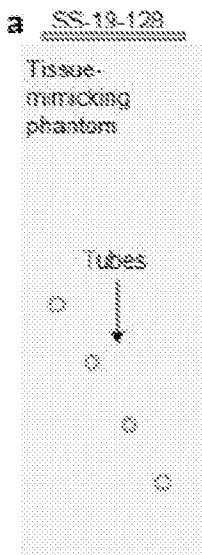


FIG. 11A

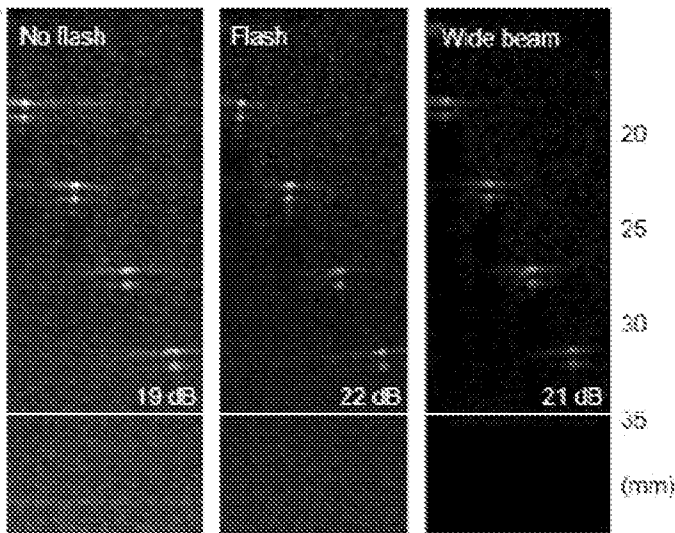


FIG. 11B

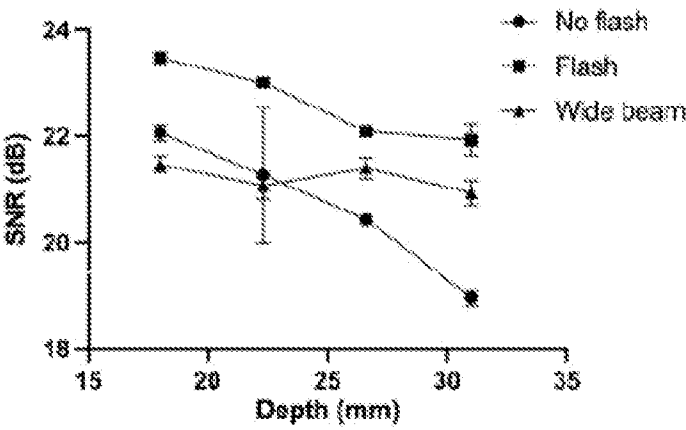


FIG. 11C

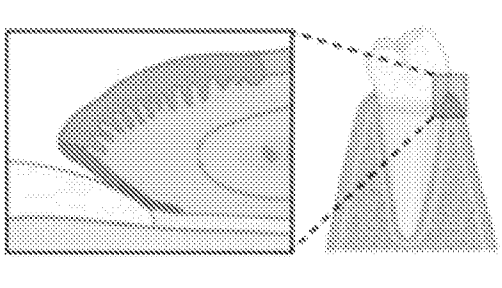


FIG. 12A

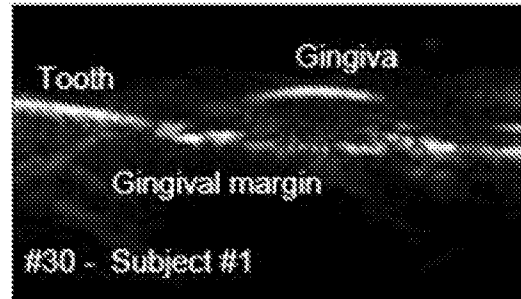


