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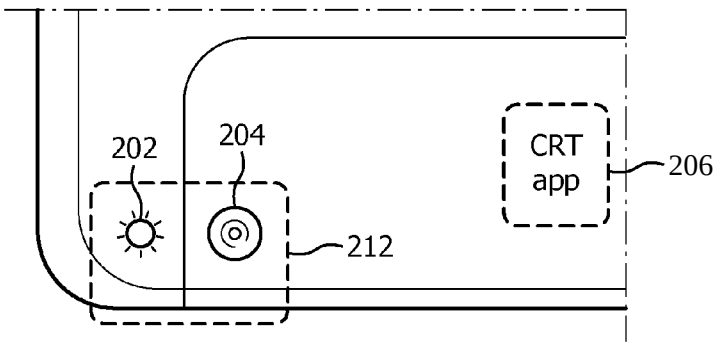

FIG. 2C

(57) Abstract: The capillary refill time (CRT) of a patient is an important feature in the determination of cardiovascular system health - quick reperfusion of the microcirculation (namely, the capillaries) is a good indication that the cardiovascular system is able to efficiently distribute blood throughout the body. Current systems use unreliable or subjective methods to test the CRT. Additionally, the calculation of CRT is not generally used in the adult medical space as it is more commonly used in pediatrics. The present application describes a system and method for calculating a patient's CRT using a mobile device (102, 200, 300) with an integrated camera (204, 302) and light source (202), or an optical head- mounted display (300) using a light source (202) in combination with ambient light to calculate the CRT. Once a patient's CRT is calculated, the integrated application (206, 306) classifies the data and sends it to the treating clinician for review.

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APPROACH FOR MEASURING CAPILLARY REFILL TIME

FIELD

The following relates generally to measurement of the capillary refill time. It finds particular application in conjunction with providing accurate subject specific capillary refill times for both pediatric subjects and adult subjects in testing and diagnosing dehydration or profusion-acute hypotension. It also finds particular application in conjunction with providing these subject specific calculations to a clinician based upon standardized inputs. However, it is to be understood that the following also finds application in other usage scenarios and is not necessarily limited to the aforementioned applications.

BACKGROUND

Capillary refill time (CRT) of a subject is a useful metric in assessing cardiovascular system health. Quick re-perfusion of the microcirculation (e.g. in the capillaries) is a good indication that the cardiovascular system is able to efficiently distribute blood throughout the body, whereas slow re-perfusion may indicate a cardiovascular problem calling for investigation. Current methods of assessing CRT employ subjective measurement made by the attending clinician, called a "finger blanch test." In this test, the clinician squeezes the subject's finger, releases, and counts the number of seconds needed for the finger to regain its pinkish color - a subjective and infrequently recorded measure. The finger blanch test is also relative as one clinician may press the subject's finger harder than another clinician.

Determining the exact time when a finger, subjected to a finger blanch test, returns to its starting color is subjective and has proven to be a difficult task to apply uniformly. Determining exactly when tissue color has returned to baseline color and counting the time accurately for a 2- or 3-second threshold is a difficult task which limits the clinical value of the test.

SUMMARY

The following also provides new and improved methods and systems which overcome the above-referenced problems and others.

In accordance with one aspect, a method for measuring CRT is disclosed. The method comprises, emitting a light from a light source and turning on a camera located near the light source to identify a patient's finger. A patient's finger is then pressed for a determined amount of time. An integrated application on a mobile device is started wherein the integrated application turns on the light source and uses the camera, which is located near the light source, to detect color changes in the patient's finger and using this information, the

method calculates the CRT from the time elapsed between the change in the color of the patient's finger.

In accordance with another aspect of the present application, an apparatus for measuring CRT is disclosed comprising, a light source for emitting light and a camera near the light source configured to identify a patient's finger. Using at least one patient finger and at least one processor configured to turn on the light source and camera, the processor further configured to use the camera to detect color changes in the patient's finger to calculate the CRT from the time elapsed between the change in the color of the patient's finger.

