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(54) **Title:** SYSTEM FOR DETECTING BLOOD IN AN ORAL CAVITY DURING TOOTHBRUSHING

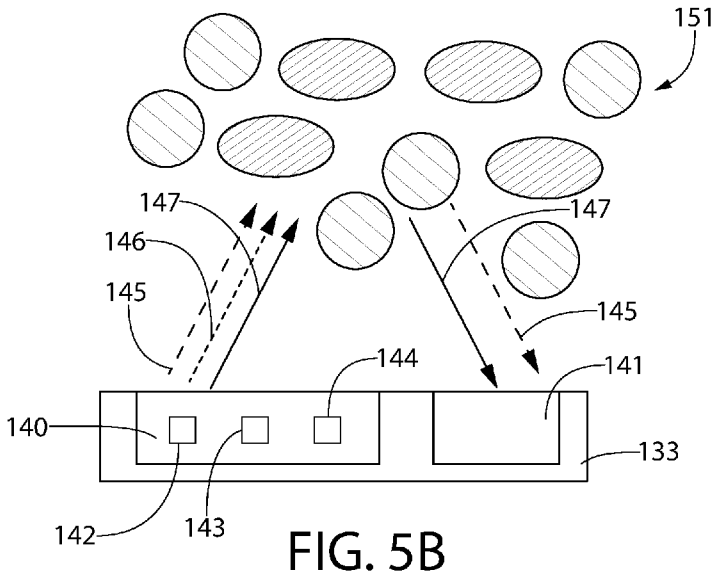


FIG. 5B

(57) **Abstract:** In one aspect, a system for detecting blood in an oral cavity during toothbrushing is disclosed. A toothbrush includes a sensor configured to emit first light at a first wavelength and second light at a second wavelength, and receive reflected portions of the light, the reflected portions having a first intensity and a second intensity, respectively. For each of a plurality of different times of a brushing session, a processor calculates a ratio of the first intensity to the second intensity. The processor identifies peaks in the ratio over the different times and, based on the number of peaks in the ratio, determines whether hemoglobin is present in the oral cavity.

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# SYSTEM FOR DETECTING BLOOD IN AN ORAL CAVITY DURING TOOTHBRUSHING

## CROSS-REFERENCE TO RELATED APPLICATION

**[0001]** This application claims the benefit of priority from U.S. Provisional Application No. 63/109,031, filed November 3, 2020, the contents of which are hereby incorporated herein by reference in their entirety.

## BACKGROUND

**[0002]** There are several different causes for gum and other oral cavity bleeding. Some of them are mechanical issues, such as excessive brushing force, using a toothbrush with stiff bristles, incorrect brushing or flossing mechanics, or improperly fitted dentures. Gum disease can also cause bleeding due to inflammation of gum tissues. Other important causes can be systemic, such as medications (e.g. blood thinners), pregnancy (hormonal changes), diabetes, vitamin deficiency (e.g. C or K), Leukemia, etc. Although the American Dental Association recommends that people with gum bleeding see a dentist or physician, a majority of the population do not feel pain when they have bleeding gums and therefore ignore this recommendation. Therefore, there is a need to provide consumers with a toothbrushing system that can monitor and/or log gum bleeding during routine tooth brushing.

## BRIEF SUMMARY

**[0003]** The invention is directed to a system and/or method for detecting hemoglobin and/or blood in the oral cavity during toothbrushing, as well as to a toothbrush capable of doing the same.

**[0004]** In one aspect, a system for detecting blood in an oral cavity during toothbrushing includes a toothbrush comprising a sensor configured to emit first light at a first wavelength and second light at a second wavelength; receive reflected portions of the first light and the second light; and, for a plurality of different times, generate a first signal indicative of a first intensity of the reflected portion of the first light and a second signal indicative of a second intensity of the reflected portion of the second light; and a processor operably coupled to the sensor and configured to, for each of the plurality of different times, receive the first signal and the second signal, and calculate a ratio of the first intensity to the second intensity; identify peaks in the ratio

over the different times; and determine whether hemoglobin is present in the oral cavity based on a number of peaks in the ratio over the different times.

**[0005]** In another aspect, a method for detecting blood in an oral cavity during toothbrushing includes, during a toothbrushing session in which a toothbrush brushes an oral cavity, emitting into the oral cavity, via a sensor of the toothbrush, first light at a first wavelength and second light at a second wavelength; receiving, via the sensor of the toothbrush, reflected portions of the first light and the second light; and, for each of a plurality of different times during the brushing session, transmitting, from the sensor to a processor, a first signal indicative of a first intensity of the reflected portion of the first light and a second signal indicative of a second intensity of the reflected portion of the second light; for each of the plurality of different times, calculating, via the processor, a ratio of the first intensity to the second intensity; identifying, via the processor, peaks in the ratio over the different times; and determining, via the processor, whether hemoglobin is present in the oral cavity based on a number of peaks in the ratio over the different times.

**[0006]** In another aspect, a system for detecting blood in an oral cavity during toothbrushing includes a toothbrush comprising a sensor configured to emit first light at a first wavelength, and emit a second light at a second wavelength; receive reflected portions of the first light and the second light; and generate a first signal indicative of a first intensity of the reflected portion of the first light, and generate a second signal indicative of a second intensity of the reflected portion of the second light; and a processor operably coupled to the sensor and configured to, for a plurality of different times, receive the first signal and the second signal; and calculate a ratio of the first intensity to the second intensity; wherein the ratios for the different times form data points; identify which of the data points are inside predetermined boundaries and which of the data points are outside the predetermined boundaries; and determine whether hemoglobin is present in the oral cavity based on a characteristic of the data points inside the predetermined boundaries or the data points outside the predetermined boundaries.

**[0007]** In another aspect, a method for detecting blood in an oral cavity during toothbrushing includes, during a toothbrushing session in which a toothbrush brushes an oral cavity, emitting into the oral cavity, via a sensor of the toothbrush, first light at a first wavelength and second light at a second wavelength; receiving, via the sensor of the toothbrush, reflected portions of the first light and the second light; and for a plurality of different times during the brushing session,

transmitting, from the sensor to a processor, a first signal indicative of a first intensity of the reflected portion of the first light and a second signal indicative of a second intensity of the reflected portion of the second light; for each of the plurality of different times, calculating, via the processor, a ratio of the first intensity to the second intensity, wherein the ratios for the different times form data points; identifying, via the processor, which of the data points are inside predetermined boundaries and which of the data points are outside the predetermined boundaries; and determining, via the processor, whether hemoglobin is present in the oral cavity based on a characteristic of the data points inside the predetermined boundaries or the data points outside the predetermined boundaries.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0008]** The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

**[0009]** FIG. 1 is a perspective view of a toothbrush having a body and a refill head in accordance with an embodiment of the present invention, with the refill head in a detached state;

**[0010]** FIG. 2 is a perspective view of the toothbrush of FIG. 1 with the refill head in an attached state;

**[0011]** FIG. 3 is a perspective view of an alternative toothbrush with the refill head in an attached state according to an embodiment of the invention;

**[0012]** FIG. 4 is a schematic illustration of a sensor of the toothbrush of FIG. 1;

**[0013]** FIGS. 5A and 5B are schematic illustrations of the sensor of FIG. 4 transmitting light into a toothpaste slurry and receiving reflected light in accordance with embodiments of the present invention;

**[0014]** FIG. 6 is a scatterplot illustrating the results of calculations performed by the toothbrush of FIG. 1 to determine the presence of hemoglobin in the oral cavity in accordance with an experiment;

**[0015]** FIG. 7 is a graph illustrating the experimental results of calculations performed by the toothbrush of FIG. 1 to determine the presence of hemoglobin in the oral cavity;

**[0016]** FIG. 8 illustrates a system for detecting blood in an oral cavity that includes a toothbrush and a portable electronic device that are in operable communication with one another;

**[0017]** FIG. 9 is an electrical block diagram of the electronic components of the toothbrush and the portable electronic device of the system of FIG. 8;

**[0018]** FIGS. 10A and 10B are illustrations of a software application launched on a display device of the portable electronic device of the system of FIG. 8, wherein the software application is indicating whether or not blood was found in the oral cavity;

**[0019]** FIG. 11 is an illustration of a software application launched on a display device of the portable electronic device of the system of FIG. 8, wherein the software application is displaying a log of data related to the detection of blood in the oral cavity during numerous toothbrushing sessions;

**[0020]** FIGS. 12A-B are plots of the R/G ratio and the IR/G ratio, respectively, for a typical bleeder over time.

**[0021]** FIGS. 13A-B are plots the R/G ratio and the IR/G ratio, respectively, for a typical non-bleeder over time.

**[0022]** FIG. 14 is a plot of the average number of normalized peaks for each panelist using the R/G ratio.

**[0023]** FIG. 15 is a plot of the average number of normalized peaks for each panelist using the IR/G ratio.

**[0024]** FIG. 16A is a plot of the R/G ratio v. the IR/G ratio for a bleeder for one brushing session.

**[0025]** FIG. 16B is a plot of the R/G ratio v. the IR/G ratio for a non-bleeder for one brushing session.

**[0026]** FIG. 17 is a plot of the average normalized vector lengths using the R, G and IR channels for datapoints outside the predetermined boundary box for each of the participants.

**[0027]** FIG. 18 is a plot of the normalized vector lengths for each of the participants averaged over 5 brushing cycles for the model using only IR and G channels.

**[0028]** FIG. 19 is a plot of normalized vector lengths for each of the participants averaged over five brushing cycles for the model using only R and G channels.

**[0029]** FIGS. 20A and 20B are plots of the average normalized spread of the datapoints in the box for each panelist over 5 brushing cycles according to the first and second methods, respectively.

**[0030]** FIG. 21 is a plot of normalized cluster spreads for participants averaged over five brushing cycles for the model using only IR and G channels.

**[0031]** FIG. 22 is a plot of normalized cluster spreads for 11 participants averaged over five brushing cycles for the model using only R and G channels.

## DETAILED DESCRIPTION

**[0032]** The following description of the preferred embodiment(s) is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses.

**[0033]** The description of illustrative embodiments according to principles of the present invention is intended to be read in connection with the accompanying drawings, which are to be considered part of the entire written description. In the description of embodiments of the invention disclosed herein, any reference to direction or orientation is merely intended for convenience of description and is not intended in any way to limit the scope of the present invention. Relative terms such as "lower," "upper," "horizontal," "vertical," "above," "below," "up," "down," "top" and "bottom" as well as derivatives thereof (e.g., "horizontally," "downwardly," "upwardly," etc.) should be construed to refer to the orientation as then described or as shown in the drawing under discussion. These relative terms are for convenience of description only and do not require that the apparatus be constructed or operated in a particular orientation unless explicitly indicated as such. Terms such as "attached," "affixed," "connected," "coupled," "interconnected," and similar refer to a relationship wherein structures are secured or attached to one another either directly or indirectly through intervening structures, as well as both movable or rigid attachments or relationships, unless expressly described otherwise. Moreover, the features and benefits of the invention are illustrated by reference to the exemplified embodiments. Accordingly, the invention expressly should not be limited to such exemplary embodiments illustrating some possible non-limiting combination of features that may exist alone or in other combinations of features; the scope of the invention being defined by the claims appended hereto.

**[0034]** As used throughout, ranges are used as shorthand for describing each and every value that is within the range. Any value within the range can be selected as the terminus of the range. In addition, all references cited herein are hereby incorporated by referenced in their entireties. In the event of a conflict in a definition in the present disclosure and that of a cited reference, the present disclosure controls.

**[0035]** Features of the present invention may be implemented in software, hardware, firmware, or combinations thereof. The computer or software programs described herein are not limited to any particular embodiment, and may be implemented in an operating system, application program, foreground or background processes, driver, or any combination thereof. The computer programs may be executed on a single computer or server processor or multiple computer or server processors.

**[0036]** Processors described herein may be any central processing unit (CPU), microprocessor, micro-controller, computational, or programmable device or circuit configured for executing computer program instructions (e.g. code). Various processors may be embodied in computer and/or server hardware of any suitable type (e.g. desktop, laptop, notebook, tablets, cellular phones, etc.) and may include all the usual ancillary components necessary to form a functional data processing device including without limitation a bus, software and data storage such as volatile and non-volatile memory, input/output devices, graphical user interfaces (GUIs), removable data storage, and wired and/or wireless communication interface devices including Wi-Fi, Bluetooth, LAN, etc.

**[0037]** Computer-executable instructions or programs (e.g. software or code) and data described herein may be programmed into and tangibly embodied in a non-transitory computer-readable medium that is accessible to and retrievable by a respective processor as described herein which configures and directs the processor to perform the desired functions and processes by executing the instructions encoded in the medium. It should be noted that non-transitory "computer-readable medium" as described herein may include, without limitation, any suitable volatile or non-volatile memory including random access memory (RAM) and various types thereof, read-only memory (ROM) and various types thereof, USB flash memory, and magnetic or optical data storage devices (e.g. internal/external hard disks, floppy discs, magnetic tape CD-ROM, DVD-ROM, optical disk, ZIP™ drive, Blu-ray disk, and others), which may be written to and/or read by a processor operably connected to the medium.

**[0038]** In certain embodiments, the present invention may be embodied in the form of computer-implemented processes and apparatuses such as processor-based data processing and communication systems or computer systems for practicing those processes. The present invention may also be embodied in the form of software or computer program code embodied in a non-transitory computer-readable storage medium, which when loaded into and executed by

the data processing and communications systems or computer systems, the computer program code segments configure the processor to create specific logic circuits configured for implementing the processes.

**[0039]** The invention described herein relates to an apparatus (i.e., toothbrush), system, and method of detecting gum bleeding (or any bleeding in an oral cavity, which may include bleeding on the soft tissues of the inner cheeks or elsewhere) using sensors that measure the hemoglobin level in saliva/toothpaste slurry. In one aspect, the detection of gum or other soft tissue bleeding occurs during toothbrushing, so the sensors may be described herein as being located on a toothbrush. The sensor may include a light transmitter and a light receiver. The light transmitter may emit visible and infrared light during toothbrushing and the intensity of the reflected light (i.e., the light reflected back from the toothpaste slurry) is received by the light receiver. Because hemoglobin has a strong red color, it absorbs green light while reflecting the majority of the red and infrared light back. Therefore, using a ratio of reflected light intensity (red/green and/or infrared/green) and applying that data to a processing algorithm, the hemoglobin can be quantified. The information obtained can either be stored on a memory device in the toothbrush or automatically transferred to a mobile phone (or other portable electronic device) app (software application), or both. In either case, the information can be provided to a user (either as logs of all information or as an indicator that blood was present in the toothpaste slurry) so that a user can be informed about gum bleeding.

**[0040]** Referring to FIGS. 1 and 2, a toothbrush 100 is illustrated in accordance with an embodiment of the present invention. In the exemplified embodiment, the toothbrush 100 generally comprises a body 110 and a refill head 120 that is detachably coupled to the body 110. More specifically, the body 110 comprises a handle portion 111 that is configured for gripping and handling by a user and a stem 112 that is configured for attachment of the refill head 120 to the body 110. The refill head 120 comprises a sleeve portion 121 and a head portion 122. The sleeve portion 121 is sized and configured to fit over the stem 112 of the body 110 for coupling the refill head 120 to the body 110. The refill head 120 may be coupled to the body 110 with a friction/interference fit or via mechanical interaction, such as the refill head 120 having a protuberance or recess that matches with a recess or protuberance on the body 110. Various techniques for coupling a refill head 120 to a body 110 of a toothbrush 100 are known and could be used in accordance with the invention described herein (i.e., magnetic, mechanical,

interference, screw threads, protuberance/detent, or the like). The refill head 120 and the body 110 are illustrated generically and the invention is not to be limited by the shape, size, and/or geometry of these components.

**[0041]** The refill head 120 also comprises cleaning elements 123 that extend from the head portion 122. The cleaning elements 123 may be bristles, elastomeric fingers, lamella, rubber elements, or the like. Specifically, the cleaning elements 123 may be any feature or structure that is known to be used for cleaning of the teeth, gums, and other oral cavity surfaces. The pattern, material, shape, rigidity, or the like of the cleaning elements is not to be limiting of the invention.

**[0042]** In certain embodiments, the exact structure, pattern, orientation, and material of the tooth cleaning elements 123 are not to be limiting of the present invention. Thus, the term "tooth cleaning elements" may be used herein in a generic sense to refer to any structure that can be used to clean, polish or wipe the teeth and/or soft oral tissue (e.g. tongue, cheek, gums, etc.) through relative surface contact. Common examples of “tooth cleaning elements” include, without limitation, bristle tufts, filament bristles, fiber bristles, nylon bristles, spiral bristles, rubber bristles, elastomeric protrusions, flexible polymer protrusions, combinations thereof, and/or structures containing such materials or combinations. Suitable elastomeric materials include any biocompatible resilient material suitable for uses in an oral hygiene apparatus. To provide optimum comfort as well as cleaning benefits, the elastomeric material of the tooth or soft tissue engaging elements has a hardness property in the range of A8 to A25 Shore hardness. One suitable elastomeric material is styrene-ethylene/butylene-styrene block copolymer (SEBS) manufactured by GLS Corporation. Nevertheless, SEBS material from other manufacturers or other materials within and outside the noted hardness range could be used.

**[0043]** The tooth cleaning elements 123 of the present invention can be connected to the head portion 122 of the refill head 120 in any manner known in the art. For example, staples/anchors, in-mold tufting (IMT), anchor free tufting (AFT), PTt anchorless tufting, or the like could be used to mount the cleaning elements/tooth engaging elements to the head portion 122 of the refill head 120.

**[0044]** In the exemplified embodiment, the cleaning elements 123 define a cleaning element field 124. Below the cleaning elements 123 is an opening or cavity 125 that is formed in the head 120. when the refill head 120 is coupled to the body 110, the cavity 125 in the head 120 is

aligned with the sensor 133 of the electronic circuit 130. Furthermore, the head portion 120 may include an optical transparent window that is aligned with the sensor 133 and the cavity 125 to prevent fluids such as saliva, water, and toothpaste slurry from contacting the sensor 133. It can be important to align the sensor 133 with the cavity 125 in the cleaning element field 124 because, as described in more detail below, in some embodiments the sensor 133 is configured to emit and receive light. Thus, in the exemplified embodiment there is a passageway through the cleaning element field 124 for the light to be passed from the sensor 133 into a user's oral cavity and then back from the oral cavity to the sensor 133 during toothbrushing. As noted above, in the exemplified embodiment this is achieved with the combination of the optical transparent window 126 and the cavity 125 in the cleaning element field 124.

**[0045]** Although in the exemplified embodiment the toothbrush 100 is one which includes a body 110 and a refill head 120 that are detachably coupled together, in other embodiments the toothbrush 100 may be a unitary component comprising a handle and a head that are fixedly coupled together, such as with most traditional manual toothbrushes in the market. Having a detachable refill head 120 may be desirable because it can prolong the use of the toothbrush 100 by enabling a user to replace the refill head 120 and hence also the bristles 123 as they become worn while reusing the body 120 which includes expensive circuitry and electronic components as described further herein below. However, it is possible to utilize the techniques and components described herein on a more conventional manual toothbrush that does not include a replaceable refill head. Thus, the invention is not limited to one which requires the toothbrush to include a refill head in all embodiments unless specifically claimed as such.

**[0046]** In the exemplified embodiment, the toothbrush 100 comprises an electronic circuit 130 for acquiring and/or generating signals related to detecting the presence of hemoglobin (and hence also blood) in the oral cavity (or a toothpaste slurry) during a toothbrushing session. The toothbrush 100 (and related system described below) is able to detect and measure hemoglobin/blood using a few wavelengths (two to three) in visible and/or infrared regions during toothbrushing. Thus, no reagents, assays, wet chemistry preparation, and/or specialized equipment is needed to detect the hemoglobin/blood using the techniques described herein.

**[0047]** As mentioned above, in the exemplified embodiment the components of the electronic circuit 130 are located within the body 110 of the toothbrush 100, which is a non-replaceable part of the toothbrush. In that regard, the body 110 of the toothbrush 100 comprises a cavity or

otherwise hollow region within which the components of the electronic circuit 130 are located. Because the electronic circuit 130 is located within the body 110 and not the refill head 120, as the cleaning elements 123 on the refill head 120 become worn, a new refill head 120 can be attached to the body 110 to prolong the usable life of the toothbrush 100. This is one reason that forming the toothbrush 100 so that it includes a body 110 and a detachable refill head 120 may be desirable.

**[0048]** In the exemplified embodiment, the electronic circuit 130 comprises, in operable coupling, a processor 131, a power source 132, a sensor 133, a memory device 134 (which could alternatively be a part of the processor 131 in some embodiments), a Bluetooth module 135, and an indicator 136. The components of the electronic circuit 130 are all located within a cavity in the body 110. Furthermore, in the exemplified embodiment the electronic circuit 130 also comprises a motor 137 that is operably coupled to the processor 131 for imparting motion and/or vibrations to the refill head 120 in instances in which the toothbrush 100 is a powered toothbrush instead of a manual toothbrush. For example, the motor 137 could include an eccentric counterweight to provide vibration during tooth cleaning. The processor 131 may be considered a microcontroller in some embodiments because it may include all peripherals in the chip itself and may not run on any operating system.

**[0049]** The illustration of FIGS. 1 and 2 is schematic in that it illustrates each of the components of the electronic circuit 130 with a box and uses a dashed line to illustrate the electrical coupling between the components. These boxes are not actually visible on the exterior of the body 110 but rather they are representative of the components of the electronic circuit 130 as described herein. Specifically, the boxes represent components of the electronic circuit 130 that are housed within a cavity defined by the body 110.

**[0050]** In the exemplified embodiment, the motor 137 and the sensor 133 are located in the stem 112 of the body 110 and the processor 131, the power source 132, the memory device 134, the Bluetooth module 135, and the indicator 136 are located in the handle portion 111 of the body 110. In some embodiments, the processor 131 may be located in the stem 112 alongside of the sensor 133 rather than in the handle portion 111. The sensor 133 may be connected to the processor 131 using any desired techniques, although a standard ADC, $I^2C$ or SPI interface may be used in some embodiments. In some embodiments, the Bluetooth module 135 may be coupled to the processor 131 through a standard serial interface. In other embodiments, the

Bluetooth module 135 and the processor 131 can be combined as a single unit. Furthermore, as noted above the memory device 134 may be a part of the processor 131 in some embodiments, and in other embodiments the memory device 134 may be omitted entirely.

**[0051]** FIG. 3 is a perspective view of an alternative toothbrush 100A with the refill head in an attached state according to an embodiment of the invention. In this embodiment, the cleaning element field 124 defines an opening or cavity 125A, which is formed by a portion of the head portion 122 not having any cleaning elements 123 extending therefrom. Thus, there is a portion of the head portion 122 that is devoid of any cleaning elements 123, and this portion is surrounded by the cleaning elements 123 to form the cavity 125A within the cleaning element field 124. Of course, in other embodiments the spacing between the cleaning elements 123 of the cleaning element field 124 may be different than that which is shown such that there is no cavity per se, but still so that a gap in the cleaning element field 124 remains.

**[0052]** Referring to FIG. 4, the sensor 133 will be described in greater detail in accordance with an embodiment of the present invention. The sensor 133 is preferably small so that it can fit within the stem 112 and/or the head portion 122 of the toothbrush 100 as depicted in the figures. In the exemplified embodiment the sensor 133 comprises a transmitter 140 and a receiver 141. Furthermore, in the exemplified embodiment the transmitter 140 comprises a first light source 142, a second light source 143, and a third light source 144. Although three light sources are depicted in the exemplified embodiment, the invention is not to be so limited in all embodiments. Specifically, in some alternative embodiments the transmitter 140 may include only the first and second light sources 142, 143 and not also the third light source 144. One example of the sensor 133 is MAX30105 from Maxim Integrated, although the invention is not to be limited to this in all embodiments and other sensors could be used. In some embodiments, the transmitter 140 can be a broadband white light emitter. In such an embodiment, the receiver 141 may have multiple channels to detect reflected light at different wavelengths separately.