FIG. 12B

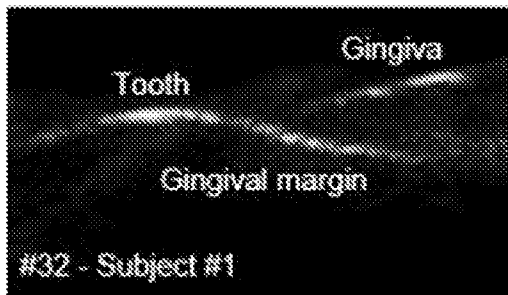


FIG. 12C

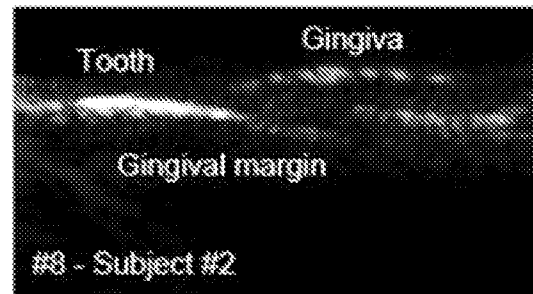


FIG. 12D

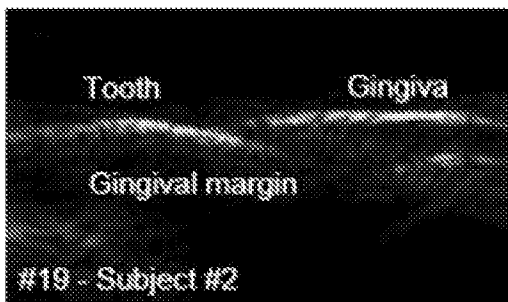


FIG. 12E

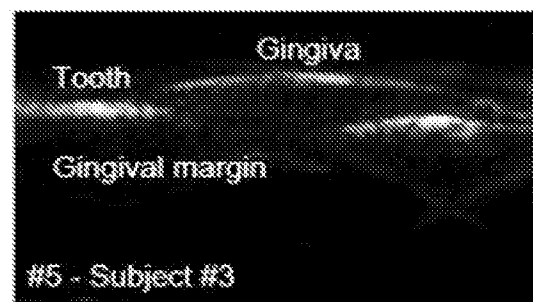


FIG. 12F

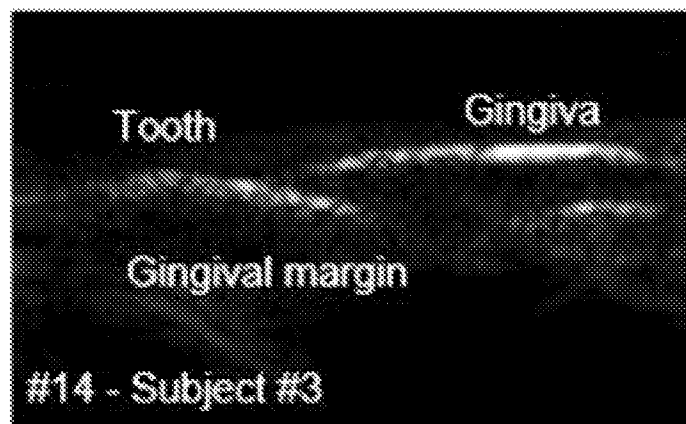