In accordance with another aspect of the present application, a system for measuring and calculating CRT is disclosed. The system comprises one or more processors configured to calculate CRT for a patient using a camera and light source to determine time elapsed between a change in color of a patient's finger from a starting position and an ending position. The system also includes memory configured to store patient data, a communication network configured to send and receive clinical information, and a user interface configured to receive inputs from the at least one processor and memory, the user interface configured to display the calculated result.

One advantage resides in improved determination and calculation of a subject's CRT based upon objective testing criteria.

Another advantage resides in improved clinical workflow.

Another advantage resides in improved patient care.

Still further advantages of the present invention will be appreciated to those of ordinary skill in the art upon reading and understanding the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may take form in various components and arrangements of components, and in various steps and arrangement of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not to be construed as limiting the invention.

FIGURE 1 illustrates a representative system embodying the method and apparatus for calculating the capillary refill time.

FIGURE 2a illustrates an example capillary refill test (CRT) apparatus with a camera lens and an integrated light source offset from the camera lens for capturing and calculating a subject's capillary refill time.

FIGURE 2b illustrates an exemplary use of the CRT apparatus of FIGURE 1 with a subject's finger to calculate the capillary refill time.

FIGURE 2c illustrates a CRT apparatus for capturing and calculating a subject's capillary refill time with a cuff for blocking ambient light from reaching a subject's finger and optionally for applying uniform pressure to the subject's finger during the test.

FIGURE 3 illustrates another example CRT apparatus for use in calculating capillary refill time.

FIGURE 4 illustrates a method for calculating the capillary refill time.

FIGURE 5 illustrates an example diagram calculating the CRT wherein the blood flow is normal, then is occluded, and finally returning to normal.

DETAILED DESCRIPTION

Disclosed herein are apparatuses and methods which determine a patient's capillary refill time (CRT) using objective techniques. (More generally, the disclosed CRT measurement techniques can be applied to a subject, who may be a patient, or a subject undergoing a routine physical examination or clinical screening, or so forth - for simplicity, the term "patient" is used herein). In one approach, using a readily available camera, embedded light source (camera flash), and an integrated application (i.e., electronic data processing device), a patient's finger is squeezed or pressed, and, using the LED wavelength scale on the camera color scale, it is determined how long it takes the patient's finger to return to its starting color before it was pressed. The CRT may be assessed using automatic evaluation of the color return. In an automatic approach, a flexible non-transparent cuff is provided that squeezes a patient's finger using a standardized and predetermined force. Upon release, the camera determines how long until the patient's finger returns to its stating color. This information is then transmitted to a user interface either on a mobile device or a separate medical device.

Disclosed herein are approaches for calculating the CRT of a patient. Upon completion of the calculation, the CRT is, in some embodiments, classified into a classification category and the results and classification are submitted to the clinician for review. In the case of an adult patient, CRT is typically used to test for dehydration or acute hypertension. CRT is typically used in the pediatrics space for checking dehydration in infants and children.

With reference to FIGURE 1, a block diagram illustrating a representative system for calculating capillary refill time (CRT) and sending it to a user interface for a

clinician to review is shown. The system 100 suitably includes a mobile or wearable device 102 equipped with a camera 103 that acquires images or optical data for the finger over a capillary refill time interval, at least one electronic processor 104 (for example, a microprocessor, a microcontroller, or the like) that computes the capillary refill time (CRT) from the acquired images or optical data, an optional transmitter 106 for transmitting calculated patient information off the mobile or wearable device 102, and memory 108 for storing calculated patient data. In some embodiments, a user interface 112 (for example, a multi-function patient monitor, a nurses' station computer, or so forth) is interconnected via a communications network 110 to receive the CRT value transmitted from the mobile device 102. Additionally or alternatively, the device 102 may display the CRT value on a display screen 114 of the device 102 without transmitting it (note that the electronic components 104, 106, 108 are typically disposed inside the mobile or wearable device 102, so that they are occluded by the display screen 114), and the value is suitably read and entered into the patient record manually by the doctor, nurse, or other medical professional acquiring the CRT. It is contemplated that the communications network 110 includes one or more of the Internet, an Intranet, a local area network, a wide area network, a wireless network, a wired network, a cellular network, a data bus, a Bluetooth, infrared, or other short-range wireless connection, and the like. It should also be appreciated that the components of the system may be located at a central location or at multiple remote locations.