**[0053]** In the exemplified embodiment, the sensor 133 is a singular structure that includes all of the features/components noted herein. However, the invention is not to be so limited and in some other embodiments the sensor may comprise multiple sensors that are independent and distinct from one another. For example, the sensor may include discrete light sources that are separate and apart from a receiver. Thus, the term sensor, as used herein, includes the situation

where a single sensor having all of the necessary components is used and the situation where multiple sensors that in combination have all of the necessary components are used.

**[0054]** The first light source 142 is configured to emit light at a first wavelength, the second light source 143 is configured to emit light at a second wavelength that is different than the first wavelength, and the third light source is configured to emit light at a third wavelength that is different than the first and second wavelengths. For example, in one embodiment the first light source 142 is configured to emit red light having a wavelength in a range of 625-740 nm, more specifically 640-680 nm. Furthermore, in one embodiment the second light source 143 is configured to emit green light having a wavelength in a range of 520-560 nm, more specifically 520-540 nm. Further still, in one embodiment the third light source 144 is configured to emit infrared light having a wavelength in a range of 700 nm – 1 micron, and more specifically 830-930 nm, and still more specifically 860-900 nm. In the exemplified embodiment, each of the first, second, and third light sources 142, 143, 144 are light emitting diodes, although other types of light sources may be used in the alternative. Thus, the transmitter 140 of the sensor 131 comprises multiple light sources such that each of the light sources transmits light at a different wavelength. The receiver 141 may be a broad spectrum light detector such that it can detect reflected light in all of the wavelengths mentioned herein (i.e., it can detect at least red, green, and infrared light).

**[0055]** In the exemplified embodiment the sensor 133 is operably coupled to the processor 131 so that measurements or other information detected by the sensor 133 can be transmitted to the processor 131 as a signal for processing. Furthermore, the processor 131 is pre-programmed with algorithms or otherwise works in association with software applications containing algorithms so that the processor 131 can perform various calculations using the information acquired by the sensor 133 to determine whether hemoglobin, and hence also blood, is being detected by the sensor 133. Specifically, the processor 131 can perform calculations and then, utilizing the pre-programmed algorithms, determine whether the results of those calculations indicate that hemoglobin/blood is present or not, and if so at what quantity.

**[0056]** Specifically, referring to FIGS. 5A and 5B, operation of the sensor 133 will be described. FIG. 5A schematically depicts the sensor 133 located within an oral cavity so that light emitted by the sensor 133 can contact and be reflected by a toothpaste slurry 150 in the oral cavity that is devoid of any blood. FIG. 5B schematically depicts the sensor 133 located within an oral cavity

so that the light emitted by the sensor 133 can contact and be reflected by a toothpaste slurry 151 in the oral cavity that comprises blood. A toothpaste slurry is a liquid formulation that includes toothpaste and saliva. Furthermore, if there is blood in the mouth, this blood will mix with the liquid formulation and also form a part of the toothpaste slurry. Thus, the sensor 133 is configured to detect whether there is blood in the toothpaste slurry, which would in turn be indicative of bleeding occurring within the oral cavity (i.e., gum bleeding or the like).

**[0057]** Referring first to FIG. 5A, the sensor 133 is located within an oral cavity that has a toothpaste slurry 150 therein that is devoid of any blood. Thus, the toothpaste slurry 150 includes toothpaste and saliva, but no blood. In this embodiment, the first light source 142 emits a first light 145 into the oral cavity and towards the toothpaste slurry 150 at the first wavelength (e.g., red light), the second light source 143 emits a second light 146 into the oral cavity and towards the toothpaste slurry 150 at the second wavelength (e.g., green light), and the third light source 144 emits a third light 147 into the oral cavity and towards the toothpaste slurry 150 at the third wavelength (e.g., infrared light). In a complicated matrix such as that of saliva/toothpaste slurry, abrasive particles and air bubbles in the toothpaste slurry reflect light at different wavelengths at a similar efficiency. Thus, as shown in FIG. 5A, the first, second, and third lights 145, 146, 147 are all reflected off of the toothpaste slurry 150 as a reflected portion of the first light 145, a reflected portion of the second light 146, and a reflected portion of the third light 147.

**[0058]** Referring to FIG. 5B, the sensor 133 is located within an oral cavity that has a toothpaste slurry 151 therein that comprises blood. Thus, the toothpaste slurry 151 includes toothpaste, saliva, and blood due to gum or other oral tissue surface bleeding within the oral cavity. In this embodiment, the first light source 142 emits the first light 145 into the oral cavity and towards the toothpaste slurry 151 at the first wavelength (e.g., red light), the second light source 143 emits a second light 146 into the oral cavity and towards the toothpaste slurry 151 at the second wavelength (e.g., green light), and the third light source 144 emits a third light 147 into the oral cavity and towards the toothpaste slurry 151 at the third wavelength (e.g., infrared light). Due to its strong red color, hemoglobin in red blood cells will strongly absorb green light, while reflecting a majority of red and infrared light back.

**[0059]** Thus, as shown in FIG. 5B, the first and third light 145, 147 are reflected from the toothpaste slurry 151 as a reflected portion of the first light 145 and a reflected portion of the

third light 147. However, the second light 146 (which is the green light in the exemplified embodiment) is absorbed by the toothpaste slurry 151. In FIG. 5B, it is illustrated such that none of the second light 146 is reflected back to the receiver 142 of the sensor 133. However, in actual practice some of the second light 146 is reflected back, but it has a reduced intensity as compared to the amount of the second light 146 that is reflected back from the toothpaste slurry 150 of FIG. 5A that is devoid of blood due to the hemoglobin absorbing some of the second light 146. Thus, the second light 146 that is reflected from the toothpaste slurry 150 that is devoid of blood has a greater intensity than the second light 146 that is reflected from the toothpaste slurry 151 that comprises blood due to the hemoglobin in the blood absorbing some of the second light 146.

**[0060]** Thus, during toothbrushing with the cleaning elements 123 of the toothbrush 100, the sensor 133 transmits the first, second, and third lights 145, 146, 147 into the oral cavity. The first, second, and third lights 145, 146, 147 contact the toothpaste slurry 150, 151 in the oral cavity and reflected portions of the first, second, and third lights 145, 146, 147 are received by the receiver 141 of the sensor 133. The intensity of the reflected portions of the first and third lights 145, 147 (red and infrared light) are relatively unchanged regardless of whether or not the toothpaste slurry comprises blood. However, the intensity of the reflected portion of the second light 146 (green light) is greater when the toothpaste slurry does not comprise blood than when it does. Thus, the sensor 133 generates a first signal indicative of a first intensity of the reflected portion of the first light 145, a second signal indicative of a second intensity of the reflected portion of the second light 146, and a third signal indicative of the third intensity of the reflected portion of the third light 147.

**[0061]** Because the intensity of the reflected portion of the second light 146 is reduced when there is blood in the toothpaste slurry while the intensity of the reflected portions of the first and third light 145, 147 remain substantially the same regardless of whether or not there is blood in the toothpaste slurry, the ratio of the reflected light intensities can be used to identify and quantify hemoglobin/blood. Thus, the processor 131 may have an algorithm that can calculate the ratios and determine whether or not (and how much) hemoglobin and blood is present.

**[0062]** Due to their operable coupling, the first, second, and third signals (although the third signal could be omitted because the system could operate just as well with only red or infrared light and green light being transmitted by the sensor 133) is transmitted from the sensor 133 to

the processor 131. The processor 131 is equipped with algorithms instructing it to perform calculations with the first, second, and third signals to assist in determining whether hemoglobin/blood is in the toothpaste slurry. Specifically, the processor 131 is configured to calculate a ratio of the first intensity of the first light 145 to the second intensity of the second light 146 and/or a ratio of the third intensity of the third light 147 to the second intensity of the second light 146. As should be appreciated, if there is hemoglobin/blood in the toothpaste slurry, the intensity of the reflected portion of the second light 146 is less than if there is no hemoglobin in the toothpaste slurry. Thus, if there is hemoglobin/blood in the toothpaste slurry, the ratio of the first intensity of the first light 145 to the second intensity of the second light 146 and the ratio of the third intensity of the third light 147 to the second intensity of the second light 146 is increased as compared to the situation where there is no hemoglobin/blood in the toothpaste slurry (due to the denominator in the ratio calculation being reduced). Using this understanding and the developed algorithms, the processor 131 can make a determination as to whether there is hemoglobin/blood in the toothpaste slurry, and if so, how much.

**[0063]** For example, the processor 131 or algorithm may be set with a predetermined threshold for the various ratios that are calculated so that upon the ratio exceeding the predetermined threshold, the processor 131 will be informed that hemoglobin/blood has been detected. Thus, the processor 131 can be programmed so that if the ratio of the first intensity of the first light 145 to the second intensity of the second light 146 exceeds a first predetermined threshold and/or the ratio of the third intensity of the third light 147 to the second intensity of the second light 146 exceeds a second predetermined threshold, hemoglobin/blood is present.

**[0064]** These predetermined thresholds may be determined based on testing with baseline samples of toothpaste slurry that do not include hemoglobin/blood and testing with test samples of toothpaste slurry that include varying amounts of toothpaste slurry, as discussed further below with reference to FIG. 6. Thus, the predetermined thresholds may be determined by running tests with the toothbrush 100 on toothpaste slurries that do not have any hemoglobin such that if the ratio is increased from the test data, it can be determined that there is blood present in the toothpaste slurry.

**[0065]** Specifically, FIG. 6 is a scatterplot illustrating the results of an experiment testing in-vitro detection of hemoglobin in blood by a prototype device having the same technology that is present in the toothbrush 100 described herein. In the experiment, lyophilized human

hemoglobin (Sigma) was reconstituted in deionized water to a concentration of 4.2% and combined with a 1 part : 3 part w/w slurry of Colgate Dental Cream (Great Regular Flavor) and deionized water to form solutions of the following final w/w concentrations of hemoglobin:

| Wt. Pct. Hemoglobin |
|---|
| 0.285714 |
| 0.259259 |
| 0.230769 |
| 0.2 |
| 0.166667 |
| 0.130435 |
| 0.090909 |
| 0.047619 |

**[0066]** As should be appreciated, the solutions with a higher concentration of hemoglobin will have a darker red color, and therefore will absorb more green light that is transmitted at it. A single 50 microliter droplet of each solution was measured using the prototype device. FIG. 6 is a scatterplot indicating a linear relationship between the measured values of reflected infrared and green light (expressed as the ratio IR/G) and the concentration of hemoglobin. As can be seen, as the wt. % of hemoglobin increases, the results of the ratio IR/G also increases (and the same occurs if the infrared light is replaced with red light). This is because with more hemoglobin present in the solution, more of the green light is absorbed by the solution and the reflected green light has a lower intensity. Thus, using this information, an algorithm can be created to determine the presence or lack thereof of hemoglobin in a toothpaste slurry and also the quantity of the hemoglobin (and therefore also blood) in the toothpaste slurry. In this example, if the ratio of IR/G is greater than approximately 4.5, it is likely that there is blood in the solution being tested (i.e., the toothpaste slurry). Thus, the predetermined threshold could be 4.5 when the light sources emit infrared and green light, respectively, in one embodiment.

**[0067]** Referring again to FIGS. 1 and 2, as noted above the electronic circuit 130 also comprises the indicator 136. In the exemplified embodiment, the indicator 136 is located on the body 110

of the toothbrush 100. The indicator 136 is operably coupled to the processor 131 so that upon the processor 131 determining that there is blood in the oral cavity or the toothpaste slurry, the processor 131 can activate the indicator 136. In one embodiment, the indicator 136 may be a light, such as a light emitting diode (LED) or the like. In such an embodiment, upon the processor 131 determining that there is hemoglobin/blood in the oral cavity (based on one of the ratios noted above being calculated to be above its corresponding predetermined threshold or using some other determination as set out in an algorithm), the processor 131 will activate the indicator 136 so that it lights up/illuminates, thereby indicating to the user that there is blood in the oral cavity (i.e. that the user's gums or the like are bleeding). Of course, the indicator 136 is not limited to being a light source in all embodiments, and it could be an audio source in other embodiments such that when activated it emits a sound that is audible to the user. In still other embodiments, the indicator 136 could take on other forms such as being a mechanical feature that is felt by the user in a tactile manner, a scented feature that upon activation emits a scent, a display screen that displays various texts, or the like.

**[0068]** In some embodiments, the indicator 136 may light up in different colors depending on the status of the toothbrush 100 or sensor 133. For example, the indicator 136 may illuminate as blue when the sensor 133 is operably coupled to a portable electronic device as described in more detail below, the indicator 136 may be red when the toothbrush 100 or power source thereof is charging, and it may be green when the toothbrush 100 is being used in a toothbrushing session. In other embodiments, the indicator 136 may light up as red (or orange or any other color) when blood is determined to be present in the toothpaste slurry/oral cavity as described herein.

**[0069]** In some embodiments, there may be a button or other type of actuator (slide switch, button, capacitive sensor, etc.) on the toothbrush 100 for activating the sensor 133. Thus, prior to a toothbrushing session, a user may press (or otherwise actuate) the button to activate the sensor 133. Pressing the button (or otherwise actuating the actuator) may also activate the motor 137 when the motor 137 is included such as when the toothbrush 100 is a powered toothbrush. Alternatively, there may be separate buttons/actuators for the motor 137 and for the sensor 133. In some embodiments, there is no motor and the toothbrush 100 is a manual toothbrush.

**[0070]** Referring to FIG. 7, a graphical representation of the results of an experimental test performed using a prototype device comprising the sensor 133 and the processor 131 is provided.

To demonstrate the capability of the toothbrush 100, two samples were measured. About 2 grams of toothpaste were mixed with about 5 mL of saliva to create toothpaste / saliva slurry, this is the "baseline sample." The same procedure was repeated, and 1 drop of human blood was added to the slurry then mixed well to create the "test sample" – toothpaste / saliva slurry with blood. One drop of the baseline sample was deposited on a glass slide and the sensor 133 was put under the slide to measure the reflected light. At least 100 data points were recorded for each of the three wavelengths of light, and the average values were used in later processing. The procedure was repeated three times to acquire baseline data for toothpaste / saliva slurry. The same procedure was repeated three times for the test sample as well.

**[0071]** FIG. 7 shows the results of a signal measured by the prototype device. The x-axis is the signal intensity ratio of red light over green light, while the y-axis is the signal intensity ratio of infrared light over green light. Clear separation of the "baseline sample" and the "test sample" was observed. To identify and quantify hemoglobin in toothpaste slurry, different data processing algorithms can be employed, such as KNN (k-Nearest Neighbor) for identification and regression for quantification.

**[0072]** Using this example, if the ratio of the intensity of the reflected portion of the first (i.e., red) light to the intensity of the reflected portion of the second (i.e., green) light is greater than 5.6, it can be determined that there is hemoglobin/blood in the oral cavity (or in the toothpaste slurry and hence also in the oral cavity). Similarly, if the ratio of the intensity of the reflected portion of the third (i.e., infrared) light to the intensity of the reflected portion of the second (i.e., green) light is greater than 4.8, it can be determined that there is hemoglobin/blood in the oral cavity (or in the toothpaste slurry and hence also in the oral cavity).

**[0073]** In some embodiments, the sensor 133 is configured to collect data continuously once activated. For example, once powered on, the sensor 133 may collect data for a predetermined period of time, for example for 120 seconds, or 130 seconds, or 140 seconds, or 150 seconds to ensure that it is collecting data for the duration of a toothbrushing session (which is ideally 120 seconds, although more frequently a shorter period of time). In some embodiments, the sensor 133 may collect two data points every second such that it may collect 240 data points during a two minute toothbrushing session. In other embodiments, the sensor 133 may collect data intermittently. For example, the sensor 133 may collect data at ten seconds, and then at thirty seconds, and then at one minute, and then at one minute and fifteen seconds, and then at one

minute and thirty seconds, and then at one minute and forty-five seconds, and then at two minutes. The exact frequency at which the sensor 133 collects data regarding the presence or absence of hemoglobin is not to be limiting of the present invention in all embodiments.

**[0074]** Referring to FIGS. 8 and 9, a system 1000 for detecting blood in an oral cavity during toothbrushing is illustrated. The system 1000 includes a toothbrush 200 and a portable electronic device 300 that are in operable communication with one another. The toothbrush 200 may be structurally identical to the toothbrush 100 described above with reference to FIGS. 1-3. Thus, in the exemplified embodiment the toothbrush 200 comprises a body 210 having a handle portion 211 and a stem (not illustrated) and a refill head 220 coupled to the body 210 in a detachable manner. For further details of the structure of the toothbrush 200, reference can be made to the toothbrush 100 described above.

**[0075]** Similar to the toothbrush 100, the toothbrush 200 comprises an electronic circuit 230 that may include a processor 231, a power source 232, a sensor 233, a memory device 234 (which could alternatively be a part of the processor 231 in some embodiments), a Bluetooth module 235, and an indicator 236. However, it may be possible to omit the processor 231, the memory device 234, and the indicator 236 in some embodiments. Thus, in some embodiments the electronic circuit 230 of the toothbrush 200 may comprise only the sensor 233 (which includes a transmitter 240 and a receiver 241), the power source 232, and the Bluetooth module 235. The toothbrush 200 may also include a motor 237 in instances where the toothbrush 200 is a powered toothbrush.

**[0076]** The reason that the toothbrush 200 need not include the processor 231, the memory device 234, and the indicator 236 (although it may include any of one or more of these components in some embodiments) is because these components are included as a part of the portable electronic device 300 that is in communication with the toothbrush 200. Specifically, the portable electronic device 300 may be a smart phone, a tablet, a computer, or a similar device that includes a processor 301, a memory 302, a user interface 303, a blood detection software application 304, and a Bluetooth module 305. The portable electronic device 300 may also include a display 306 (which can be the same as the user interface 303 or distinct from the user interface 303). In the exemplified embodiment, the processor 301 of the portable electronic device 300 is in operable communication with the sensor 233 of the toothbrush 200 via Bluetooth due to the incorporation of the Bluetooth module 235 in the toothbrush 200 and the

Bluetooth module 305 in the portable electronic device 300 (when the toothbrush 200 and the portable electronic device 300 are in sufficiently close proximity to one another so as to allow for such a Bluetooth connection). Of course, Bluetooth is merely one exemplary way that the toothbrush 200 and the portable electronic device 300 can be in communication. In other embodiments, there may be a wired connection between the toothbrush 200 and the portable electronic device 300 or they may communicate using other wireless protocols (infrared wireless communication, satellite communication, radio, microwave, Zigbee, Z-wave, or the like). Of course, the sensor 233 may have a built-in microcontroller in some embodiments.

**[0077]** In this embodiment, the sensor 233 will operate in the same way as the sensor 133 described above. Thus, the transmitter 240 of the sensor 233 comprises multiple light sources that emit light at different wavelengths and the receiver 241 of the sensor 233 receives reflected light. The sensor 233 then generates signals indicative of the intensities of the various reflected lights. However, in this embodiment the signals are then transmitted, via Bluetooth or otherwise, from the sensor 233 of the toothbrush 200 to the processor 301 of the portable electronic device 300. The transmission of these signals from the sensor 233 of the toothbrush 200 to the processor 301 of the portable electronic device 300 may occur so long as the toothbrush 200 and the portable electronic device 300 are in operable communication (either via Bluetooth or other wireless technologies or through a wired connection).

**[0078]** In some embodiments, the information associated with the signals and the information detected by the sensor 133 may be stored in the memory 234 and/or processor 231 of the toothbrush 200 initially and then transferred to the processor 301 of the portable electronic device 300 in batches. Thus, data or information corresponding to a plurality of different toothbrushing sessions may initially be stored in the memory 234 and/or processor of the toothbrush 231. This can be useful in instances in which the user brushes his/her teeth at a time that the toothbrush 200 is not in operable communication with the portable electronic device 300. In this way, the toothbrush 200 will initially store all of the data, and then once the toothbrush 200 becomes operably coupled to the portable electronic device 300, the data can be transmitted to the portable electronic device 300 for further processing as described herein (either automatically or in response to manual user input). In such embodiments, the processor 231 may be able to process the data just like the processor 131 of the toothbrush 100 so that the processor

231 can activate the indicator 236 when it determines that hemoglobin/blood is present in the oral cavity or toothpaste slurry.

**[0079]** As noted above, the portable electronic device 300 may have a blood detection software application 304 downloaded thereon. Thus, during or just prior to a toothbrushing session, a user may open the blood detection software application 304 and put the toothbrush 200 into operable (wireless or wired) communication with the portable electronic device 300. Alternatively, the operable coupling between the toothbrush 200 and the portable electronic device 300 may cause the blood detection software application 304 to automatically launch on the portable electronic device 300. In such a situation, as the sensor 233 of the toothbrush 200 is gathering information/data related to the intensity of the reflected light, it will transmit this data/information to the processor 301 of the portable electronic device 300. In some embodiments, this transmission of data/information from the sensor 233 to the processor 301 may occur automatically so long as the toothbrush 200 and the portable electronic device 300 are in operable communication with one another. Of course, as noted above, this data/information can alternatively (or additionally) be stored locally on the memory device 234 of the toothbrush 200 and then transmitted to the portable electronic device 300 in batches. The processor 301 of the portable electronic device 300 may make this data/information available to a user in various ways on the portable electronic device 300 using the blood detection software application 304.

**[0080]** Specifically, referring first to FIGS. 10A and 10B, one embodiment of the blood detection software application 304 is illustrated as displayed on the display 306 of the portable electronic device 300. In this reasonably simple embodiment of the blood detection software application 304, the blood detection software application 304 merely informs the user whether or not blood was detected in the oral cavity (or in the toothpaste slurry) during a toothbrushing session. Thus, as the processor 301 receives the signals from the sensor 233 and processes the signals in accordance with the algorithm(s) as described herein, the processor 301 causes the blood detection software application 304 to indicate whether or not blood is present. In FIG. 10A, no blood is present and thus the display 306 on the portable electronic device 300 is blank. In FIG. 10B, blood is present and thus the display 306 on the portable electronic device 300 is depicted with a shaded area 307. This shaded area 307 may be colored red as an indication that blood is present, although other colors, designs, or the like could be used, including text being displayed to indicate whether or not blood was present. Thus, in this embodiment the shaded

area 307 on the display 306 of the portable electronic device 300 serves as an indicator to a user to let the user know whether or not blood was present. Stated another way, the shaded area 307 is an output of the system 1000 that serves as an indication to a user of the presence or absence of blood in the toothpaste slurry. The processor 301 may further track this information over multiple uses in the blood detection software application 304 so that a user can review a log of data for each day indicating whether blood was present during toothbrushing or not during the toothbrushing session(s) that occurred in a given day.

**[0081]** In some embodiments, if blood is detected at any time during the toothbrushing session, the display 306 on the portable electronic device 300 will indicate this throughout the entirety of the toothbrushing session. In some embodiments, the display 306 on the portable electronic device 300 will update during the toothbrushing session depending on whether blood is being detected at a given time during the toothbrushing session. In some embodiments, the output on the display 306 may be an indication that blood was detected, and/or an indication of the quantity of blood detected, and/or an indication as to whether blood was detected and if so the time during the toothbrushing session that it was detected (for example, the display 306 may indicate that blood was first detected eighteen seconds into the toothbrushing session).

**[0082]** For example, referring to FIG. 11, the display 306 of the portable electronic device 300 is depicted in accordance with one embodiment with the blood detection software application 304 open so that a log of data from previous toothbrushing sessions is displayed. Thus, a user can open the blood detection software application 304 and navigate the application to the blood detection application log. In the exemplified embodiment, the log includes a date, a simple yes or no as to whether blood was detected on that particular date, and a concentration of blood that was detected as a weight percentage for each day. Various modifications can be made to the blood detection software application 304 to provide the user with any desired information or data about the blood that is or is not being detected during various toothbrushing sessions. In some embodiments, the blood detection software application 304 may be programmed with an algorithm the analyzes the sensor data log, and provides users a warning signal if continuous bleeding is detected, e.g. bleeding 7 days in a row. Thus, the depiction in FIG. 11 is merely exemplary and is not intended to illustrate the full scope of possibilities available through the blood detection software application 304. The information provided in this format may be the highest quantity of blood detected by the sensors 133, 233 during the toothbrushing session, an

average of the amount of blood detected by the sensors 133, 233 during the toothbrushing session, or the like.