FIG. 12G

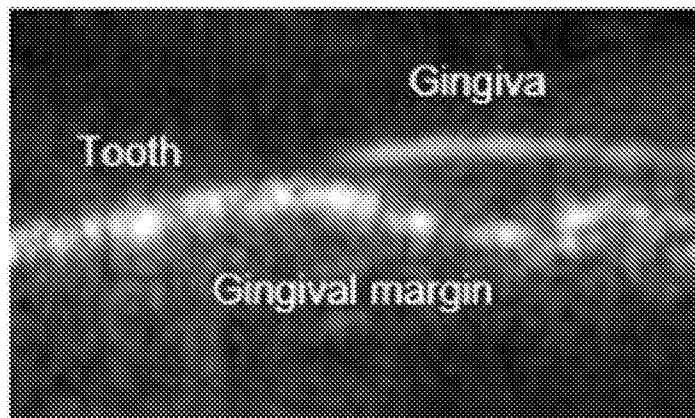


FIG. 12H

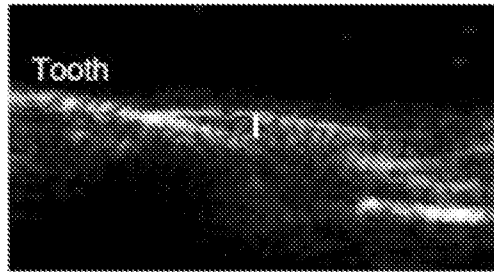


FIG. 13A

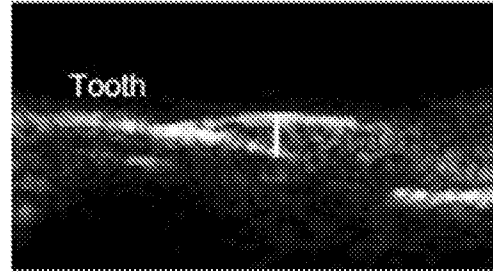


FIG. 13B

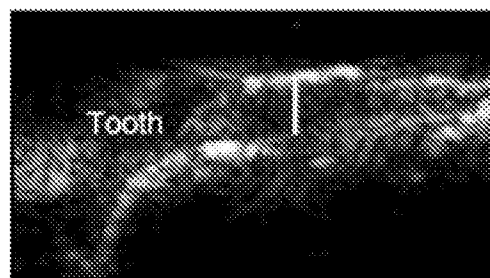


FIG. 13C

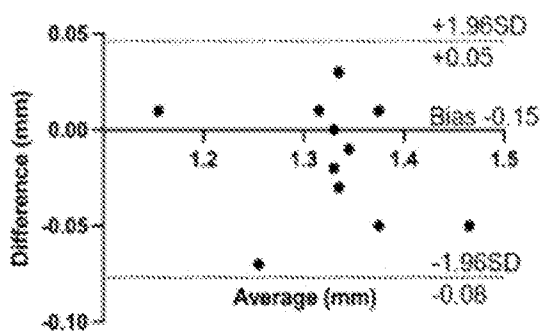


FIG. 13D

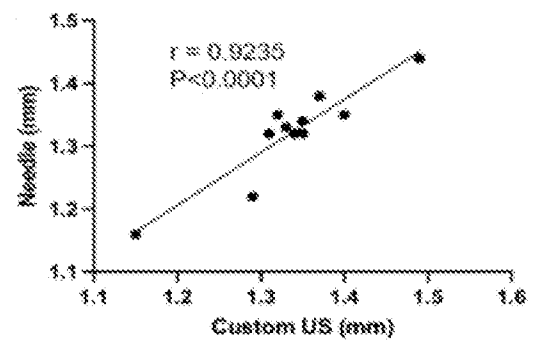


FIG. 13E

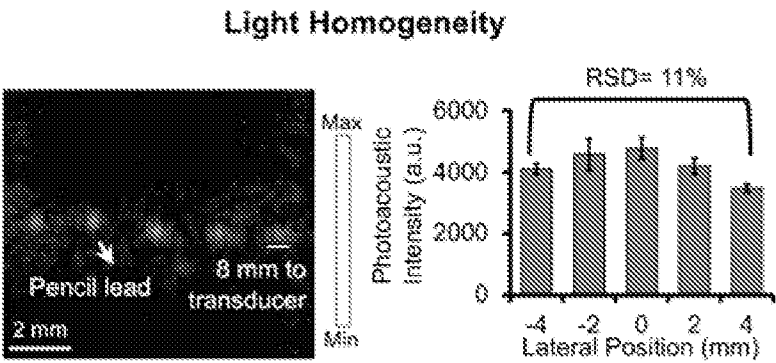


FIG. 14A

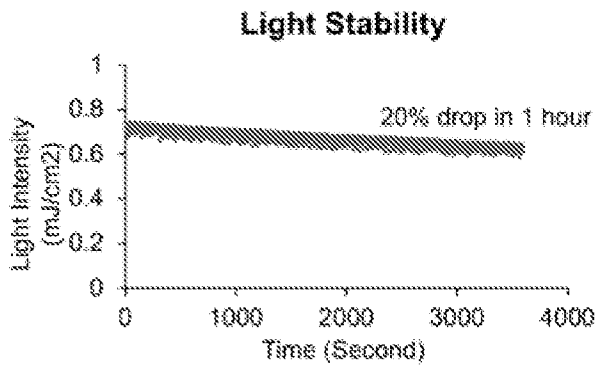


FIG. 14B

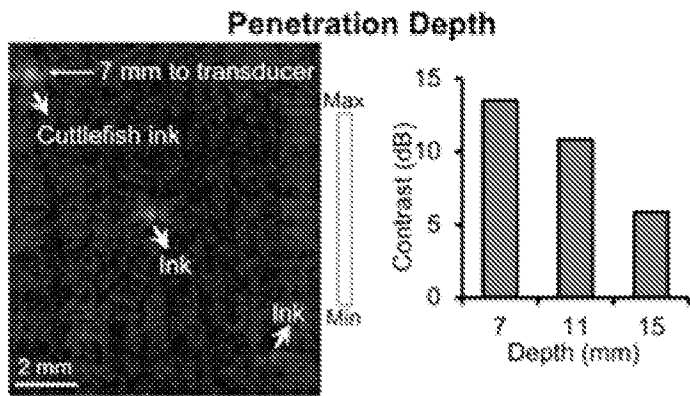
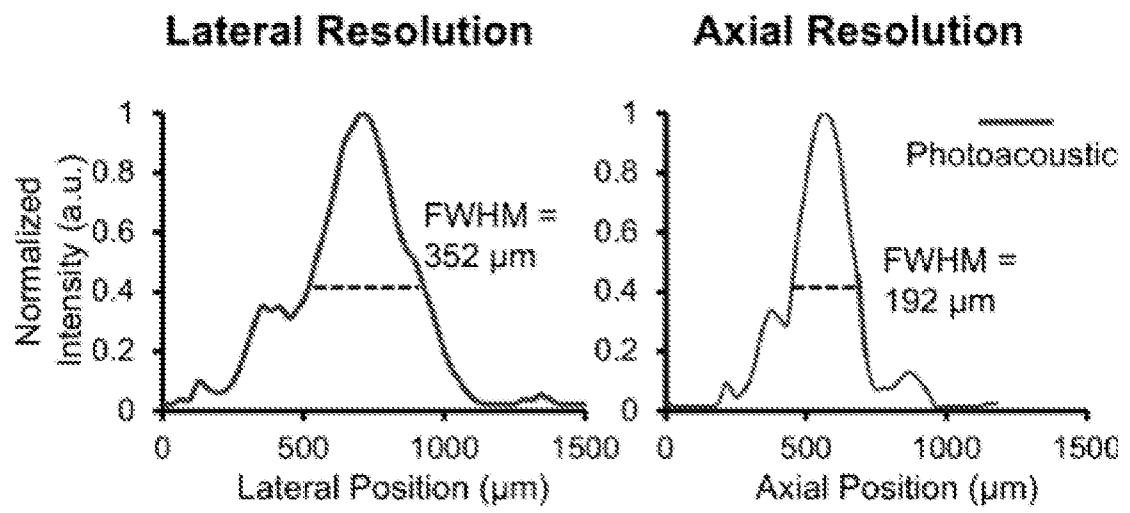