**[0083]** Thus, with the data provided in FIG. 11, a user can be informed regarding how many times they were bleeding during toothbrushing over the last week, over the last two weeks, over the last three weeks, over the last month, and so on (this timeframe can be an adjustable setting in some embodiments). Typically, when a person bleeds during toothbrushing they notice it when the expectorate the toothpaste slurry or they taste it during brushing, but they forget about the fact that they were bleeding soon after they finish toothbrushing. Thus, even if a person bleeds daily, they do not put too much thought into it. By providing the user with a log of information from past toothbrushing sessions, this can make the user more aware of the frequency of bleeding during toothbrushing so that the user can seek treatment if necessary. The data provided in FIG. 11 could be displayed to the user, for example on the display of the portable electronic device 300 or elsewhere (i.e., on a computer or wherever it may be displayed) in tabulated form, such as in a bar graph, a line graph, or the like.

**[0084]** In some embodiments, sensor data can be uploaded to a remote cloud server(s) for achieving further analysis. The toothbrush 100, 200 could include a WiFi chip so that it can transmit data to the cloud or to a remote server, or the toothbrush 100, 200 can transmit the data to the portable electronic device 300, which in turn can send the data to the cloud/server. Users can use their computers (larger screen) to access their long term data log to see the trend (on a software app or program, on a website, or the like), and choose to share these data with their oral care service providers for better care. Oral care service providers can review these data to monitor their patients in between their regularly scheduled visits. Researchers can utilize these data for oral health study or efficacy evaluation of existing or experimental oral care products or regimens, as well as epidemiology studies in oral care. Insurance companies can reduce their cost by requesting high risk population to take early or preventive treatments.

**[0085]** In some embodiments, the system 1000 or toothbrush 100 may be able to detect how much blood (i.e., quantity) that a user bleeds in a single toothbrushing session. However, this information may not be as helpful as it seems because it may be dependent on when the user brushes a particularly blood-prone region of the oral cavity during the toothbrushing session. Thus, if the user tends to bleed from the gums above the first molar in the upper left quadrant of the mouth, if the user brushes the upper left quadrant of the mouth first during the toothbrushing

session than there would be more blood during the toothbrushing session than if the user brushes the upper left quadrant of the mouth last during the toothbrushing session. That said, obtaining a value for the quantity of blood bled during a toothbrushing session may still have some value to a user or medical professional.

**[0086]** Referring again to FIG. 1, in some embodiments, the toothbrush 100 (or the toothbrush 200) may be configured to track the location in the mouth during a toothbrushing session in addition to tracking blood/hemoglobin in the oral cavity or toothpaste slurry. Thus, the toothbrush 100 may include one or more location tracking sensors (or position sensors) 139 that are configured to track the location of the toothbrush 100, 200 in the oral cavity. In the exemplified embodiment, the tracking sensor 139 is located within the stem 112 of the body 110, but it may be located anywhere so long as it is configured to operate as described herein. The tracking sensor 139 is operably coupled to the processor 131 so that the processor 131 can receive signals detected/generated by the tracking sensor 139 and process those signals to determine where in the mouth the head 120 of the toothbrush 100 is located at a given time during a toothbrushing session. For example, in some embodiments the location sensor 139 could be located in the handle portion 111 of the body 110.

**[0087]** One example of such a toothbrush that is configured to track the location in the oral cavity is described in United States Patent No. 10,349,733, issued on July 16, 2019, the entirety of which is incorporated herein by reference. Thus, the one or more location tracking sensors may be accelerometers, motion sensors, inertial sensors, gyroscopes, magnetometers, and other sensors capable of detecting positions, movement, and acceleration. The location tracking sensors may transmit signals to the processor 131, 231 so that the processor 131, 231 may be configured to determine where in the oral cavity the toothbrush head is located at a given time during the toothbrushing session. The tracking sensor 139 may be a single sensor or it may be multiple sensors, and it may comprise sensors of different types (accelerometers, gyroscopes, proximity sensors, etc.).

**[0088]** Thus, combining this location tracking with the blood tracking, the processor 131, 231 may keep a log of where in the mouth the toothbrush is located when blood is first detected. Because the sensors 133, 233 may take measurements/collect data every second in some embodiments, the sensors 133, 233 will detect blood almost instantaneously. Thus, if the head of the toothbrush 100, 200 is located in the upper right quadrant of the mouth and the gums in that

region start to bleed, the system 1000 will be able to track this information and provide it to the user (such as via the blood detection software application 304 or the like). Specifically, the system 1000 will know where the toothbrush 100, 200 was located at the time that blood was first detected, which is a good indication that the blood is coming from the region of the oral cavity that the toothbrush 100, 200 is located at that time. The system 1000 may be able to track locations of bleeding based on which of four quadrants (upper left, upper right, lower left, lower right) of the oral cavity that the bleeding occurs or it may be able to provide more specific information such as that the gums above the first molar in the upper left quadrant of the mouth are bleeding. Furthermore, it need not be based on four quadrants and could instead simply track whether the blood is coming from the top or bottom of the oral cavity. In still other embodiments, the oral cavity may be divided into more than four quadrants to provide a more precise indication as to where the blood is coming from. In this way, the system 1000 (or toothbrush 100) will be able to track which part of the oral cavity is bleeding and provide that information to the user or to a medical professional. This can be beneficial information for a user to provide to a medical professional or simply for the user to have so that the user can treat that area of the oral cavity as needed.

**[0089]** Thus, the system 1000 (or the toothbrushes 100, 200) may determine that at forty-five seconds into the toothbrushing session, blood was first detected. The system 1000 can then determine where in the mouth/oral cavity the toothbrush 100, 200 (or the head or cleaning elements thereof) was located forty-five seconds into the toothbrushing session. In this way, the system 1000 can determine the location within the oral cavity of the toothbrush 100, 200 at the time that blood was first detected, which is very likely to be the location of the oral cavity that is bleeding. This information can be provided to the user on a graphical display. For example, the display 306 on the portable electronic device 300 may show a visual representation of a set of teeth or an oral cavity, and the display may indicate which region of the oral cavity (such as by highlighting that region or coloring it red or the like) the blood was first detected.

**[0090]** Along these same lines, the system 1000 (or the toothbrush 100, 200 itself) may also be able to determine when there is a second location within the oral cavity that is bleeding. For example, the system 1000 may keep track of the quantity/amount of blood that is in the oral cavity during the toothbrushing session. If at any time there is a significant increase in the amount of blood detected, the system 1000 may determine that there is a second location in the

oral cavity that is bleeding. Thus, for example, if it is detected ten seconds into the toothbrushing session that there is 0.1ml of blood and then at forty-five seconds into the toothbrushing session it is determined that there is 0.3ml of blood, then the system 1000 may understand this to mean that there is a second location that is bleeding. Thus, the system 1000 may determine the location of the head of the toothbrush at the moment that the quantity of blood increased to determine the second bleeding location in the oral cavity.

**[0091]** Operation of the system 1000 will now be briefly described in accordance with a method of detecting blood in a toothpaste slurry during toothbrushing. The method includes having a user brush his or her teeth and gums with the cleaning elements 123 of the toothbrush 100 during a toothbrushing session. During such toothbrushing, if toothpaste has been pre-applied onto the cleaning elements 123, a toothpaste slurry will be formed in the oral cavity during the toothbrushing session. Next, signals containing information related to the presence or absence of hemoglobin in the toothpaste slurry is generated. In accordance with the exemplified embodiment, these signals are generated with a sensor 133 that is coupled to the toothbrush 100. More specifically, the sensor 133 will transmit first light at a first wavelength and second light at a second wavelength into the oral cavity where the toothpaste slurry is located. Portions of the first and second light will then be reflected off of the toothpaste slurry. A receiver 141 of the sensor 133 will receive the reflected portions of the first and second light.

**[0092]** Next, the processor 131, 301 will receive the signals corresponding to the intensities of the reflected portions of the first and second light. The processor 131, 301 will process these signals to determine whether hemoglobin (and therefore blood) is present in the toothpaste slurry. This may be achieved by the processor calculating a ratio of the first intensity of the reflected portion of the first light to the second intensity of the reflected portion of the second light. Using the results of this calculation, the processor 131, 301 can determine whether hemoglobin/blood is present in the toothpaste slurry. In some instances, when the processor 131, 301 determines that hemoglobin is present in the toothpaste slurry, the method may include providing an indication of the presence of blood in the toothpaste slurry to a user. This may involve displaying such an indication on the display 306 of the portable electronic device 300 or activating an indicator 136 located on the toothbrush 100.

**[0093]** The above described system and method is a "reagent" free system and method to measure hemoglobin using only a few wavelengths of light (2-3) in both visible and infrared

regions during tooth brushing. The surfactant Sodium Lauryl Sulfate ("SLS") in most toothpaste compositions serves as the stabilizing agent for hemoglobin, so the method does not require additional reagent specific for hemoglobin detection.

**[0094]** It should be noted that although the description provided herein relates to using the toothbrush 100, 200 and/or system 1000 to detect hemoglobin in order to determine whether there is blood in the oral cavity and/or toothpaste slurry, the invention is not to be so limited in all embodiments. For example, in some embodiments the toothbrush 100, 200 and/or system 1000 may be used to detect Serum albumin, which is also abundant in blood. However, Serum albumin does not have a strong spectral signature. Thus, when the toothbrush 100, 200 and/or system 1000 is used to detect Serum albumin, a dye such as bromocresol green or the like may first be added. The Serum albumin with a dye as noted herein would absorb red light, so the sensor 133, 233 noted herein could be used to detect this Serum albumin/dye in the same manner as noted above in order to determine whether blood is present, although the algorithm would have to be modified so that red light is the denominator in the equations.

Detecting Peaks in Reflectance Ratio

**[0095]** The hardware components discussed above and the reflectance data gathered may be used to detect hemoglobin by alternative means. Three models will be discussed below. The exemplified modeling uses the temporal sequence of the signal, that is, the individual peaks in the reflectance spectra during the entire brushing cycle, instead of the overall mean reflectance of the brushing slurry. This approach overcomes background influence coming from colored food, drinks, or toothpastes more effectively. In these cases, the net baseline reflectance will be higher but the bleeding spots will still show as peaks. Detecting an increase in the mean reflectance ratio of the brushing slurry cannot be used to detect the position of the bleeding spot, and can only detect hemoglobin at a higher concentration that can generate a detectable increase in the mean signal even after getting diluted in the brushing slurry. Further, the methods disclosed herein are reagent-free and cause minimal interference with user habits. This will help in bringing gum bleeding awareness in the users at the right time which will help them take better care of their gums.

**[0096]** In one embodiment (sometimes referred to as "model 1"), the reflectance ratios of red to green (R/G) and infrared to green (IR/G) are plotted versus time, as shown in FIGS. 12A-B and FIGS. 13A-B, respectively. FIGS. 12A-B are plots of the R/G ratio and the IR/G ratio,

respectively, for a typical bleeder over time, while FIGS. 13A-B are plots of the R/G ratio and the IR/G ratio, respectively for a typical non-bleeder. It is observed that for a bleeder these curves (R/G and IR/G v. time) have a significantly higher number of peaks 149 as compared to a non-bleeding subject. These peaks 149 are attributed to the increased reflectance ratios, R/G and IR/G, when the sensor sees hemoglobin (blood) in the case of the bleeding subjects. For non-bleeding subjects, the ratios remain consistently near baseline due to the absence of any blood, and hence the peaks are typically absent. Using the models discussed herein, the bleeders and non-bleeders were able to be grouped confidently with an AUROC of 0.75-0.8 respectively. AUROC is the area under the receiver operating characteristic curve, which is a standard method in data science to determine model robustness.

**[0097]** Tracking peaks according to this method also allows the system to detect the location of individual bleeding sites by equipping the brush with positional sensors to identify the locations of the bleeding spots. For example, a toothbrush may include the tracking sensor discussed above configured to generate location signals related to a location of a head of the toothbrush to determine a location of the head of the toothbrush. In one embodiment, the system could, for each peak, determine the corresponding location of the head at that time, thus identifying specific bleeding spots.

**[0098]** For the data collection described below, 5 bleeding and 6 non-bleeding subjects were used. They fasted overnight and brushed with a toothbrush with optical sensors (such as toothbrush 100, 100A, or 200 discussed above) and Colgate dental cream toothpaste in the morning. The LEDs in the brushes were turned on during brushing and the reflectance data from the toothpaste slurry was collected using the sensors in the brush and streamed directly to a smartphone. The reflectance data was collected at wavelengths 527 nm (green), 660 nm (red), 880 nm (infrared) every second during the brushing cycle which continued for around two minutes (for a total of about 120-130 data points). It is understood that other wavelengths may be used. It is further understood that the frequency with which reflectance data is collected may be altered such that data is collected more or less frequently. For example, more frequent collection of reflectance data could lead to more data points. Further, reflectance data may be collected at different times. For example, rather than collecting reflectance data at a consistent frequency throughout an entire brushing session (e.g., every 1 second), reflectance data may only be collected at an end or beginning of the brushing session, or at some other time during the brushing

session. Further, the frequency of data collection may vary during the course of the brushing session. Also, the data may be stored in the toothbrush and collected later or stored in the toothbrush and streamed to a smartphone simultaneously. In the current example, the data collection was repeated for five days for all the subjects and used for further analysis and modeling.

**[0099]** Returning to Figs. 12A-B and 13A-B, the number of peaks 149 may be calculated. There are various methods for identifying such peaks. In the exemplified embodiment, the "find_peaks" function in the Python programming language was used to find the local maxima, where a predetermined threshold ratio value was set to 8 and a minimum distance between two peaks (a predetermined time value) was set to 5s. But the invention is not so limited. A peak may be understood as any datapoint or datapoints that represents a brief and noteworthy increase in the ratio value over time before the ratio value returns to a baseline range of values. A peak, when seen as part of a waveform, would make the shape of a peak or spike, as shown in the peaks 149 of Figs. 12A-B. In one embodiment, a peak may be understood as a local maxima in the ratio value over time such that the signal at the peak is significantly more than the noise values relative to the baseline (e.g., the peak is 2 or more times the noise values relative to the baseline). Though the invention is not so limited. As indicated above, in the described embodiments, further criteria may be used, such as setting a minimum threshold value (e.g., 8) for peak signals, and setting a minimum time gap (e.g., 5s) between two peaks. In other embodiments, the minimum threshold value and/or the minimum time gap can be omitted. In yet other embodiments, the presence of a peak may be based entirely on the minimum threshold value and/or the minimum time gap. In other embodiments, any other standard method may be employed to calculate the number of peaks. See, for example, Yang, Comparison of Public Peak Detection Algorithms for MALDI Mass Spectrometry Data Analysis, BMC Bioinformatics (published online 2009), which is incorporated herein by reference in its entirety. Peaks may be identified using any programming language, such as C, C++, or Java, or computer math software such as Origin or Matlab.

**[0100]** Further, while the invention is not so limited, the number of peaks (A) may be normalized (A') as follows:

$$A' = A/Q*100$$

**[0101]** A' is the normalized number of peaks, A in the number of peaks, and Q is the total number of data points included in the analysis after the quality check. In this example, the R or IR

signal greater than or equal to 6000 was used, though this value may be altered. For each panelist, an average A' for IR/G curves and R/G curves over five brushing cycles was calculated.

**[0102]** FIG. 14 is a plot of the average number of normalized peaks for each panelist using the R/G ratio, and FIG. 15 is a plot of the average number of normalized peaks for each panelist using the IR/G ratio. For each of FIG. 14 and FIG. 15, if a line was drawn parallel on the x-axis at y = 4, the system would predict 4 bleeders (P2, P4, P10 and P11) correctly as they have normalized number of peaks above the threshold value. The system would also predict 5 non-bleeders (P3, P5, P6, P8 and P9) correctly as non-bleeders. There is one false positive of P7 (non-bleeder but predicted as a bleeder) and one false negative P1 (bleeder but predicted as non-bleeder).

**[0103]** For all the models discussed herein, the sensitivity and specificity were calculated using the following formula:

$$\text{Sensitivity}=TP/(TP+FN)$$

$$\text{Specificity}=TN/(TN+FP)$$

**[0104]** where, TP is the number of true positives, FN is the number of false negatives, TN is the number of true negatives, and FP is the number of false positives as predicted by the model.

**[0105]** The sensitivity and specificity of this model are 0.8 and 0.83, respectively, for both R/G and IR/G. The AUROC are 0.75 and 0.77 for R/G and IR/G, respectively. It is noted that in other embodiments, other predetermined numbers (other than 4) may be used as a reference to determine whether or not the number of spikes is indicative of bleeding.

**[0106]** Since the grouping for bleeders and non-bleeders is done based on the number of peaks and not the overall mean signal, it is possible to avoid background interference due to external factors like residual colored food or drinks like red wine or colored toothpaste, etc. In case of the presence of such external interferences, the mean signal or baseline will go up, but bleeding spots would still be identifiable by monitoring the spikes or peaks.

**[0107]** It is noted that, in another embodiment, the system could consider both the R/G number of peaks and the IR/G number of peaks to determine whether blood is present. For example, blood would not be considered present unless both ratios satisfied a minimum number of peaks (which may be the same or different for each ratio).

Determining Vector Length of Datapoints Outside Predetermined Boundaries

**[0108]** In alternative embodiments, the determination of whether hemoglobin is present can be based on comparing ratios and determining characteristics (such as mathematical characteristics) of data points inside or outside predetermined boundaries. Two such embodiments are discussed below, which are sometimes referred to as model 2 (vector length) and model 3 (spread of cluster).

**[0109]** FIG. 16A is a plot of the R/G ratio v. the IR/G ratio for a bleeder for one brushing session. FIG. 16B is a plot of the R/G ratio versus the IR/G ratio for a non-bleeder for one brushing session. In the exemplified embodiments, a box 148 for each of these plots is created with the following four corners: [0,0], [8,0], [8,8] and [0,8]. This box 148 defines a predetermined boundary having a predetermined area. Any data point inside this box 148 is considered as part of the cluster and any data point outside of the box is considered an outlier. While in this embodiment, the predetermined boundaries form a 2-dimensional box, in other embodiments the predetermined boundaries may be defined simply by 2 points, such as a minimum and a maximum, which will be described in more detail below. In other embodiments, the box (the predetermined area) may have a different size or location. Further, the predetermined area may have a different shape. For example, the box may instead be a circle, an oval, or a diamond.

**[0110]** Returning to FIGS. 16A-B, the x and y coordinates of the center of the cluster are located as follows:

$$Cx = \text{sum of IR/G values of all points in box/ } M$$
$$Cy = \text{sum of R/G values of all points in the box/}M$$

**[0111]** where M is the number of points within the box after the quality check. In this embodiment, the ratio R/G was plotted against IR/G for each brushing cycle for all the participants.

**[0112]** Returning to FIGS. 16A and 16B, it can be seen that for a bleeder (FIG. 16A), the cluster is much more dispersed than a non-bleeder (FIG. 16B) where the data is clustered more tightly. This is due in part to the large number of peaks in the reflectance data for the bleeder (see above), as compared to non-bleeders where the ratios are relatively constant with time.

**[0113]** As quality checks, a minimal reflectance signal value, e.g., 6000 in this case, was set for the R and IR channels for all the models. In cases where all three wavelengths for R, G and IR were used for analysis, an additional quality check was included; the upper and lower limits of the

IR/R ratio were set to be 1.2 and 0.8, respectively. Thus, any point where the overall R and IR signals were less than 6000 (quality check for signal) were eliminated. Further, in the cases where analysis was done using all three wavelengths (e.g., in models 2 and 3), any point where the IR/R ratio was less than 0.8 or greater than 1.2 (quality check for red color) was eliminated. The invention, however, is not limited to a particular type of quality check.

**[0114]** In the exemplified embodiment for model 2 (vector length), the system calculates a representative vector length indicating the sum of the distance of the points outside the box from the center of the cluster (Cx, Cy). For a given outlier point P, the x and y distance from the center of the cluster was calculated as follows:

$$Px = (IR/G \text{ value of } P) - Cx$$
$$Py = (R/G \text{ value of } P) - Cy$$

**[0115]** The representative vector length V of the outliers were calculated using two methods as follows:

*Method 1*

$$V = \text{sqrt}\left[ \left( \sum Px \right)^2 + \left( \sum Py \right)^2 \right]$$

*Method 2*

$$Vmod = \sum \left[ \text{sqrt}\left( Px^2 + Py^2 \right) \right]$$

**[0116]** Further, the vector length was normalized with respect to the number of data points used for analysis as follows:

$$V' = (V*100)/N$$
$$Vmod' = (Vmod*100)/N$$

**[0117]** where N is the total number of points included in the analysis after the quality check. In this exemplified embodiment, for each panelist the average V' and Vmod' over five brushing cycles was calculated.

**[0118]** The sum of the vector length of the datapoints outside the box from the center of the cluster was calculated by the two methods. The average normalized vector length was calculated for each panelist over five brushing cycles. FIG. 17 is a plot of the average normalized vector lengths using the R, G and IR channels for datapoints outside the predetermined boundary box for each of the 11 participants. Using either method 1 or method 2, the results are very similar. FIG. 17 shows that, if 20 was used as a threshold value for bleeding, the system identifies four bleeders (P2, P4, P10 and P11) correctly as bleeders, and identifies five non-bleeders (P3, P5, P6, P8 and

P9) correctly as non bleeders. There is one false positive in P7 (non-bleeder predicted as a bleeder) and one false negative in P1 (bleeder predicted as a non-bleeder). Sensitivity and specificity of the model is 0.8 and 0.83 respectively. The AUROC is 0.75 indicating a robust model. This model performs similar to model 1 in terms of sensitivity and specificity.

**[0119]** In alternative embodiments, only two channels may be used at a time, for example, only the R/G ratio or the IR/G ratio, and not both together. In this case, rather than using a box 148 as in FIGS. 16A and 16B to define the predetermined boundaries of the cluster, two points or values are used for the predetermined boundary, a minimum and a maximum. According to a method 3, only IR and G channels are used. The following equation is utilized:

*Method 3*

$$Px = (IR/G \text{ value of } P) - Cx$$

**[0120]** where, Cx is the mean of the IR/G data for the points with IR/G values less than 8 after the quality check (as with the box above, in other embodiments, boundary values 0 and 8 may be replaced with other values). In this embodiment, the representative vector length Vir/g is calculated as follows:

$$Vir/g = \sum Px$$

**[0121]** The vector length is normalized as follows:

$$Vir/g' = (Vir/g*100)/Nx$$

**[0122]** where Nx is the total number of points included in the analysis after the quality check. FIG. 18 is a plot of the normalized vector lengths for each of the 11 participants averaged over 5 brushing cycles for the model using only IR and G channels.

**[0123]** According to a method 4, only R and G channels are used. The following equation is utilized:

*Method 4*

$$Py = (R/G \text{ value of } P) - Cy$$

**[0124]** where Cy is the mean of the R/G data for the points with R/G values less than 8 after the quality check. The representative vector length of the outliers is calculated as follows:

$$Vr/g = \sum Py$$

**[0125]** The vector length is normalized as follows:

$$Vr/g' = (Vr/g*100)/Ny$$

**[0126]** where Ny is the total number of points included in the analysis after the quality check. FIG. 19 is a plot of normalized vector lengths for each of the 11 participants averaged over five brushing cycles for the model using only R and G channels. The sensitivity, specificity, and AUROC of using these 2-channel methods are 0.8, 0.83 and 0.74-0.75, respectively. As can be observed from the figures, the 2-channel methods had similar results to the three-channel methods.

Determining Spread of Datapoints Inside Predetermined Boundaries

**[0127]** In the third model, hemoglobin is detected based on the spread of the data points inside the box defined by coordinates [0,0], [8,0], [8,8] and [0,8] (see above). In other embodiments, the box (the predetermined area) may have a different size or location. The spread of the points in the box is sometimes referred to herein as the "cluster spread". In the exemplified embodiment, the cluster spread is calculated as follows. Using the center of the cluster (as determined above), the distance from the center of the cluster may be determined as follows:

Dx = Absolute value (IR/G value of a given point - Cx)
Dy = Absolute value (R/G value of a given point - Cy)

**[0128]** The spread (S) may be determined, for example, by one of the following two methods:

*Method 1*

$$Ex = \sum Dx / M$$
$$Ey = \sum Dy / M$$
$$S = \text{sqrt}\ (Ex^2 + Ey^2)$$

*Method 2*

$$Smod = [\sum [\text{sqrt}\ (Dx^2 + Dy^2)]] / M$$

**[0129]** where M is the number of points within the box after the quality check. The spread may be normalized with respect to the number of data points used for analysis as follows:

$$S' = (S*100)/N$$
$$Smod' = (Smod*100)/N$$

**[0130]** where N is the total number of points after the quality checks. For each panelist, the average normalized spread over five brushing cycles was calculated.

**[0131]** FIGS. 20A and 20B are plots of the average normalized spread of the datapoints in the box for each panelist over five brushing cycles according to the first and second methods,

respectively. If a spread threshold of 0.37 is used for method 1 (FIG. 20A) and a spread threshold of 0.4 is used for method 2 (FIG. 20B), then the system can effectively identify all the bleeders P1, P2, P4, P10 and P11 correctly. It can also identify P3, P5, P6, P8 and P9 correctly as non-bleeders. There is one false positive, P7, using this model. For this method, the sensitivity and specificity are 1 and 0.83, respectively. The AUROC is 0.8 indicating a robust model.

**[0132]** In alternative embodiments, only two channels may be used at a time, for example, only the R/G ratio or the IR/G ratio, and not both together. According to a method 3, only IR and G channels are used. The following equation is utilized:

*Method 3*

$$Dx = \text{Absolute value (IR/G value of a given point - Cx)}$$

$$Sir/g = \sum Dx/\ Mx$$

**[0133]** where, Cx is the mean of the IR/G data for the points with IR/G values less than 8 after quality check, and Mx is the number of points after the quality check whose IR/G values are less than 8.

**[0134]** The spread is normalized as follows:

$$Sir/g' = (Sir/g*100)/Nx$$

**[0135]** where Nx is the number of points after the quality check. FIG. 21 is a plot of normalized cluster spreads for 11 participants averaged over five brushing cycles for the model using only IR and G channels.

**[0136]** According to a method 4, only R and G channels are used. The following equation is utilized:

*Method 4 (Using only R and G channels)*

$$Dy = \text{Absolute value (R/G value of a given point - Cy)}$$

$$Sr/g = \sum Dy/\ My$$

**[0137]** where, Cy is the mean of the R/G data for the points with R/G values less than 8 after quality check, and My is the number of points after the quality check whose R/G values are less than 8.

**[0138]** The spread is normalized as follows:

$$Sr/g' = (Sr/g*100)/Ny$$

**[0139]** where Ny is the number of points after the quality check. FIG. 22 is a plot of normalized cluster spreads for 11 participants averaged over five brushing cycles for the model using only R

and G channels. The sensitivity, specificity, and AUROC of using these two methods are 1, 0.67 and 0.77-0.78 respectively using both the methods. The specificity and AUROC is slightly lower than if we use three channels for the analysis as shown above, but sensitivity is generally more crucial and having a lower specificity (larger number of false positives) is less concerning.

**[0140]** It is noted that the bleeding data determined and collected (by any of the means discussed herein) may be used to determine cumulative bleeding data. This cumulative bleeding data may be any representation of bleeding data for one or more prior brushing sessions, such as an indication of a percentage of previous brushing sessions where bleeding was detected (and/or where bleeding was detected in a certain location). The data may be displayed (and/or determined) through a separate electronic device, such as a smartphone or computer in communication with the toothbrush (as discussed above). In other embodiments, cumulative data is displayed (and/or determined) by the toothbrush itself.

**[0141]** In one example where cumulative data is displayed by the toothbrush itself, the toothbrush has an LED. The LED blinks rapidly for 2 seconds to indicate the result of a single brushing session, where blinking green represents no bleeding, and blinking red represents bleeding detected. Then the LED is steady for 2 seconds to present the cumulative results of previous brushing sessions, where steady green represents that less than 10% of the previous sessions had bleeding, steady yellowish green represents that 10-50% of the previous sessions had bleeding, and steady red represents that more than 50% of the previous sessions had bleeding. In this embodiment, the brush requires at least 5 valid brushing sessions before the brush will show cumulative results using steady on LED. The brush will save raw data from the last 28 brushing sessions in its memory (using a round-robin format) to compute the cumulative results. Further, if a user wants to review his or her cumulative results, the user may press the button twice rapidly. In response, the LED will be on steady for 2 seconds to show the results the results using the color scheme described above. Of course, the embodiment described is just one of a variety ways of determining and/or displaying cumulative brushing data. For example, different LEDs, colors, timing schemes, percentages, number of brushing sessions, and button-pressing schemes may be utilized or omitted. The invention is not limited to any particular embodiment.

**[0142]** It is further noted that, while in the above embodiments, certain steps for equations for normalization and other calculations are used. Such steps are not required, and the specific equations provided are simply non-limiting examples.

**[0143]** While the invention(s) have been described with respect to specific examples including presently preferred modes of carrying out the invention, those skilled in the art will appreciate that there are numerous variations and permutations of the above described systems and techniques. It is to be understood that other embodiments may be utilized and structural and functional modifications may be made without departing from the scope of the present invention. Thus, the spirit and scope of the invention should be construed broadly as set forth in the appended claims.

Exemplary Claims

**[0144]** The following are exemplary claims the above invention(s):

**[0145]** 1. A system for detecting blood in an oral cavity during toothbrushing, the system comprising: a toothbrush comprising a sensor configured to: emit first light at a first wavelength and second light at a second wavelength; receive reflected portions of the first light and the second light; and for each of a plurality of different times, generate a first signal indicative of a first intensity of the reflected portion of the first light and a second signal indicative of a second intensity of the reflected portion of the second light; and a processor operably coupled to the sensor and configured to: for each of the plurality of different times, receive the first signal and the second signal, and calculate a ratio of the first intensity to the second intensity; identify peaks in the ratio over the different times; and determine whether hemoglobin is present in the oral cavity based on a number of peaks in the ratio over the different times.

**[0146]** 2. The system of claim 1 wherein the plurality of different times are separated by a predetermined period of time.

**[0147]** 3. The system of any of the preceding claims wherein the determination whether hemoglobin is present is based on the number of peaks during a brushing meeting or exceeding a predetermined non-zero number.

**[0148]** 4. The system of any of the preceding claims wherein each of the peaks has a peak ratio value that meets or exceeds a predetermined threshold value.

**[0149]** 5. The system of any of the preceding claims wherein each of the peaks is separated from each of the other peaks by a predetermined time value.

**[0150]** 6. The system of any of the preceding claims wherein the processor is configured to calculate an amount of blood detected in the oral cavity during a toothbrushing session based on the number of peaks.

**[0151]** 7. The system of any of the preceding claims wherein the toothbrush further comprises a tracking sensor configured to generate location signals related to a location of a head of the toothbrush within the oral cavity during toothbrushing, and wherein the processor is operably coupled to the tracking sensor and configured to receive the location signals to determine a location of the head of the toothbrush within the oral cavity when each peak is detected.

**[0152]** 8. The system of any of the preceding claims: wherein the sensor is further configured to emit third light at a third wavelength, receive reflected portions of the third light, and generate a third signal indicative of a third intensity of the reflected portion of the third light; and wherein the processor is further configured to: at the plurality of different times, receive the third signal, and calculate a second ratio of the third intensity to the second intensity; and identify peaks in the second ratio over the different times; wherein the determination whether hemoglobin is present is based further on the number of peaks in the second ratio over the different times.

**[0153]** 9. The system of the preceding claim wherein the first light is red light, the second light is green light, and the third light is infrared light.

**[0154]** 10. The system of any of the preceding claims further comprising an indicator configured to provide an indication to a user that blood is present in the oral cavity.

**[0155]** 11. The system of any of the preceding claims wherein the toothbrush comprises the processor.

**[0156]** 12. The system of the preceding claim wherein the toothbrush further comprises an indicator configured to provide an indication to a user that blood is present in the oral cavity.

**[0157]** 13. The system of any of the preceding claims further comprising a portable electronic device that comprises the processor.

**[0158]** 14. The system of the preceding claim further comprising a software application stored on the portable electronic device, wherein the software application is configured to cause a display screen of the portable electronic device to provide an indicator to a user that blood is present in the oral cavity.

**[0159]** 15. The system of the preceding claim wherein the software application is configured to store information related to detection of blood in the oral cavity for each of a plurality of distinct

toothbrushing sessions, and wherein the information is displayed on the display screen of the portable electronic device.

**[0160]** 16. The system of any of the preceding claims wherein the toothbrush further comprises: a handle; a head coupled to the handle, wherein the sensor is located in the head; and a plurality of cleaning elements extending from the head in a cleaning element field, the cleaning element field having an opening that forms an optical path for the first and second light to be emitted from and received by the sensor.

**[0161]** 17. The system of any of the preceding claims wherein the toothbrush comprises: a body comprising a handle portion and a stem extending from the handle portion, the sensor being located in the stem; and a refill head comprising a sleeve portion that fits over the stem to couple the refill head to the body, a head portion that is aligned with the sensor in the stem, and a plurality of cleaning elements extending from the head portion.

**[0162]** 18. A method for detecting blood in an oral cavity during toothbrushing, the method comprising: during a toothbrushing session in which a toothbrush brushes an oral cavity: emitting into the oral cavity, via a sensor of the toothbrush, first light at a first wavelength and second light at a second wavelength; receiving, via the sensor of the toothbrush, reflected portions of the first light and the second light; and for each of a plurality of different times during the brushing session, transmitting, from the sensor to a processor, a first signal indicative of a first intensity of the reflected portion of the first light and a second signal indicative of a second intensity of the reflected portion of the second light; for each of the plurality of different times, calculating, via the processor, a ratio of the first intensity to the second intensity; identifying, via the processor, peaks in the ratio over the different times; and determining, via the processor, whether hemoglobin is present in the oral cavity based on a number of peaks in the ratio over the different times.

**[0163]** 19. The method of claim 18 wherein the plurality of different times are separated by a predetermined period of time.

**[0164]** 20. The method of any of claims 18-19 wherein the determination whether hemoglobin is present is based on the number of peaks during a brushing meeting or exceeding a predetermined non-zero number.

**[0165]** 21. The method of any of claims 18-20 wherein each of the peaks has a peak ratio value that meets or exceeds a predetermined threshold value.

**[0166]** 22. The method of any of claims 18-21 wherein each of the peaks is separated from each of the other peaks by a predetermined time value.

**[0167]** 23. The method of any of claims 18-22 further comprising the processor calculating an amount of blood detected in the oral cavity during a toothbrushing session based on the number of peaks.

**[0168]** 24. The method of any of claims 18-23 further comprising: a tracking sensor of the toothbrush generating location signals related to a location of a head of the toothbrush within the oral cavity during toothbrushing; and the processor receiving the location signals to determine a location of the head of the toothbrush within the oral cavity when each peak is detected.

**[0169]** 25. The method of any of claims 18-24 further comprising: the sensor emitting third light at a third wavelength, receiving reflected portions of the third light, and generating a third signal indicative of a third intensity of the reflected portion of the third light; and the processor, at the plurality of different times, receiving the third signal, and calculating a second ratio of the third intensity to the second intensity; and the processor identifying peaks in the second ratio over the different times; wherein the determination whether hemoglobin is present is based further on the number of peaks in the second ratio over the different times.

**[0170]** 26. The method of the preceding claim wherein the first light is red light, the second light is green light, and the third light is infrared light.

**[0171]** 27. The method of any of claims 18-26 further comprising an indicator providing an indication to a user that blood is present in the oral cavity.

**[0172]** 28. The method of any of claims 18-27 wherein the toothbrush comprises the processor.

**[0173]** 29. The method of the preceding claim wherein the toothbrush further comprises an indicator providing an indication to a user that blood is present in the oral cavity.

**[0174]** 30. The method of any of claims 18-29 wherein the processor forms part of a portable electronic device.

**[0175]** 31. The method of the preceding claim further comprising a software application stored on the portable electronic device causing a display screen of the portable electronic device to provide an indicator to a user that blood is present in the oral cavity.

**[0176]** 32. The method of the preceding claim further comprising the software application storing information related to detection of blood in the oral cavity for each of a plurality of distinct

toothbrushing sessions, and displaying the information on the display screen of the portable electronic device.

**[0177]** 33. The method of claims 18-32 wherein the toothbrush further comprises: a handle; a head coupled to the handle, wherein the sensor is located in the head; and a plurality of cleaning elements extending from the head in a cleaning element field, the cleaning element field having an opening that forms an optical path for the first and second light to be emitted from and received by the sensor.

**[0178]** 34. The method of claims 18-33 wherein the toothbrush comprises: a body comprising a handle portion and a stem extending from the handle portion, the sensor being located in the stem; and a refill head comprising a sleeve portion that fits over the stem to couple the refill head to the body, a head portion that is aligned with the sensor in the stem, and a plurality of cleaning elements extending from the head portion.

**[0179]** 35. A system for detecting blood in an oral cavity during toothbrushing, the system comprising: a toothbrush comprising a sensor configured to: emit first light at a first wavelength, and emit a second light at a second wavelength; receive reflected portions of the first light and the second light; and generate a first signal indicative of a first intensity of the reflected portion of the first light, and generate a second signal indicative of a second intensity of the reflected portion of the second light; and a processor operably coupled to the sensor and configured to: for a plurality of different times: receive the first signal and the second signal; and calculate a ratio of the first intensity to the second intensity; wherein the ratios for the different times form data points; identify which of the data points are inside predetermined boundaries and which of the data points are outside the predetermined boundaries; and determine whether hemoglobin is present in the oral cavity based on a characteristic of the data points inside the predetermined boundaries or the data points outside the predetermined boundaries.

**[0180]** 36. The system of claim 35 wherein the predetermined boundaries are formed by a minimum value and a maximum value.

**[0181]** 37. The system of any of claims 35-36: wherein the sensor is further configured to emit a third light at a third wavelength, receive reflected portions of the third light, and generate a third signal indicative of a third intensity of the reflected portion of the third light; wherein the processor is further configured to, for the plurality of different times, receive the third signal, and calculate a second ratio of the third intensity to the second intensity; wherein each of the data

points comprises the ratio as a first coordinate and the second ratio as a second coordinate; and wherein the predetermined boundaries form a predetermined area that each of the data points is inside or outside.

**[0182]** 38. The system of any of claims 35-37: wherein the characteristic upon which the determination whether hemoglobin is present is vector lengths for each of the data points outside the predetermined boundaries; and wherein the vector lengths are measured from a center of the data points inside the predetermined boundaries to the data points outside the predetermined boundaries.

**[0183]** 39. The system of the preceding claim wherein the characteristic upon which the determination whether hemoglobin is present is either whether a sum of vector lengths exceeds a predetermined number; or whether an average of the vector lengths exceeds a predetermined number.

**[0184]** 40. The system of any of claims 35-39 wherein the characteristic upon which the determination whether hemoglobin is present is a spread of the data points inside the predetermined boundaries.

**[0185]** 41. The system of the preceding claim wherein the spread is based on, for each of the data points within the predetermined boundaries, a distance between the data point and a center of the data points inside the predetermined boundaries.

**[0186]** 42. The system of any of claims 35-41 wherein the processor is configured to calculate an amount of blood detected in the oral cavity during a toothbrushing session based on the characteristic of the data points inside or outside the predetermined boundaries.

**[0187]** 43. The system of any of claims 35-42 wherein the toothbrush further comprises a tracking sensor configured to generate location signals related to a location of a head of the toothbrush within the oral cavity during toothbrushing, and wherein the processor is operably coupled to the tracking sensor and configured to receive the location signals to determine a location of the head when the determination that hemoglobin is present occurs.

**[0188]** 44. The system of any of claims 35-43 further comprising an indicator configured to provide an indication to a user that blood is present in the oral cavity.

**[0189]** 45. The system of any of claims 35-44 wherein the toothbrush comprises the processor.

**[0190]** 46. The system of the preceding claim wherein the toothbrush further comprises an indicator configured to provide an indication to a user that blood is present in the oral cavity.

**[0191]** 47. The system of any of claims 35-46 further comprising a portable electronic device that comprises the processor.

**[0192]** 48. The system of the preceding claim further comprising a software application stored on the portable electronic device, wherein the software application is configured to cause a display screen of the portable electronic device to provide an indicator to a user that blood is present in the oral cavity.

**[0193]** 49. The system of the preceding claim wherein the software application is configured to store information related to detection of blood in the oral cavity for each of a plurality of distinct toothbrushing sessions, and wherein the information is displayed on the display screen of the portable electronic device.

**[0194]** 50. The system of any of claims 35-49 wherein the toothbrush further comprises: a handle; a head coupled to the handle, wherein the sensor is located in the head; and a plurality of cleaning elements extending from the head in a cleaning element field, the cleaning element field having an opening that forms an optical path for the first and second light to be emitted from and received by the sensor.

**[0195]** 51. The system of any of claims 35-50 wherein the toothbrush comprises: a body comprising a handle portion and a stem extending from the handle portion, the sensor being located in the stem; and a refill head comprising a sleeve portion that fits over the stem to couple the refill head to the body, a head portion that is aligned with the sensor in the stem, and a plurality of cleaning elements extending from the head portion.

**[0196]** 52. A method for detecting blood in an oral cavity during toothbrushing, the system comprising: during a toothbrushing session in which a toothbrush brushes an oral cavity: emitting into the oral cavity, via a sensor of the toothbrush, first light at a first wavelength and second light at a second wavelength; receiving, via the sensor of the toothbrush, reflected portions of the first light and the second light; and for a plurality of different times during the brushing session, transmitting, from the sensor to a processor, a first signal indicative of a first intensity of the reflected portion of the first light and a second signal indicative of a second intensity of the reflected portion of the second light; for each of the plurality of different times, calculating, via the processor, a ratio of the first intensity to the second intensity, wherein the ratios for the different times form data points; identifying, via the processor, which of the data points are inside predetermined boundaries and which of the data points are outside the predetermined boundaries;

and determining, via the processor, whether hemoglobin is present in the oral cavity based on a characteristic of the data points inside the predetermined boundaries or the data points outside the predetermined boundaries.

**[0197]** 53. The method of claim 52 wherein the predetermined boundaries are formed by a minimum value and a maximum value.

**[0198]** 54. The method of any of claims 52-53 further comprising: the sensor emitting a third light at a third wavelength, receiving reflected portions of the third light, and generating a third signal indicative of a third intensity of the reflected portion of the third light; and the processor, for the plurality of different times, receiving the third signal, and calculating a second ratio of the third intensity to the second intensity; wherein each of the data points comprises the ratio as a first coordinate and the second ratio as a second coordinate; and wherein the predetermined boundaries form a predetermined area that each of the data points is inside or outside.

**[0199]** 55. The method of any of claims 52-54: wherein the characteristic upon which the determination whether hemoglobin is present is vector lengths for each of the data points outside the predetermined boundaries; and wherein the vector lengths are measured from a center of the data points inside the predetermined boundaries to the data points outside the predetermined boundaries.

**[0200]** 56. The method of the preceding claim wherein the characteristic upon which the determination whether hemoglobin is present is either whether a sum of vector lengths exceeds a predetermined number, or whether an average of the vector lengths exceeds a predetermined number.

**[0201]** 57. The method of any of claims 52-56 wherein the characteristic upon which the determination whether hemoglobin is present is a spread of the data points inside the predetermined boundaries.

**[0202]** 58. The method of the preceding claim wherein the spread is based on, for each of the data points within the predetermined boundaries, a distance between the data point and a center of the data points inside the predetermined boundaries.

**[0203]** 59. The method of any of claims 52-58 further comprising the processor calculating an amount of blood detected in the oral cavity during a toothbrushing session based on the characteristic of the data points inside or outside the predetermined boundaries.

**[0204]** 60. The method of any of claims 52-59 wherein the toothbrush further comprises a tracking sensor, the tracking sensor generating location signals related to a location of a head of the toothbrush within the oral cavity during toothbrushing, and the processor receiving the location signals to determine a location of the head when the determination that hemoglobin is present occurs.

**[0205]** 61. The method of any of claims 52-60 further comprising an indicator providing an indication to a user that blood is present in the oral cavity.

**[0206]** 62. The method of any of claims 52-61 wherein the toothbrush comprises the processor.

**[0207]** 63. The method of the preceding claim wherein the toothbrush further comprises an indicator providing an indication to a user that blood is present in the oral cavity.

**[0208]** 64. The method of any of claims 52-63 wherein the processor forms part of a portable electronic device.

**[0209]** 65. The method of the preceding claim further comprising a software application stored on the portable electronic device causing a display screen of the portable electronic device to provide an indicator to a user that blood is present in the oral cavity.

**[0210]** 66. The method of the preceding claim further comprising the software application storing information related to detection of blood in the oral cavity for each of a plurality of distinct toothbrushing sessions, and displaying the information on the display screen of the portable electronic device.

**[0211]** 67. The method of claims 52-66 wherein the toothbrush further comprises: a handle; a head coupled to the handle, wherein the sensor is located in the head; and a plurality of cleaning elements extending from the head in a cleaning element field, the cleaning element field having an opening that forms an optical path for the first and second light to be emitted from and received by the sensor.

**[0212]** 68. The method of claims 52-67 wherein the toothbrush comprises: a body comprising a handle portion and a stem extending from the handle portion, the sensor being located in the stem; and a refill head comprising a sleeve portion that fits over the stem to couple the refill head to the body, a head portion that is aligned with the sensor in the stem, and a plurality of cleaning elements extending from the head portion.

# CLAIMS

WHAT IS CLAIMED IS:

1. A system for detecting blood in an oral cavity during toothbrushing, the system comprising:

a toothbrush comprising a sensor configured to:

emit first light at a first wavelength and second light at a second wavelength;

receive reflected portions of the first light and the second light; and

for each of a plurality of different times, generate a first signal indicative of a first intensity of the reflected portion of the first light and a second signal indicative of a second intensity of the reflected portion of the second light; and

a processor operably coupled to the sensor and configured to:

for each of the plurality of different times, receive the first signal and the second signal, and calculate a ratio of the first intensity to the second intensity;

identify peaks in the ratio over the different times; and

determine whether hemoglobin is present in the oral cavity based on a number of peaks in the ratio over the different times.

2. The system of claim 1 wherein the plurality of different times are separated by a predetermined period of time.

3. The system of any of the preceding claims wherein the determination whether hemoglobin is present is based on the number of peaks during a brushing meeting or exceeding a predetermined non-zero number.

4. The system of any of the preceding claims wherein each of the peaks has a peak ratio value that meets or exceeds a predetermined threshold value.

5. The system of any of the preceding claims wherein each of the peaks is separated from each of the other peaks by a predetermined time value.

6. The system of any of the preceding claims wherein the processor is configured to calculate an amount of blood detected in the oral cavity during a toothbrushing session based on the number of peaks.

7. The system of any of the preceding claims wherein the toothbrush further comprises a tracking sensor configured to generate location signals related to a location of a head of the toothbrush within the oral cavity during toothbrushing, and wherein the processor is operably coupled to the tracking sensor and configured to receive the location signals to determine a location of the head of the toothbrush within the oral cavity when each peak is detected.

8. The system of any of the preceding claims:

wherein the sensor is further configured to emit third light at a third wavelength, receive reflected portions of the third light, and generate a third signal indicative of a third intensity of the reflected portion of the third light; and

wherein the processor is further configured to:

at the plurality of different times, receive the third signal, and calculate a second ratio of the third intensity to the second intensity; and

identify peaks in the second ratio over the different times;

wherein the determination whether hemoglobin is present is based further on the number of peaks in the second ratio over the different times.