FIG. 14C

**FIG. 14D**

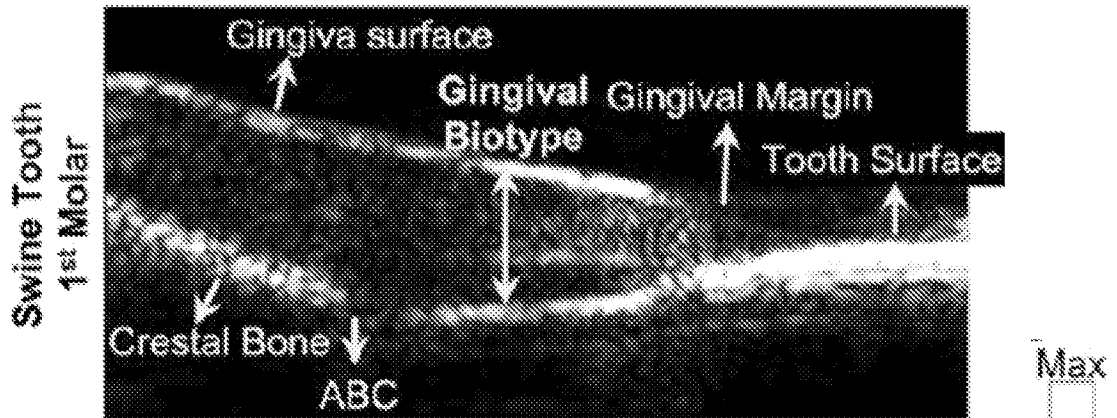


FIG. 15A

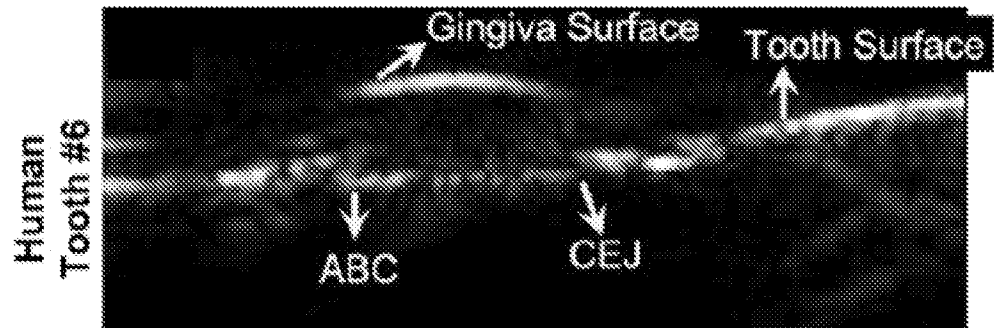


FIG. 15B

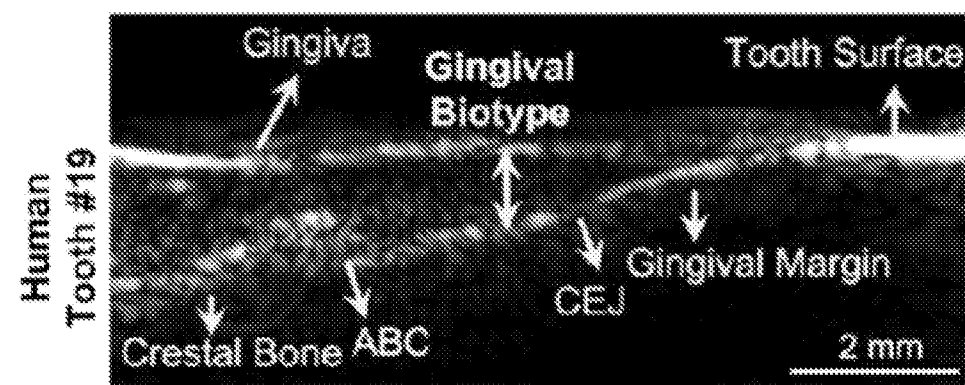


FIG. 15C

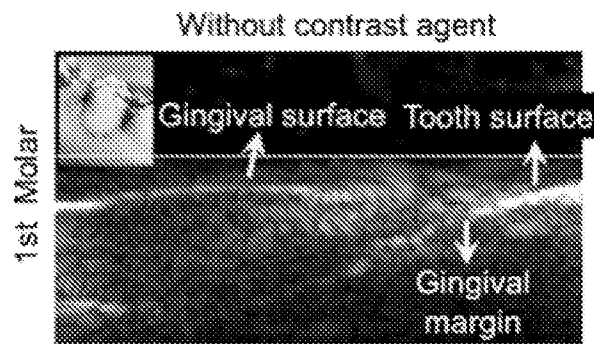


FIG. 16A