9. The system of the preceding claim wherein the first light is red light, the second light is green light, and the third light is infrared light.

10. The system of any of the preceding claims further comprising an indicator configured to provide an indication to a user that blood is present in the oral cavity.

11. A method for detecting blood in an oral cavity during toothbrushing, the method comprising:

during a toothbrushing session in which a toothbrush brushes an oral cavity:

emitting into the oral cavity, via a sensor of the toothbrush, first light at a first wavelength and second light at a second wavelength;

receiving, via the sensor of the toothbrush, reflected portions of the first light and the second light; and

for each of a plurality of different times during the brushing session, transmitting, from the sensor to a processor, a first signal indicative of a first intensity of the reflected portion of the first light and a second signal indicative of a second intensity of the reflected portion of the second light;

for each of the plurality of different times, calculating, via the processor, a ratio of the first intensity to the second intensity;

identifying, via the processor, peaks in the ratio over the different times; and

determining, via the processor, whether hemoglobin is present in the oral cavity based on a number of peaks in the ratio over the different times.

12. The method of claim 11 wherein the plurality of different times are separated by a predetermined period of time.

13. The method of any of claims 11-12 wherein the determination whether hemoglobin is present is based on the number of peaks during a brushing meeting or exceeding a predetermined non-zero number.

14. The method of any of claims 11-13 wherein each of the peaks has a peak ratio value that meets or exceeds a predetermined threshold value.

15. The method of any of claims 11-14 wherein each of the peaks is separated from each of the other peaks by a predetermined time value.

16. The method of any of claims 11-15 further comprising the processor calculating an amount of blood detected in the oral cavity during a toothbrushing session based on the number of peaks.

17. A system for detecting blood in an oral cavity during toothbrushing, the system comprising:

a toothbrush comprising a sensor configured to:

emit first light at a first wavelength, and emit a second light at a second wavelength;

receive reflected portions of the first light and the second light; and

generate a first signal indicative of a first intensity of the reflected portion of the first light, and generate a second signal indicative of a second intensity of the reflected portion of the second light; and

a processor operably coupled to the sensor and configured to:

for a plurality of different times:

receive the first signal and the second signal; and

calculate a ratio of the first intensity to the second intensity;

wherein the ratios for the different times form data points;

identify which of the data points are inside predetermined boundaries and which of the data points are outside the predetermined boundaries; and

determine whether hemoglobin is present in the oral cavity based on a characteristic of the data points inside the predetermined boundaries or the data points outside the predetermined boundaries.

18. The system of claim 17 wherein the predetermined boundaries are formed by a minimum value and a maximum value.

19. The system of any of claims 17-18:

wherein the sensor is further configured to emit a third light at a third wavelength, receive reflected portions of the third light, and generate a third signal indicative of a third intensity of the reflected portion of the third light;

wherein the processor is further configured to, for the plurality of different times, receive the third signal, and calculate a second ratio of the third intensity to the second intensity;

wherein each of the data points comprises the ratio as a first coordinate and the second ratio as a second coordinate; and

wherein the predetermined boundaries form a predetermined area that each of the data points is inside or outside.

20. The system of any of claims 17-19:

wherein the characteristic upon which the determination whether hemoglobin is present is vector lengths for each of the data points outside the predetermined boundaries; and

wherein the vector lengths are measured from a center of the data points inside the predetermined boundaries to the data points outside the predetermined boundaries.

21. The system of the preceding claim wherein the characteristic upon which the determination whether hemoglobin is present is either whether a sum of vector lengths exceeds a predetermined number; or whether an average of the vector lengths exceeds a predetermined number.

22. The system of any of claims 17-21 wherein the characteristic upon which the determination whether hemoglobin is present is a spread of the data points inside the predetermined boundaries.

23. The system of the preceding claim wherein the spread is based on, for each of the data points within the predetermined boundaries, a distance between the data point and a center of the data points inside the predetermined boundaries.

24. The system of any of claims 17-23 wherein the processor is configured to calculate an amount of blood detected in the oral cavity during a toothbrushing session based on the characteristic of the data points inside or outside the predetermined boundaries.

25. The system of any of claims 17-24 wherein the toothbrush further comprises a tracking sensor configured to generate location signals related to a location of a head of the toothbrush within the oral cavity during toothbrushing, and wherein the processor is operably coupled to the tracking sensor and configured to receive the location signals to determine a location of the head when the determination that hemoglobin is present occurs.

26. The system of any of claims 17-25 further comprising an indicator configured to provide an indication to a user that blood is present in the oral cavity.

27. A method for detecting blood in an oral cavity during toothbrushing, the system comprising:

during a toothbrushing session in which a toothbrush brushes an oral cavity:

emitting into the oral cavity, via a sensor of the toothbrush, first light at a first wavelength and second light at a second wavelength;

receiving, via the sensor of the toothbrush, reflected portions of the first light and the second light; and

for a plurality of different times during the brushing session, transmitting, from the sensor to a processor, a first signal indicative of a first intensity of the reflected portion of the first light and a second signal indicative of a second intensity of the reflected portion of the second light;

for each of the plurality of different times, calculating, via the processor, a ratio of the first intensity to the second intensity, wherein the ratios for the different times form data points;

identifying, via the processor, which of the data points are inside predetermined boundaries and which of the data points are outside the predetermined boundaries; and

determining, via the processor, whether hemoglobin is present in the oral cavity based on a characteristic of the data points inside the predetermined boundaries or the data points outside the predetermined boundaries.

28. The method of claim 27 wherein the predetermined boundaries are formed by a minimum value and a maximum value.

29. The method of any of claims 27-28 further comprising:

the sensor emitting a third light at a third wavelength, receiving reflected portions of the third light, and generating a third signal indicative of a third intensity of the reflected portion of the third light; and

the processor, for the plurality of different times, receiving the third signal, and calculating a second ratio of the third intensity to the second intensity;

wherein each of the data points comprises the ratio as a first coordinate and the second ratio as a second coordinate; and

wherein the predetermined boundaries form a predetermined area that each of the data points is inside or outside.

30. The method of any of claims 27-29:

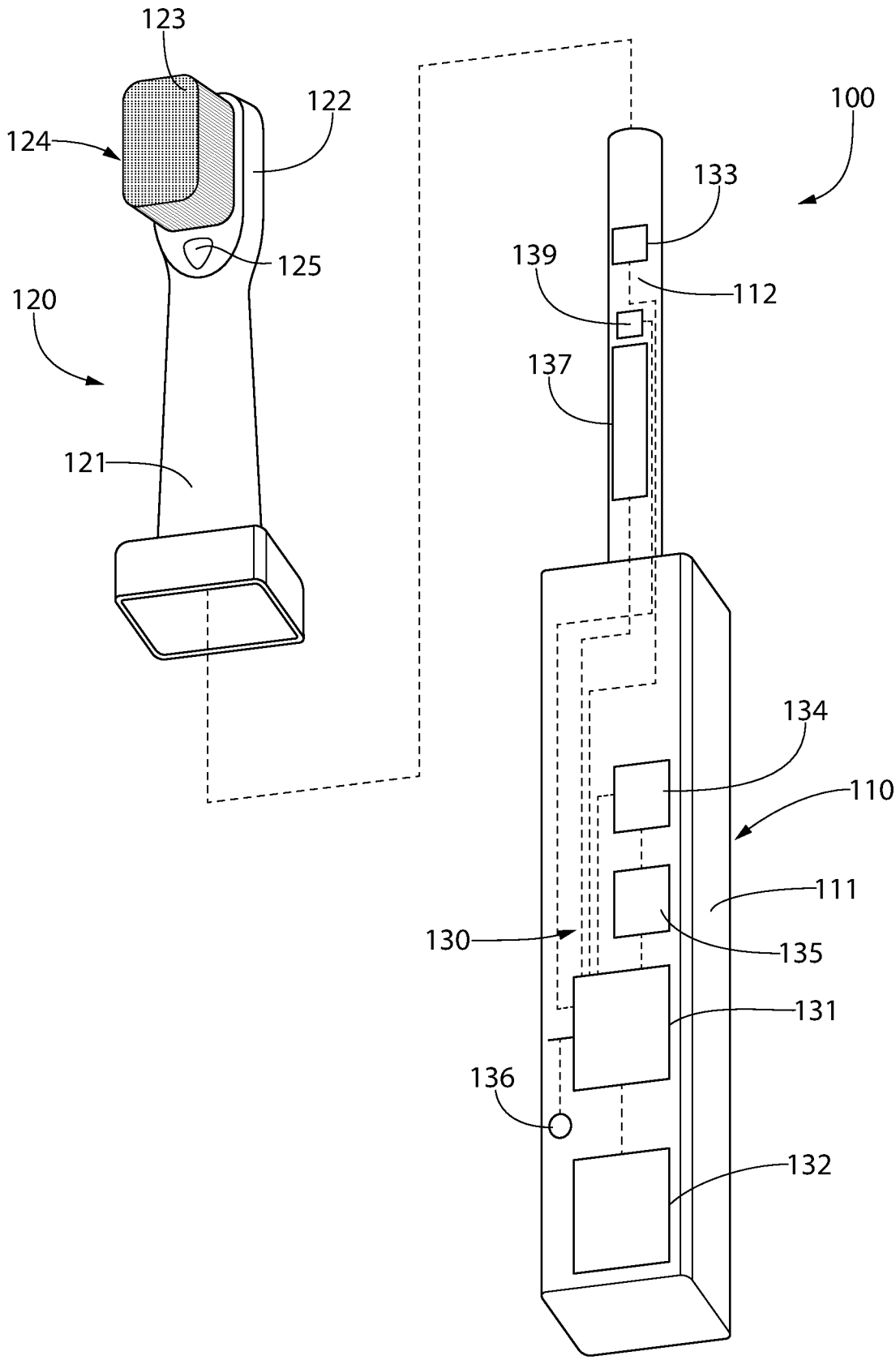
wherein the characteristic upon which the determination whether hemoglobin is present is vector lengths for each of the data points outside the predetermined boundaries; and

wherein the vector lengths are measured from a center of the data points inside the predetermined boundaries to the data points outside the predetermined boundaries.

31. The method of the preceding claim wherein the characteristic upon which the determination whether hemoglobin is present is either whether a sum of vector lengths exceeds a predetermined number, or whether an average of the vector lengths exceeds a predetermined number.

32. The method of any of claims 27-31 wherein the characteristic upon which the determination whether hemoglobin is present is a spread of the data points inside the predetermined boundaries.

33. The method of the preceding claim wherein the spread is based on, for each of the data points within the predetermined boundaries, a distance between the data point and a center of the data points inside the predetermined boundaries.


123
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111
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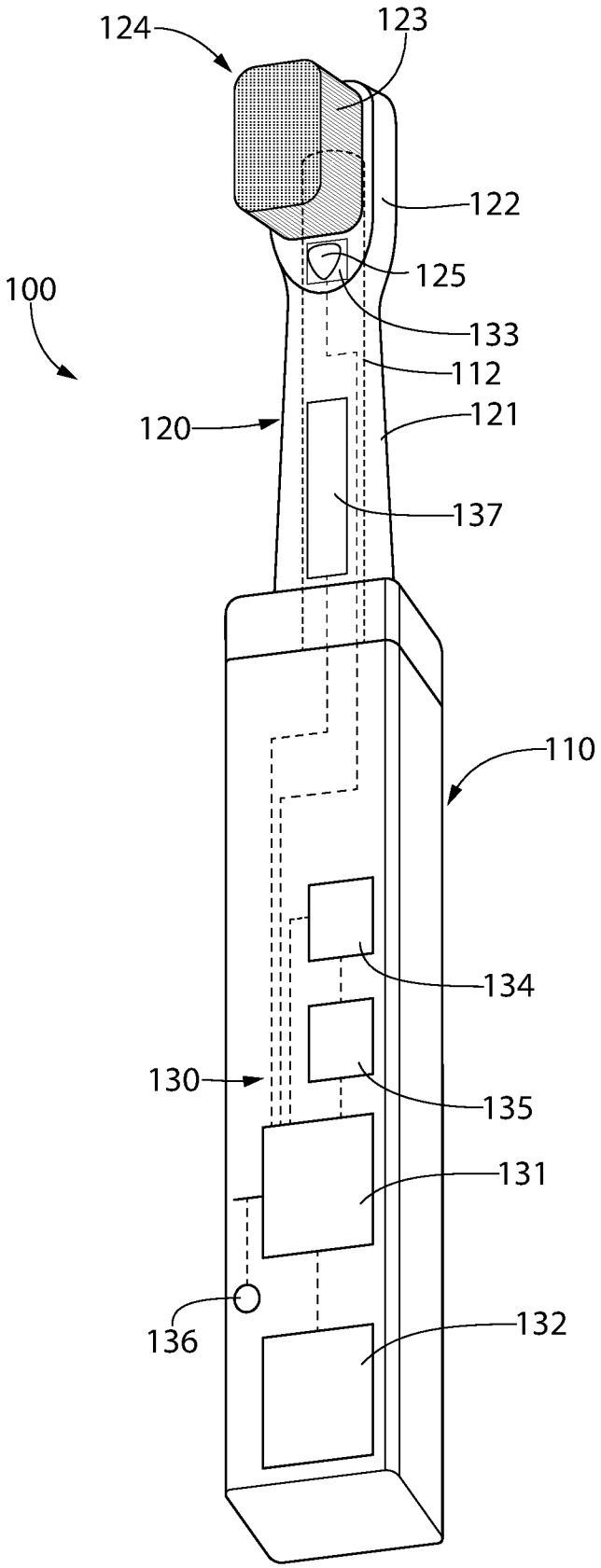
131
136
132

FIG. 1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132

FIG. 2

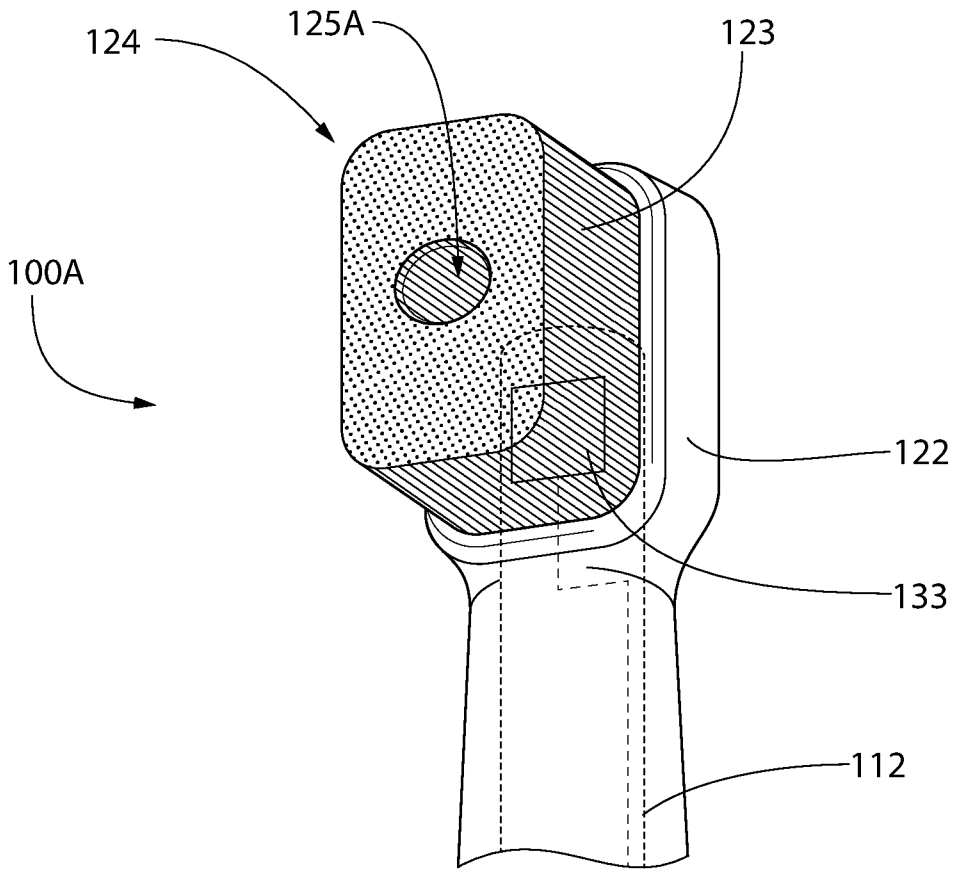



FIG. 3

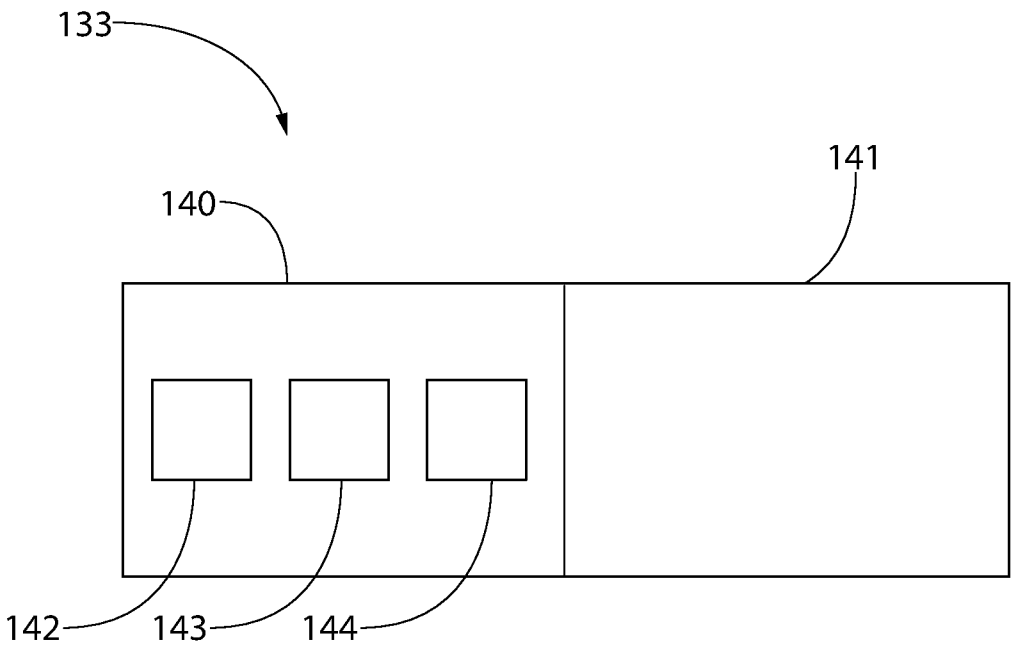
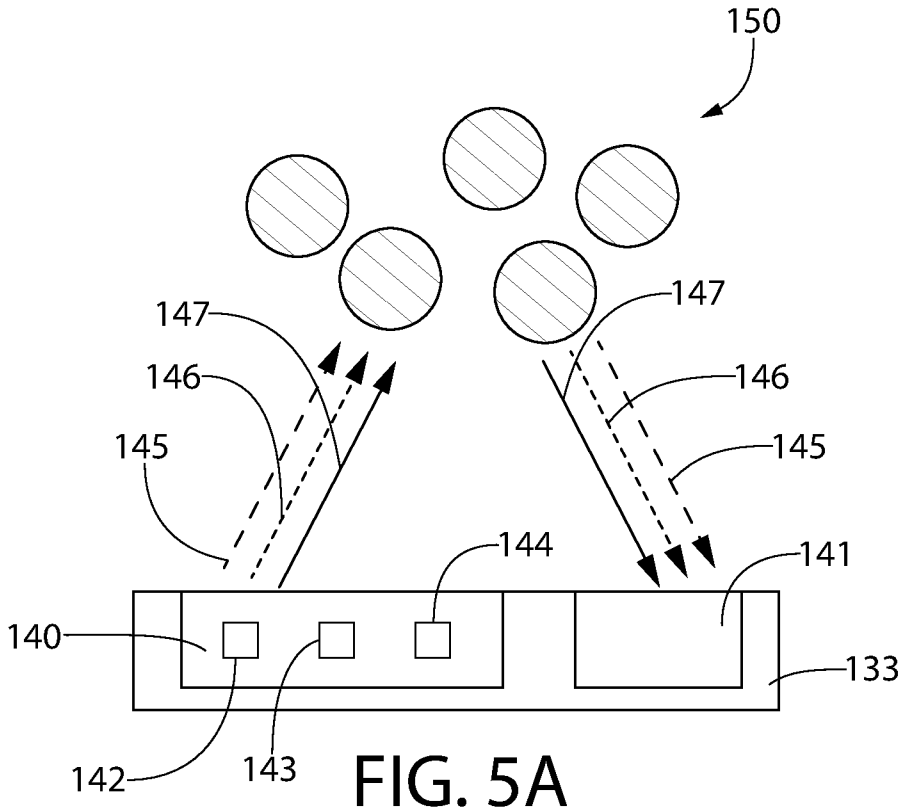



FIG. 4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147
146
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145
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141
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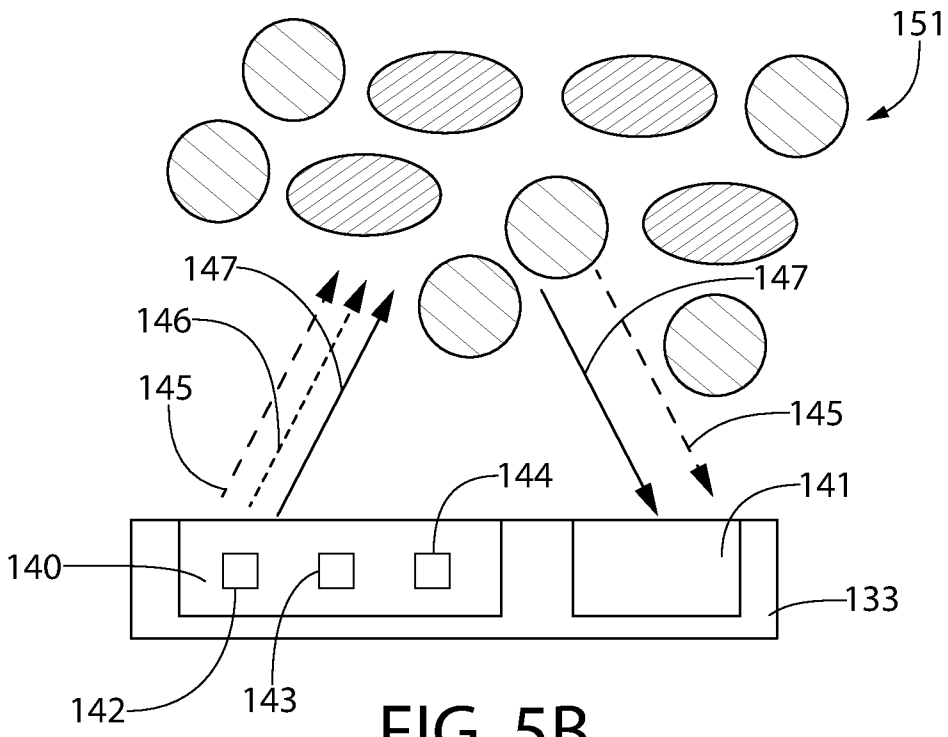
133
142
143

FIG. 5A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133
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143