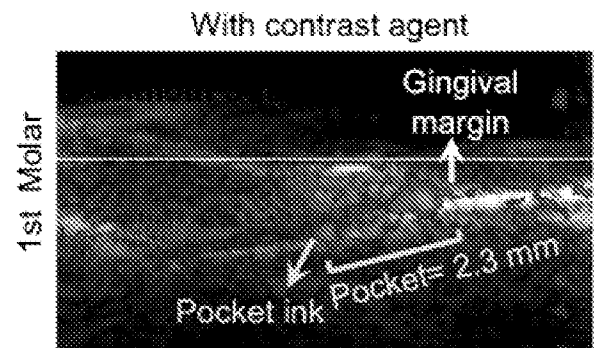


FIG. 16C

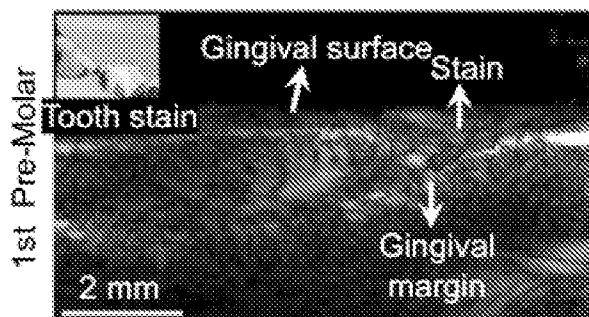


FIG. 16B

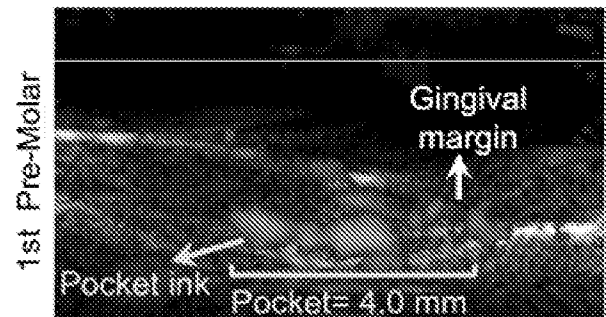


FIG. 16D

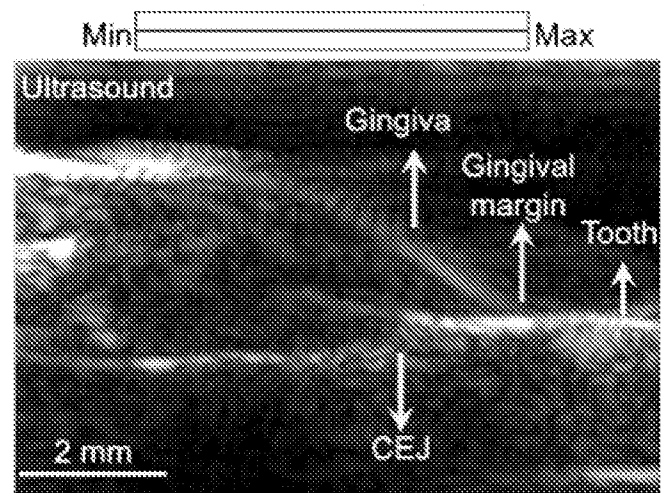


FIG. 17A

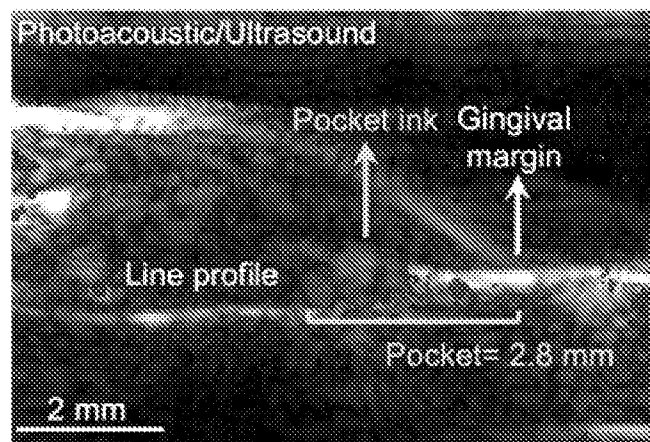


FIG. 17B

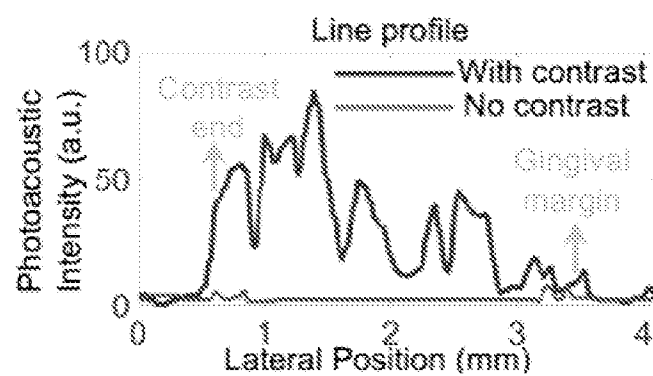


FIG. 17C

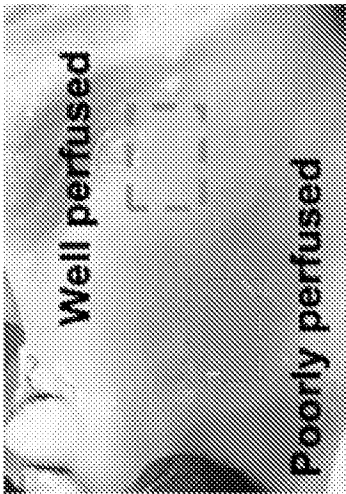


FIG. 18A

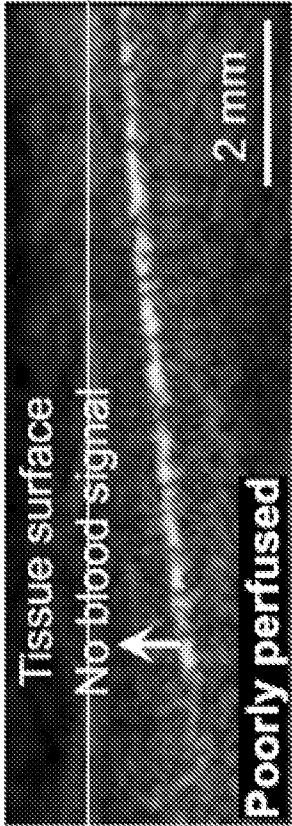


FIG. 18B

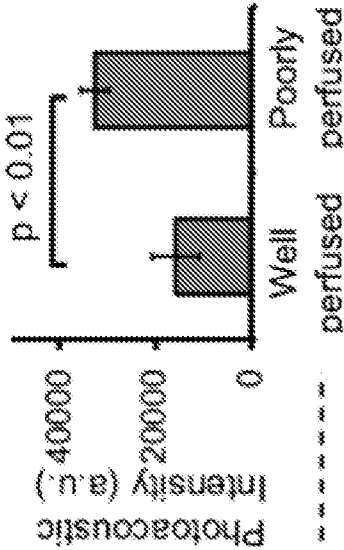


FIG. 18D

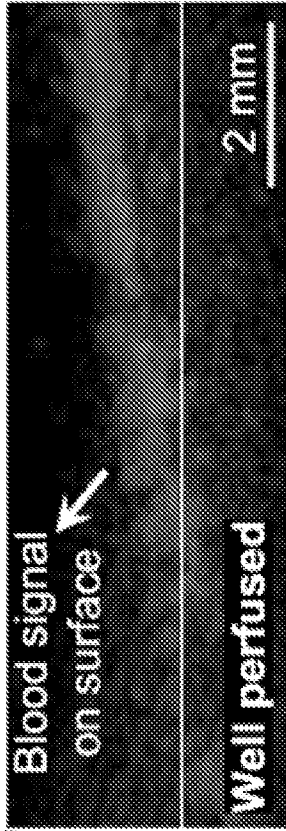


FIG. 18C