FIG. 5B

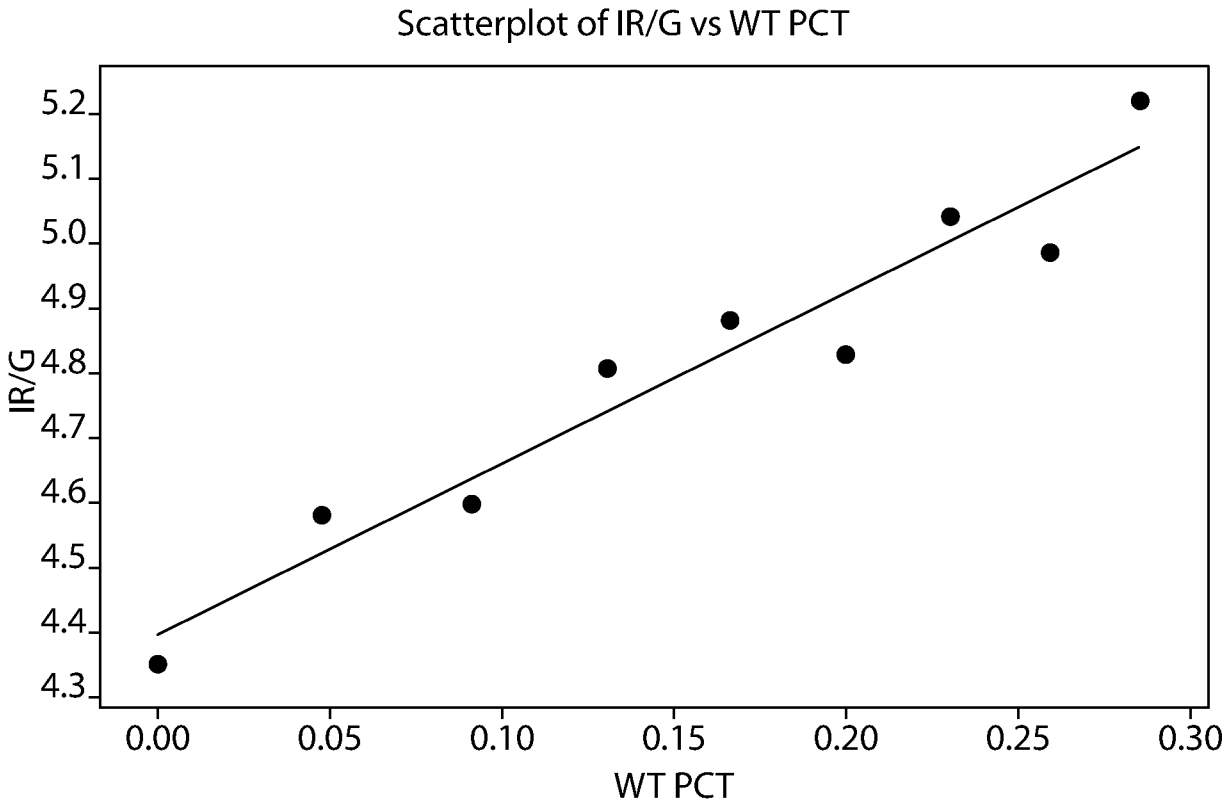

Scatterplot of IR/G vs WT PCT
IR/G
5.2
5.1
5.0
4.9
4.8
4.7
4.6
4.5
4.4
4.3
0.00
0.05
0.10
0.15
0.20
0.25
0.30
WT PCT

FIG. 6

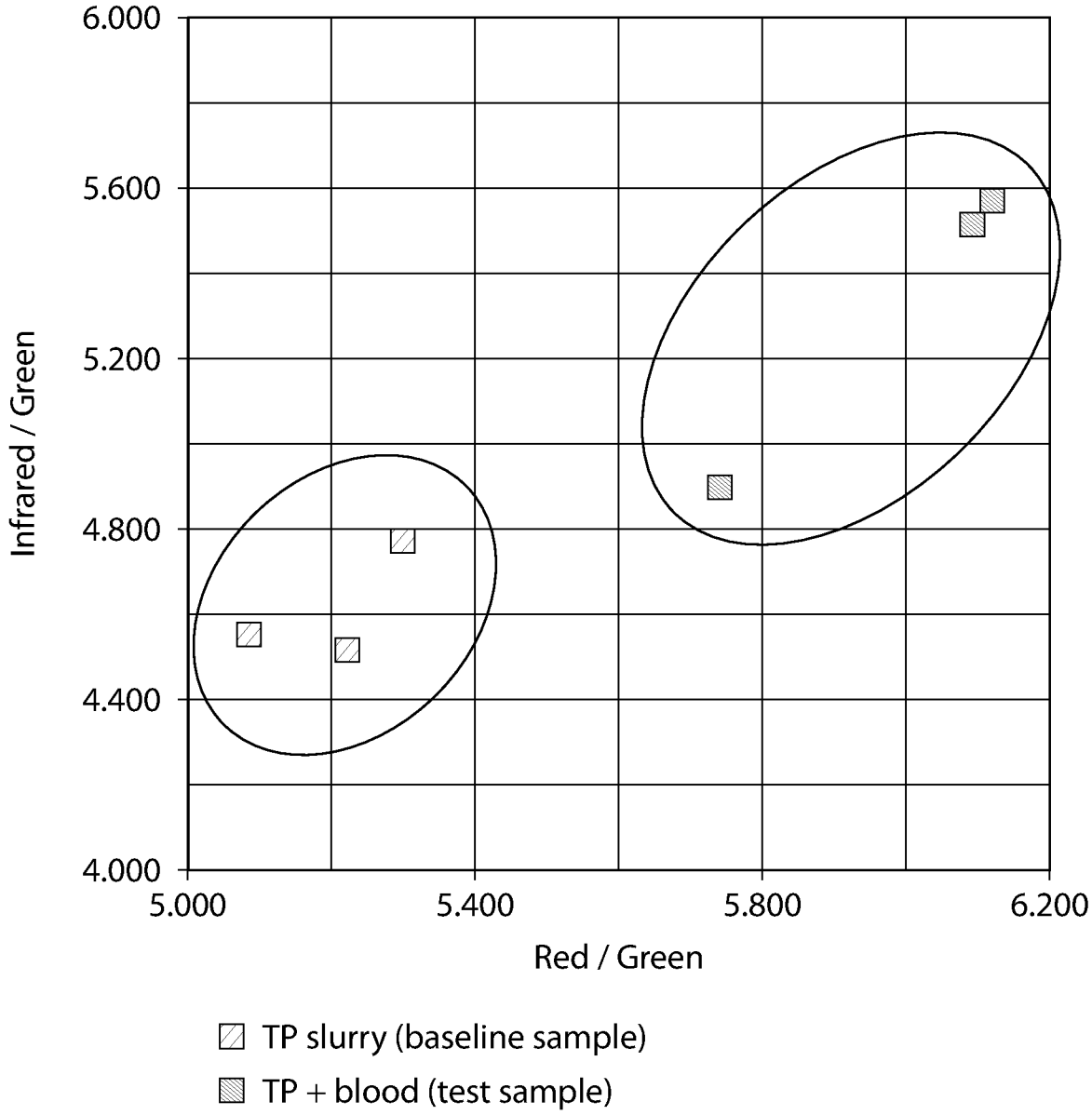

6.000
5.600
5.200
4.800
4.400
4.000
Infrared / Green
5.000
5.400
5.800
6.200
Red / Green
TP slurry (baseline sample)
TP + blood (test sample)

FIG. 7

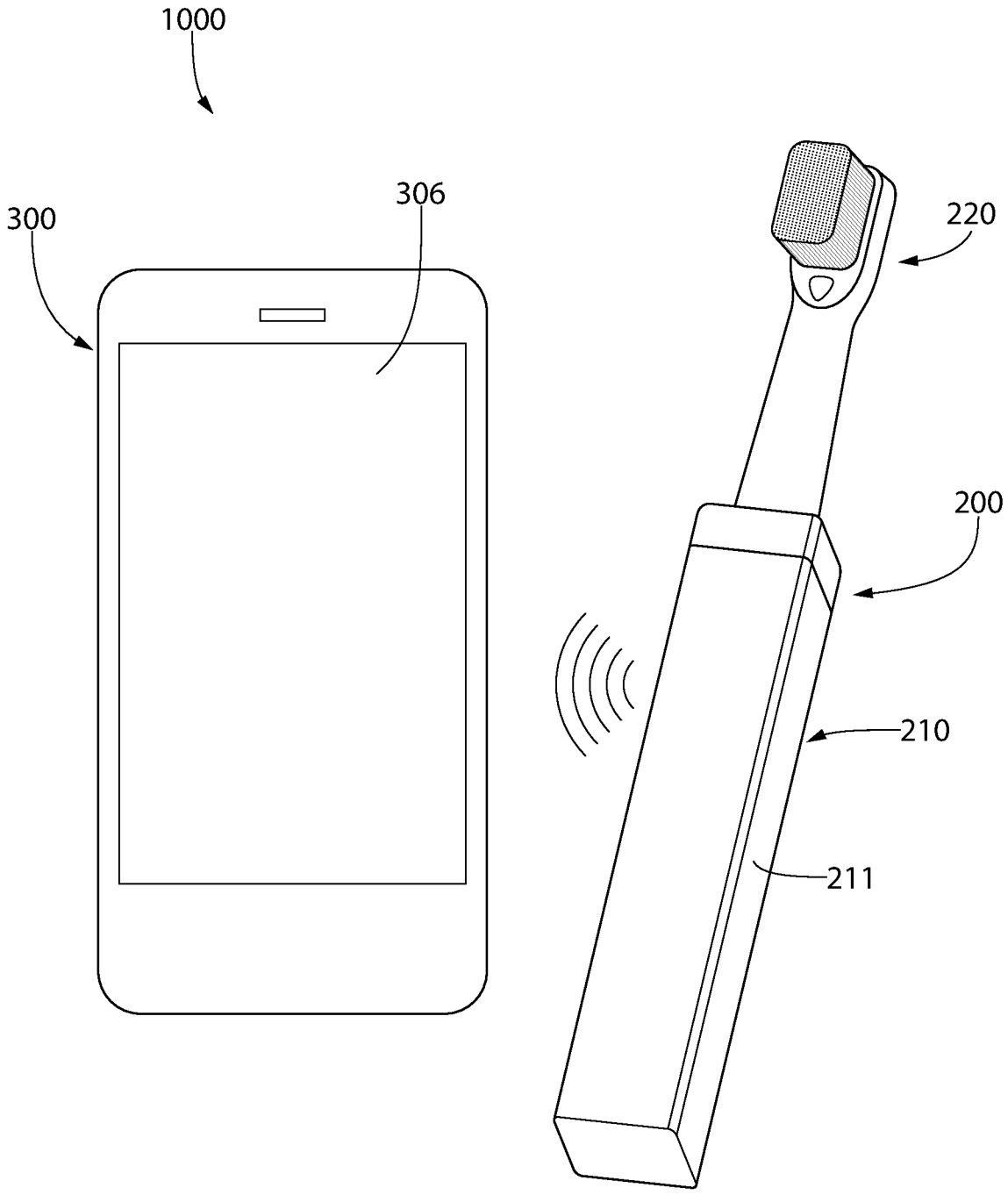
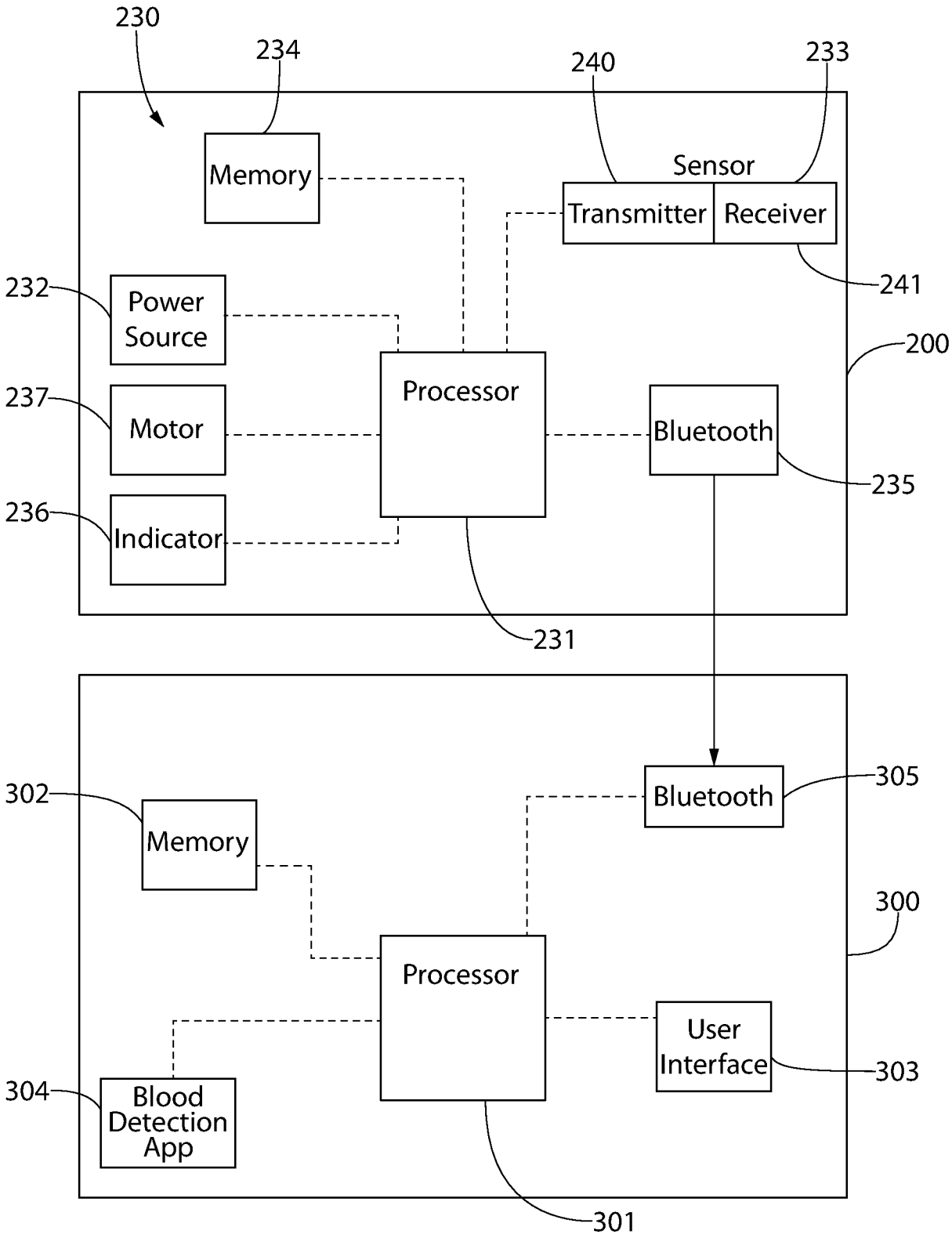



FIG. 8


230
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Memory
Sensor
Transmitter
Receiver
241
232
Power Source
200
237
Motor
Processor
Bluetooth
235
236
Indicator
231
302
Memory
Bluetooth
305
300
Processor
User Interface
303
304
Blood Detection App
301

FIG. 9

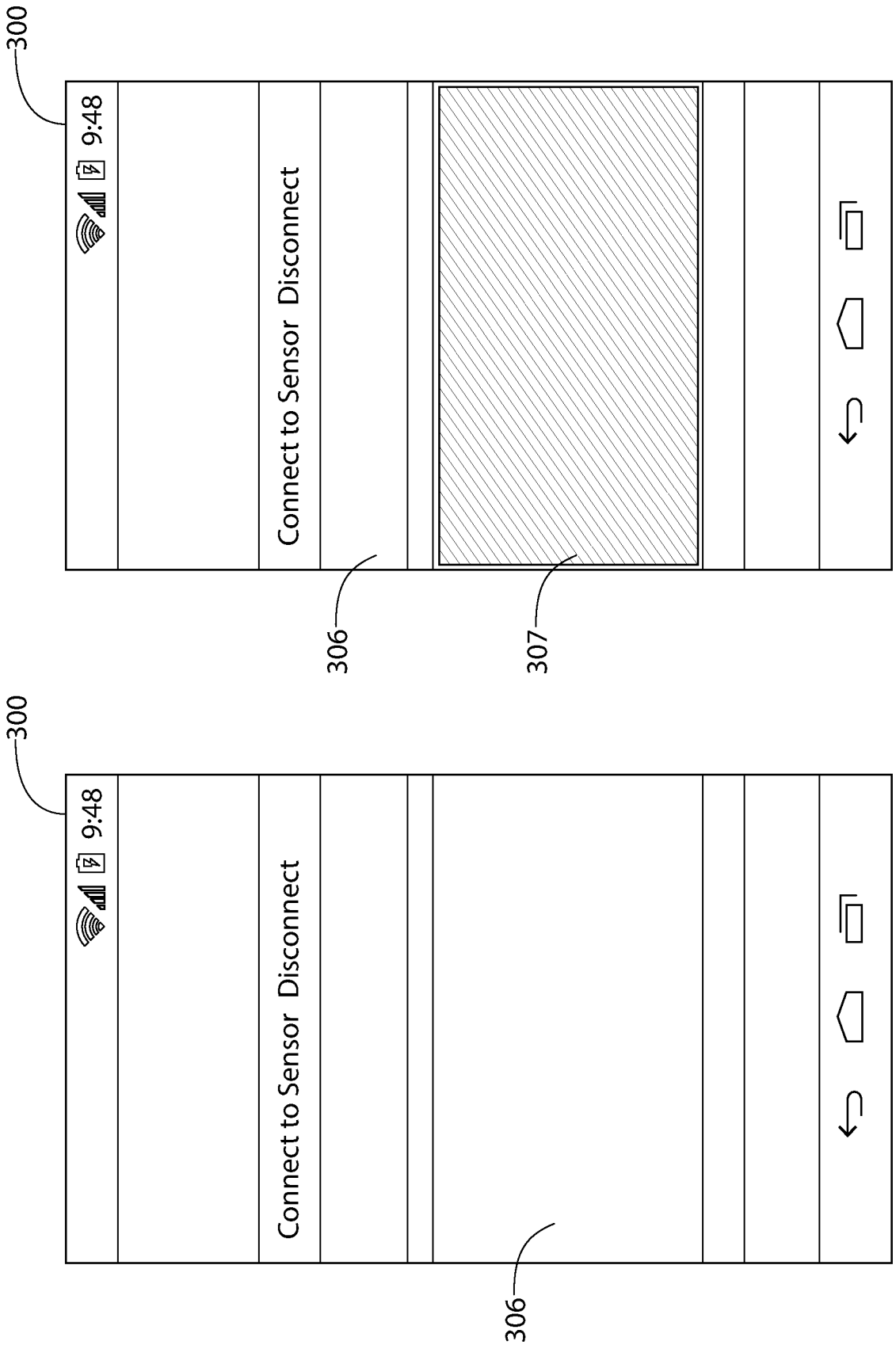
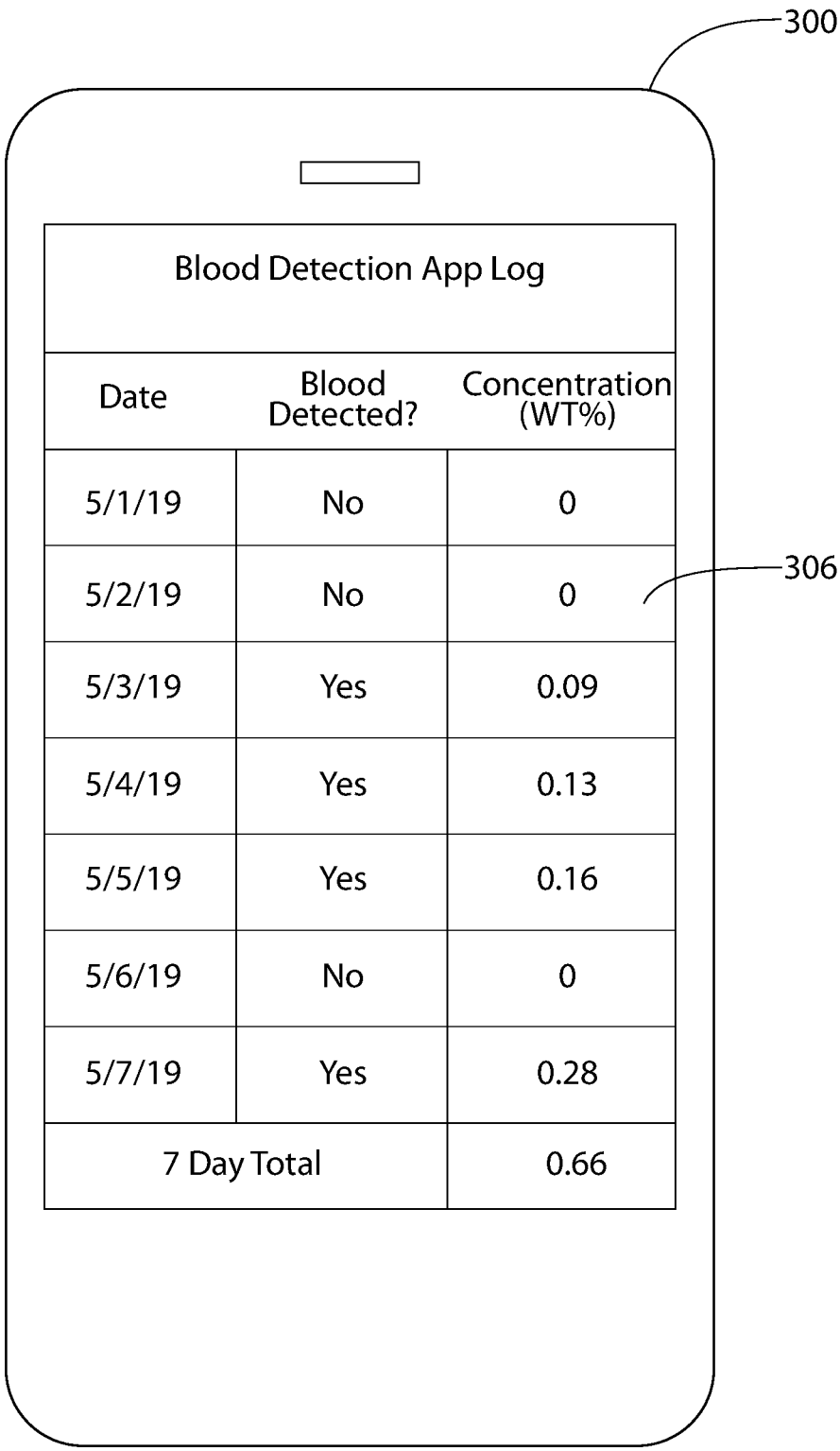



FIG. 10B




FIG. 10A




| Blood Detection App Log | | |
|---|---|---|
| Date | Blood Detected? | Concentration (WT%) |
| 5/1/19 | No | 0 |
| 5/2/19 | No | 0 |
| 5/3/19 | Yes | 0.09 |
| 5/4/19 | Yes | 0.13 |
| 5/5/19 | Yes | 0.16 |
| 5/6/19 | No | 0 |
| 5/7/19 | Yes | 0.28 |
| 7 Day Total | | 0.66 |

FIG. 11

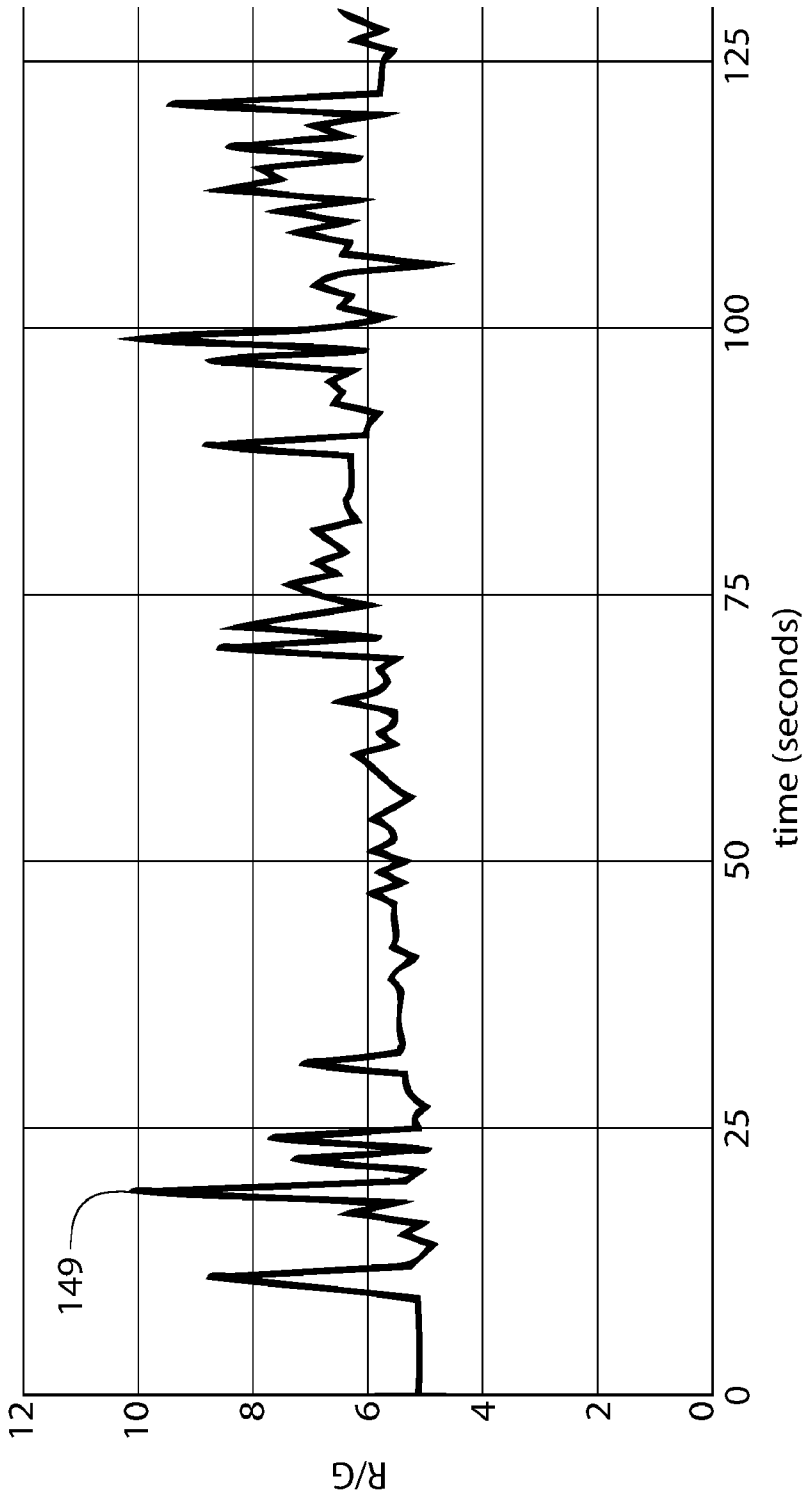



FIG. 12A

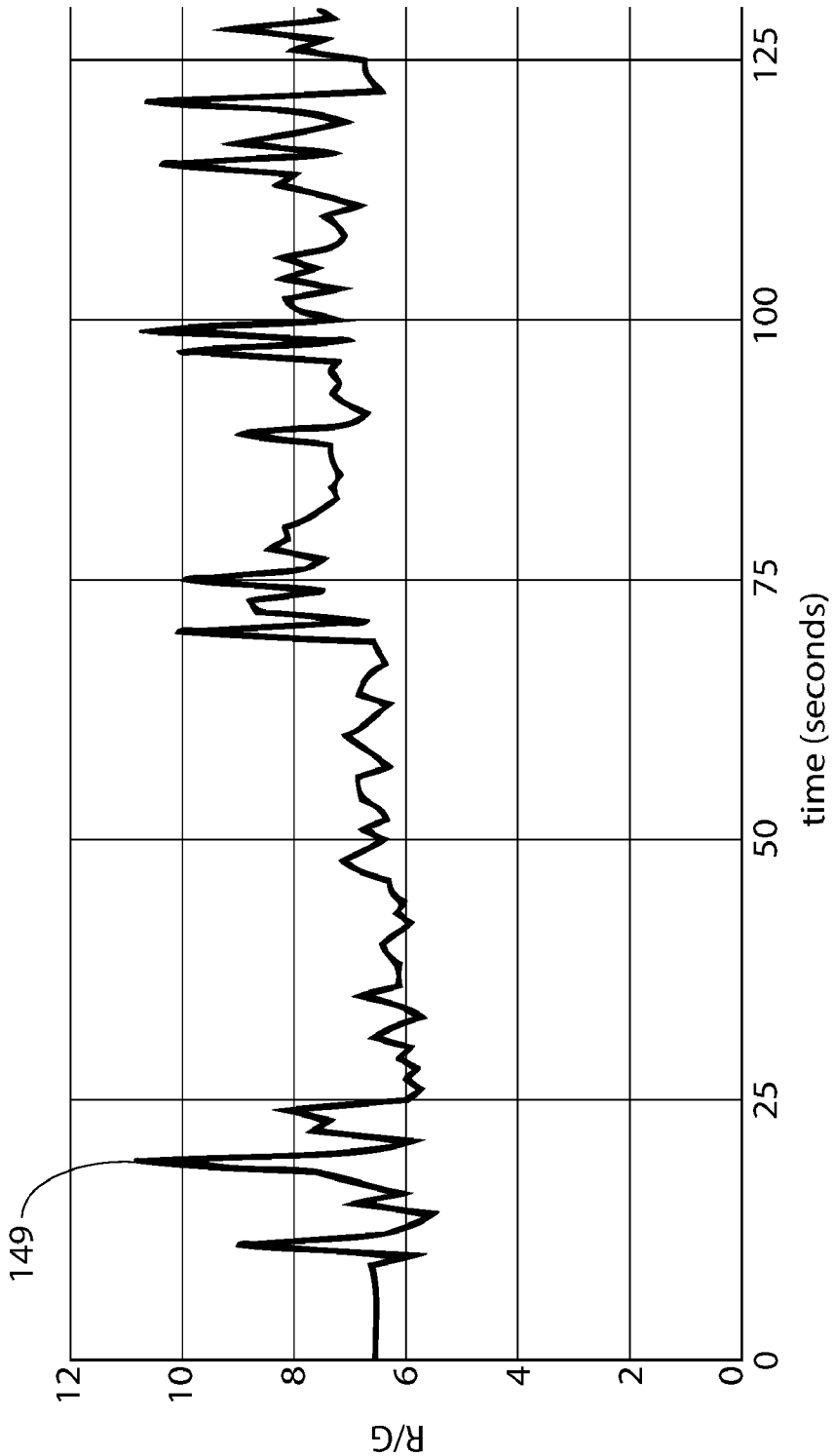



FIG. 12B

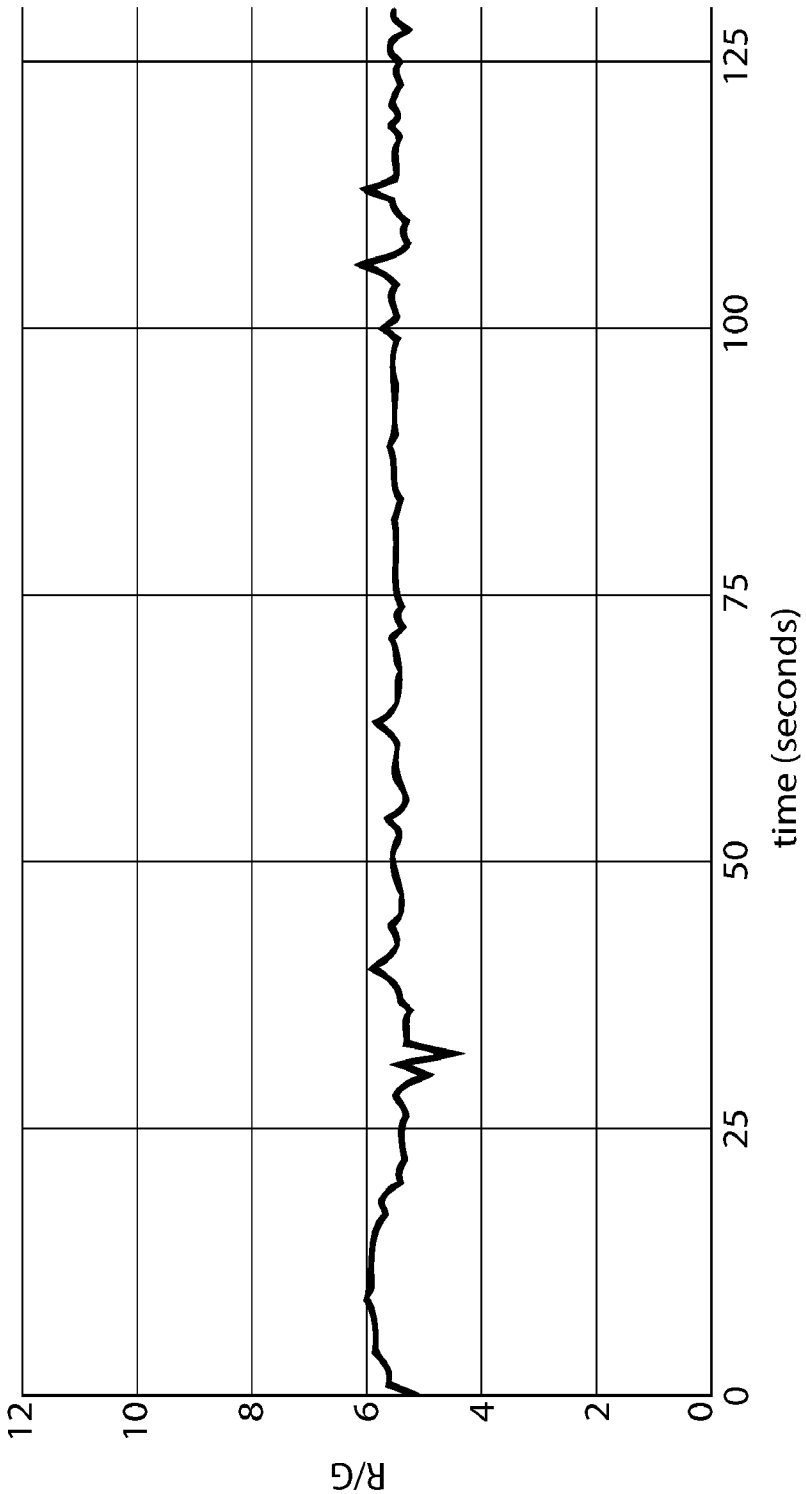



FIG. 13A

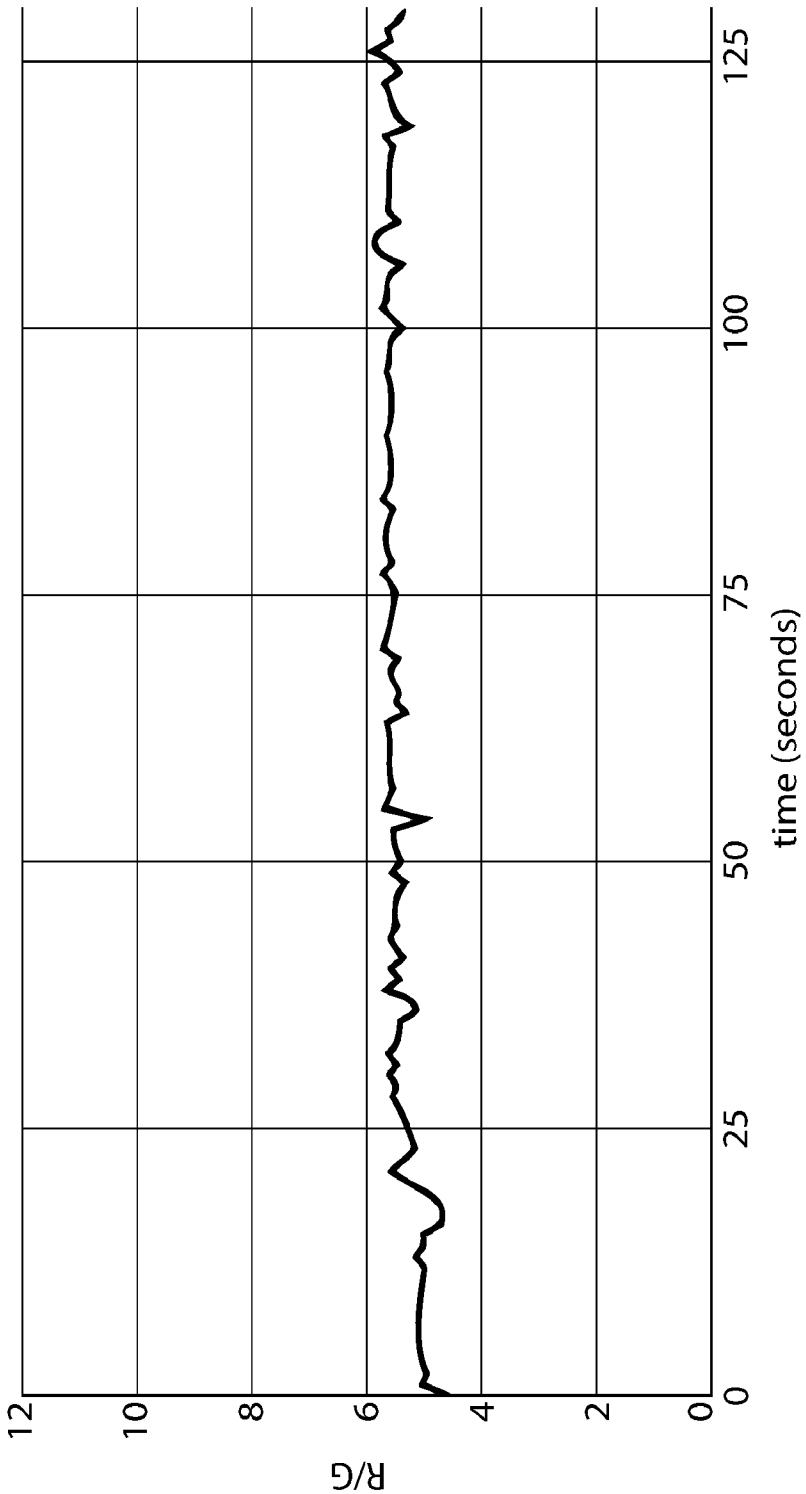



FIG. 13B

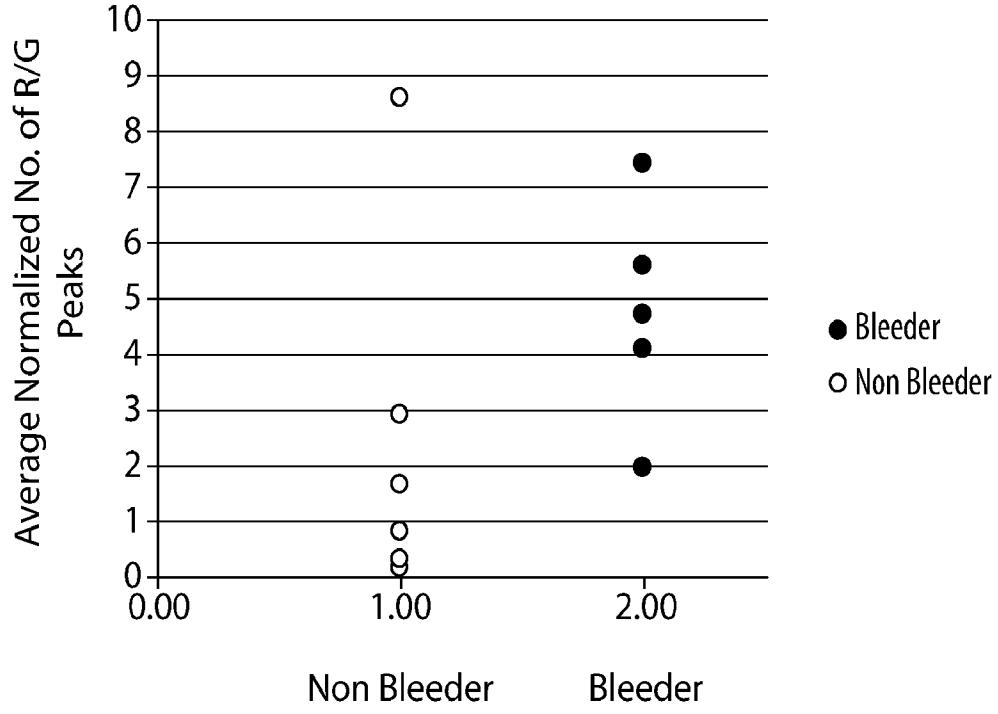

Average Normalized No. of R/G Peaks
10
9
8
7
6
5
4
3
2
1
0
0.00
1.00
2.00
Non Bleeder
Bleeder
Bleeder
Non Bleeder

FIG. 14

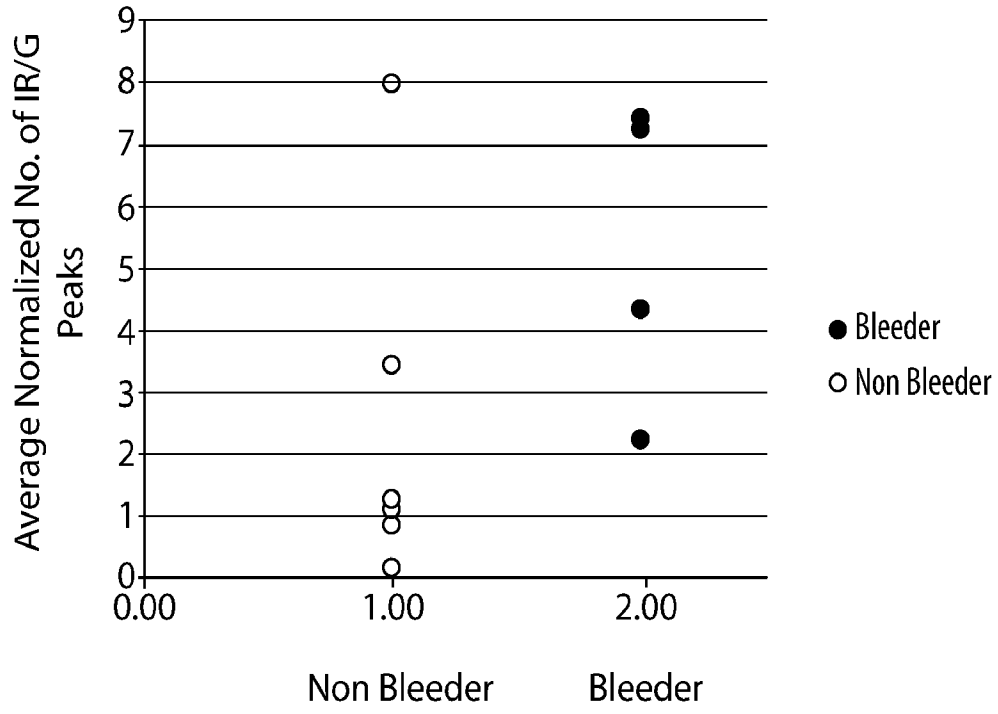

Average Normalized No. of IR/G Peaks
9
8
7
6
5
4
3
2
1
0
0.00
1.00
2.00
Non Bleeder
Bleeder
Bleeder
Non Bleeder

FIG. 15

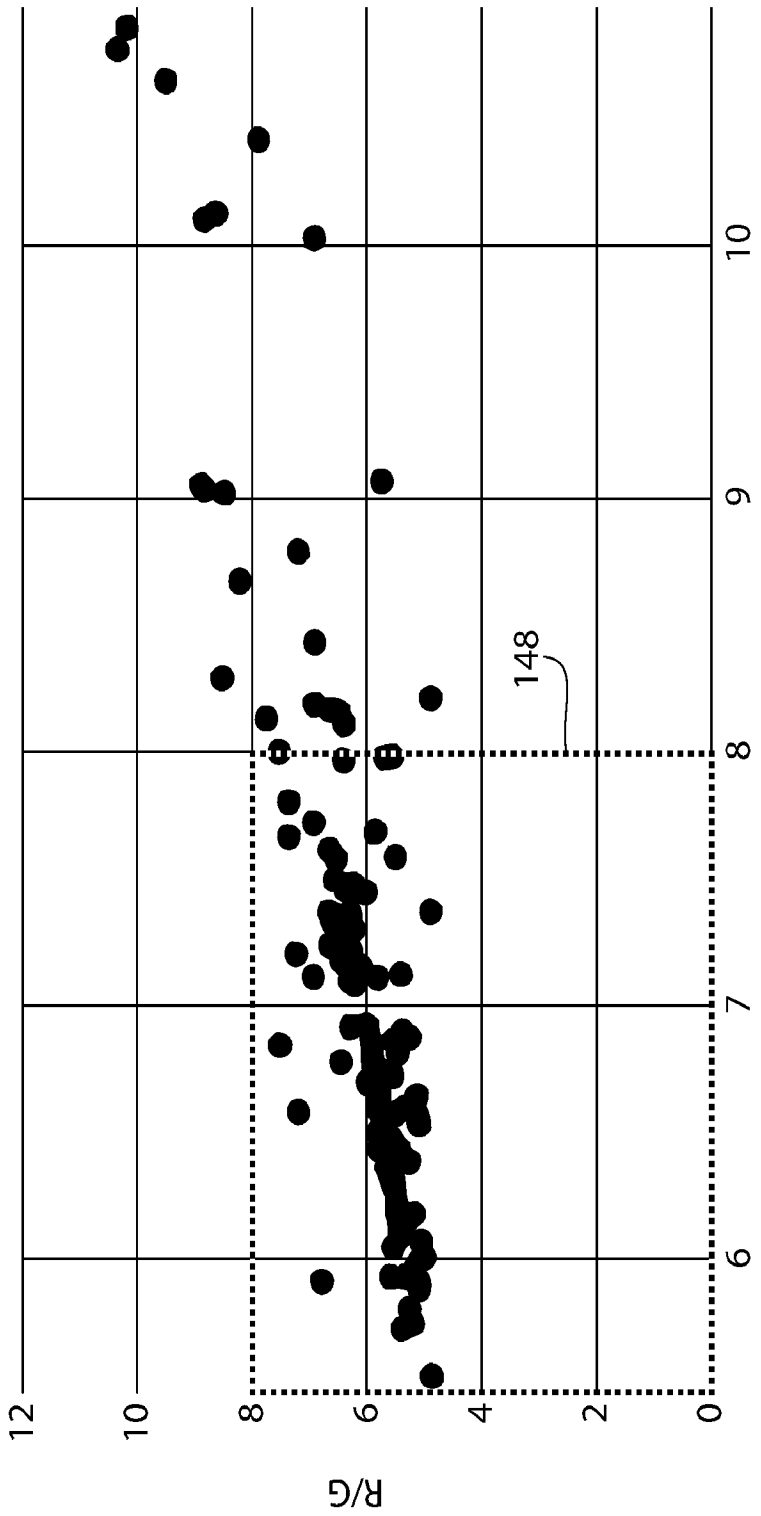



FIG. 16A

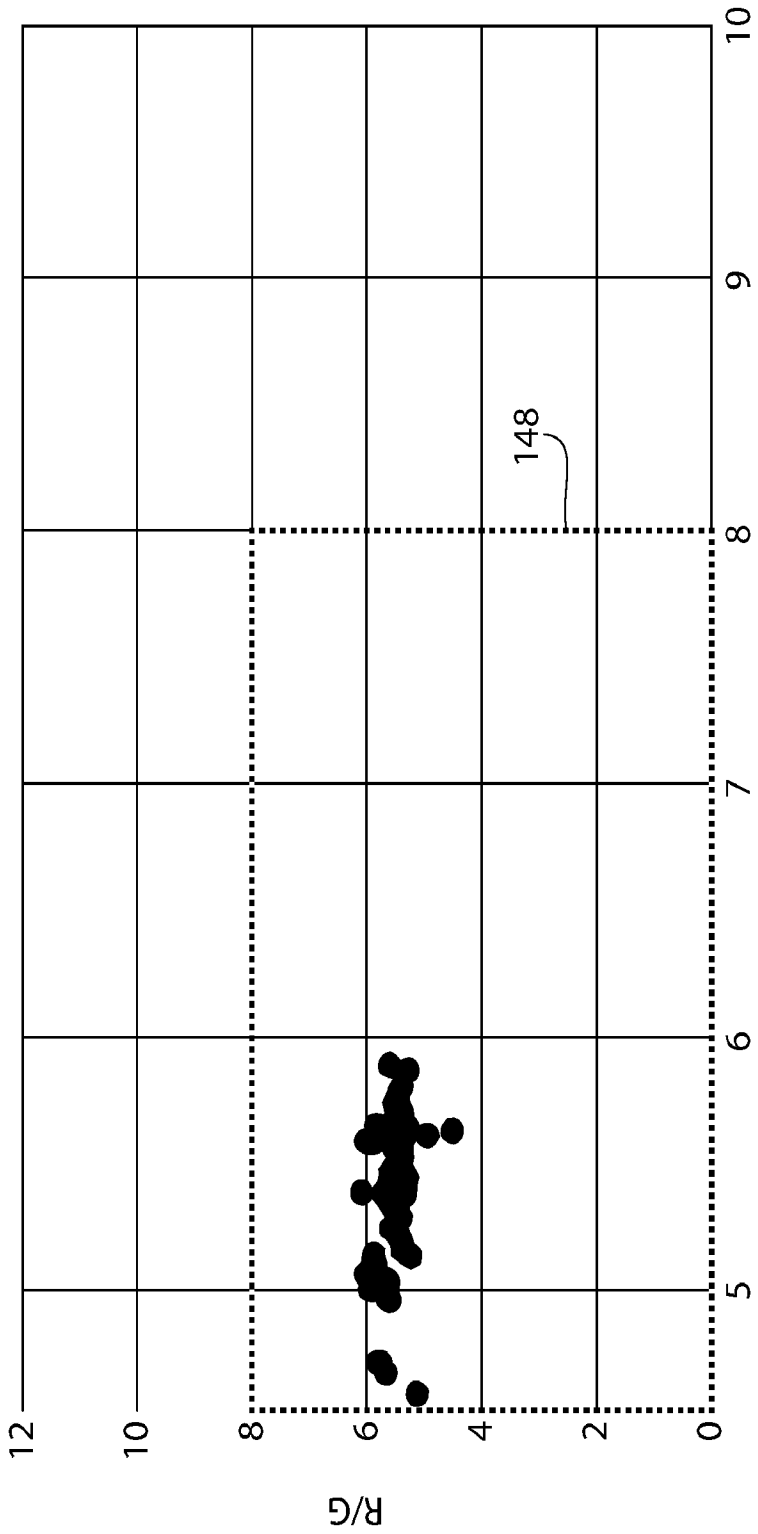



FIG. 16B

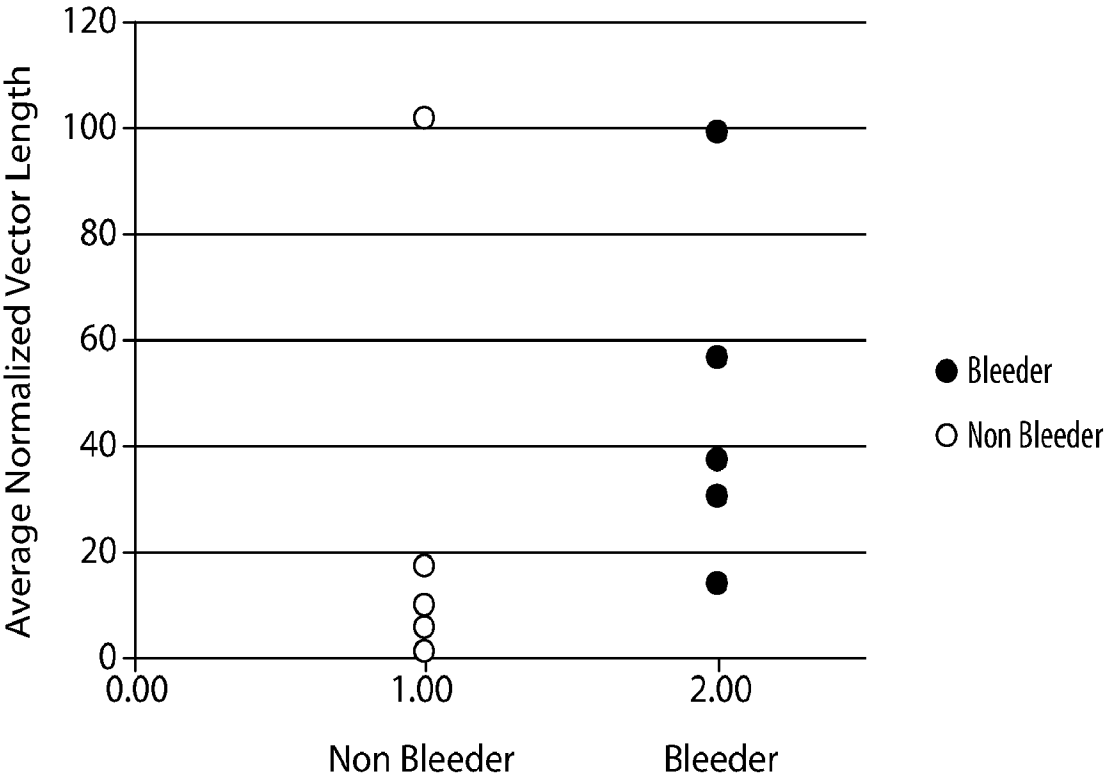

Average Normalized Vector Length
120
100
80
60
40
20
0
0.00
1.00
2.00
Non Bleeder
Bleeder
Bleeder
Non Bleeder

FIG. 17

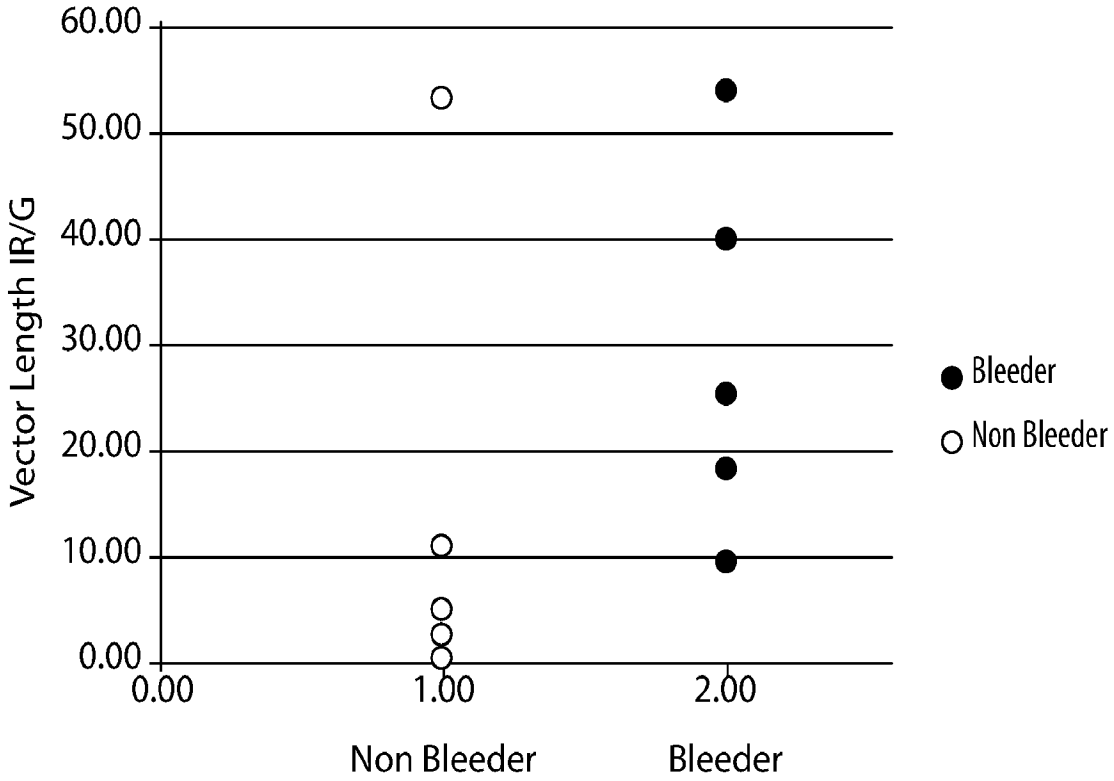

Vector Length IR/G
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.00
1.00
2.00
Non Bleeder
Bleeder
Bleeder
Non Bleeder

FIG. 18

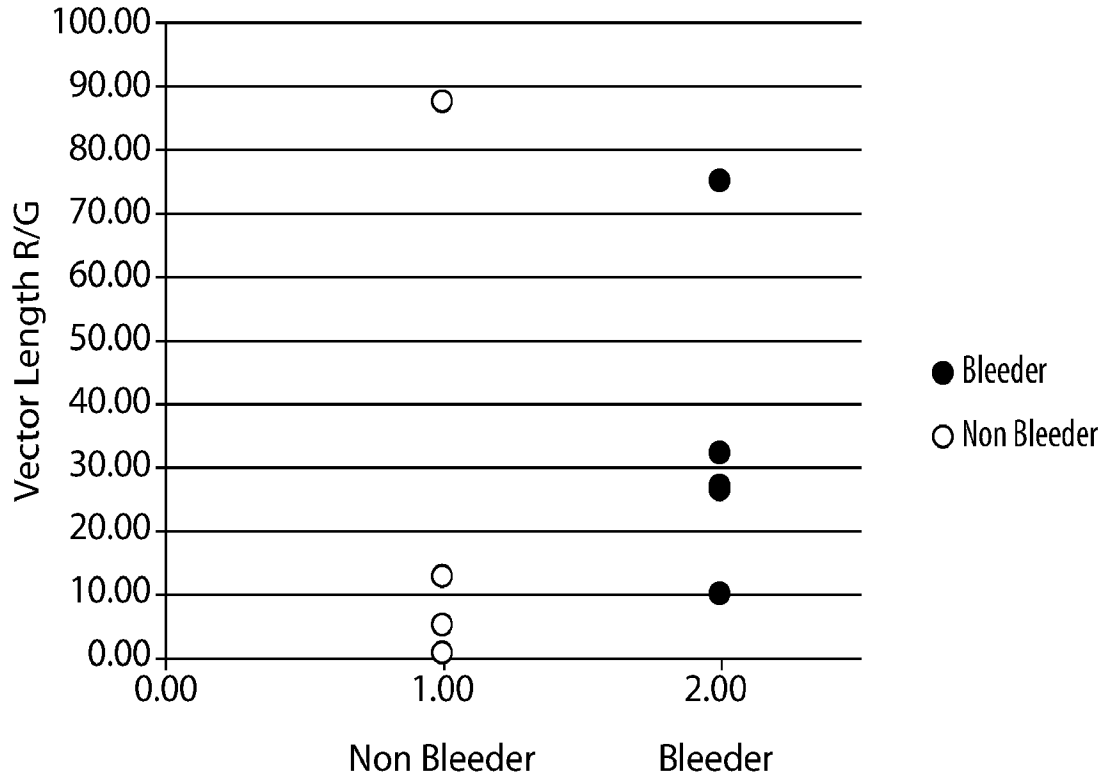



FIG. 19

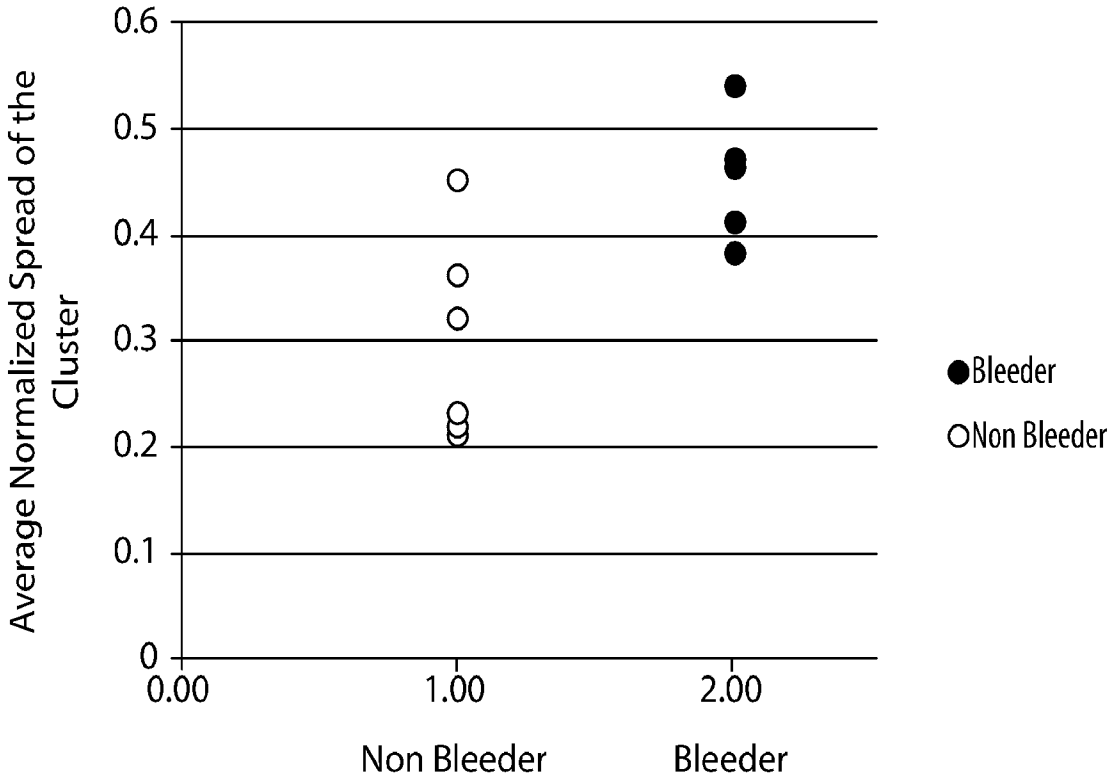



FIG. 20A

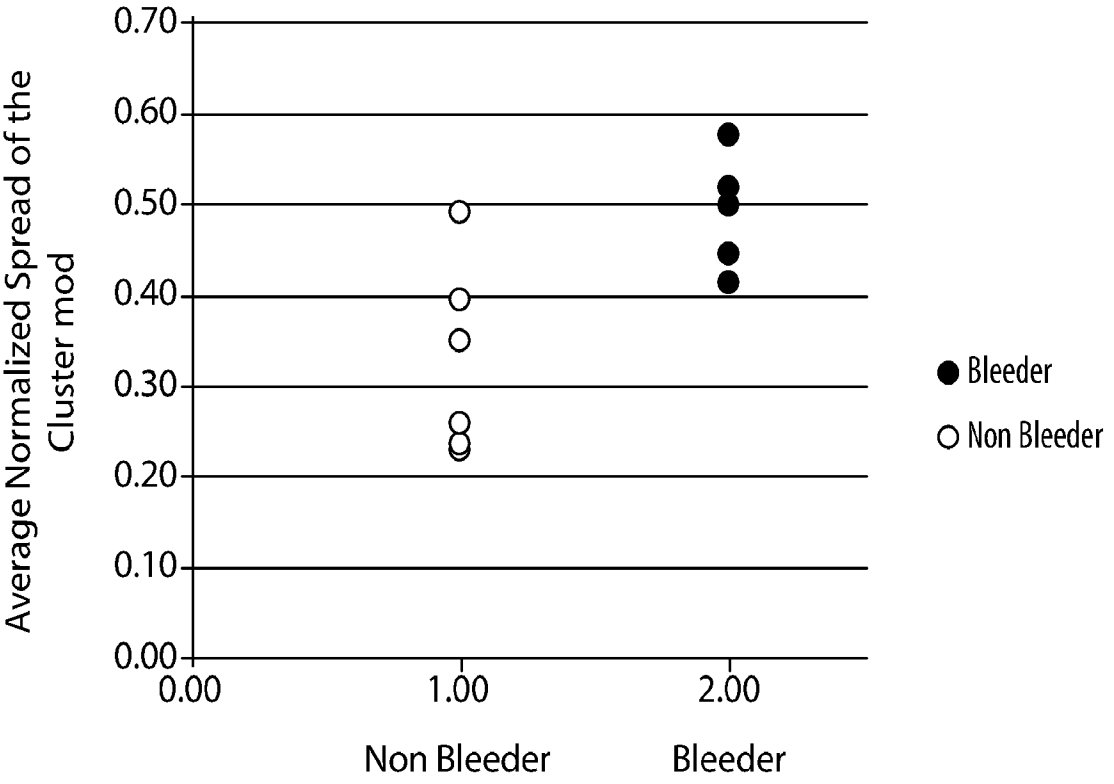



FIG. 20B

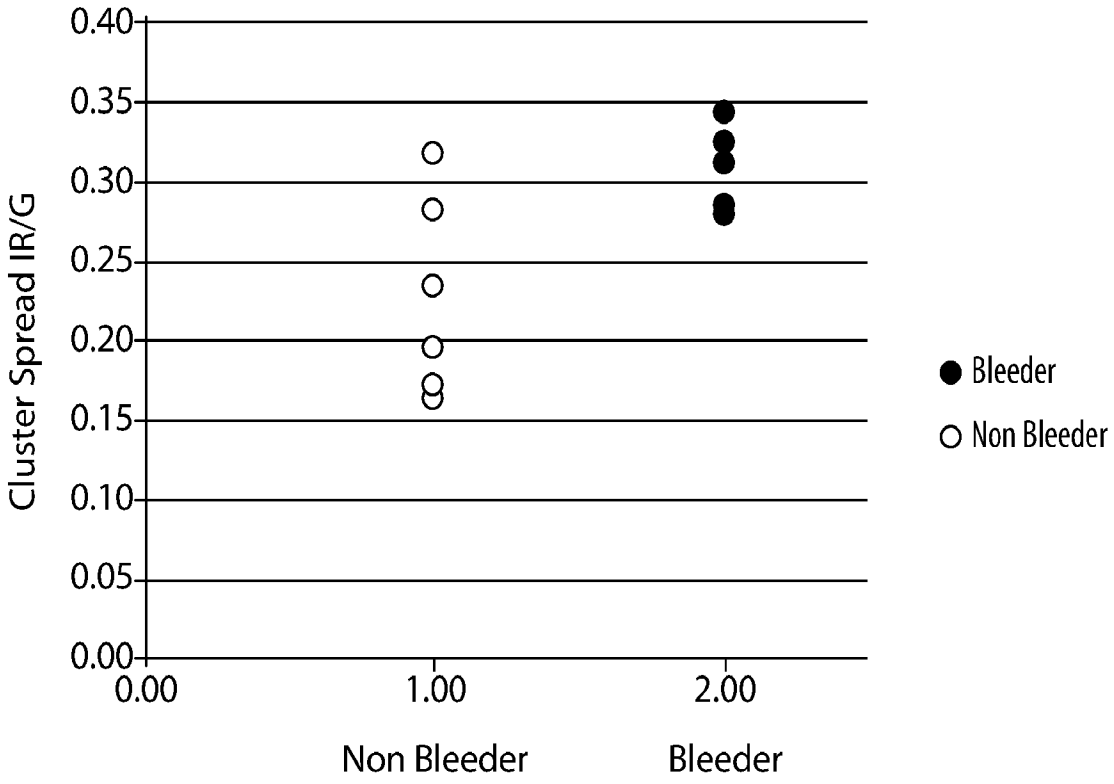



FIG. 21

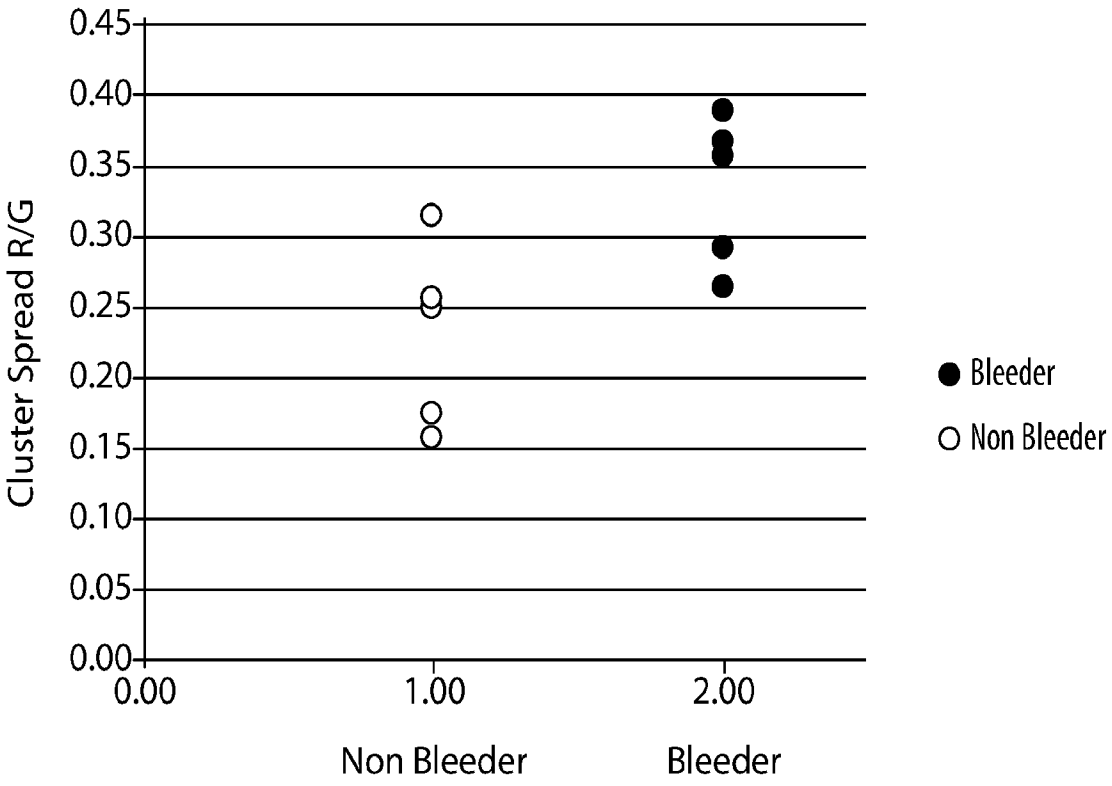

0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Cluster Spread R/G
0.00
1.00
2.00
Non Bleeder
Bleeder
Bleeder
Non Bleeder

FIG. 22

# INTERNATIONAL SEARCH REPORT

International application No
PCT/US2021/056928

A. CLASSIFICATION OF SUBJECT MATTER
INV. A46B15/00 A61C17/22 G16H15/00 G16H40/63 G16H50/30
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A46B A61C G16H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | WO 2018/065374 A1 (UNILEVER PLC)<br>12 April 2018 (2018-04-12)<br>page 38, line 23 - page 39, line 6<br>page 31, lines 7-29<br>claims 1-3 | 1-10,<br>17-26 |
| A | US 2017/020277 A1 (BARNES ET AL.)<br>26 January 2017 (2017-01-26)<br>paragraph [0261]; claims 1,30 | 1-10,<br>17-26 |
| A | US 2013/091642 A1 (DYKES ET AL)<br>18 April 2013 (2013-04-18)<br>paragraphs [0001] - [0009], [0041]<br>claims 1,14,38 | 1-10,<br>17-26 |

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 20 January 2022 | 04/02/2022 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Raybould, Bruce |

1

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2021/056928

**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 11-16, 27-33
because they relate to subject matter not required to be searched by this Authority, namely:
see FURTHER INFORMATION sheet PCT/ISA/210

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:

**Remark on Protest**

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.1

Claims Nos.: 11-16, 27-33

Rule 39.1(iv) PCT - Method for treatment of the human or animal body by therapy Brushing teeth and gums is a method for removing plaque and bacteria in order to avoid caries and gingivitis/parodontitis. Preventive methods fall within the scope of therapeutic methods. The claimed methods cannot be defined without the method Step of brushing teeth and gum and the method of detecting blood according to the present invention can only be applied whilst brushing teeth and gums.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2021/056928

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| WO 2018065374 A1 | 12-04-2018 | BR 112019006175 A2 | 18-06-2019 |
| | | CN 109788845 A | 21-05-2019 |
| | | EP 3522753 A1 | 14-08-2019 |
| | | WO 2018065374 A1 | 12-04-2018 |
| US 2017020277 A1 | 26-01-2017 | NONE | |
| US 2013091642 A1 | 18-04-2013 | US 2013091642 A1 | 18-04-2013 |
| | | WO 2013056071 A1 | 18-04-2013 |