The one or more processors 104 suitably execute computer executable instructions embodying the foregoing functionality and controlling the camera 103 to acquire the images or optical data, where the computer executable instructions are stored on the memory 108 associated with the processors 104. It is, however, contemplated that at least some of the foregoing functionality is implemented in hardware without the use of processors. For example, analog circuitry can be employed to implement some of the operational/control functions of the camera 103. Further, the components of the system 100 optionally include transmitter units 106 providing the processors 104 an interface from which to communicate over the communications network 110 and provide the information to the physician over the user interface 112.

With reference to FIGURE 2(a), in one illustrative embodiment the mobile device 102 of FIGURE 1 comprises a camera-equipped mobile device 200 (for example, a camera-equipped cellular telephone, a camera-equipped tablet computer, or so forth) with an integrated light source (e.g., an LED) 202, the integrated light source being conventionally used as a flash light for still picture photography, or as a torch light for sustained

illumination, e.g., for taking videos, and a camera **204.** In general, the camera **204** includes a charge-coupled device (CCD), CMOS or other image sensor array optically coupled with a lens (which could be a pinhole lens, although typically a refractive lens element such as a compound lens is provided). In some embodiments, the camera **204** may be configured to provide adjustable focus. The camera-equipped mobile device **200** is configured by suitable firmware or software to operate the light source **202** and camera **204** to acquire photographs of people, places, objects, or so forth. For example, the camera may be a "point-and-shoot" camera. As disclosed herein, the camera is additionally configured, for example by way of a suitable application program ("app") **206** (diagrammatically indicated in FIGURE 2(a)) executing on the mobile device **102,** to perform capillary refill time (CRT) measurement using the camera **204** and light source **202.** For example, the mobile device **200** may be running the iOS mobile operating system (available from Apple Corp. Cupertino, CA, USA) and the CRT app **206** is an iOS app. In another embodiment, the mobile device **200** runs the Android mobile operating system and the CRT app **206** is an Android app.

With reference to FIGURE 2(b), to measure capillary refill time, a clinician would start the CRT app **206,** for example by touching an icon representing the CRT app **206** shown on a display of the mobile device **200.** (The display is on the opposite side of the mobile device **200** and hence is not visible in the views of FIGURES 2(a) and 2(b)). The CRT app **206** then prompts the user (for example, via text shown on the display and/or via a simulated voice message) to place one of the patient's fingers **210** over both the camera **204** and the integrated light source **202,** and hold it there for a few seconds without pressing. After a few seconds, the clinician is prompted by the CRT app **206** to press or squeeze the patient's finger **210** onto the camera **204** for a few seconds, and then to release the pressure on the patient's finger while holding the patient's finger **210** there for another few seconds. (In an alternative embodiment, the CRT app **206** does not prompt the clinician to press or squeeze the finger but instead monitors the output of the camera **204** to detect this operation automatically based on optically detected blanching of the finger.) In conjunction with the test, the CRT app **206** operates the integrated light source **202** to cause the light source **202** to generate light that illuminates the finger **210** at least proximate to the point where the finger is pressing against the camera **204.** It will be noted that the light source **202** is laterally offset from the camera **204,** so that the light source **202** does not directly illuminate the point where the finger is pressing against the camera **204.** However, the inventors have found that a typical human finger is sufficiently translucent that a sufficient amount of light "leaks" from the light source **202** into the field-of-view of the camera **204** to provide illumination for the

CRT measurement. The CRT app **206** calculates the patient's CRT by analyzing the camera image stream generated by the camera **204.** In one approach, the CRT analysis makes use of the Red and/or Green and/or Blue component of the image stream, and looks for signal distortions (e.g. color changes) that identify the onset of squeezing, a second distortion that identifies the release, and, finally, the return of the signals to their pre-squeeze characteristics. The CRT can be derived from the time elapsed between the latter two events.

In some mobile operating systems, low-level access to the camera may be unavailable. In such cases, the detection of the onset of finger pressure, release of the finger pressure, and measurement of the color return is suitably based on a time series of "images" acquired by the camera. For example, in video mode the camera acquires a time series of images (frames), typically at a rate of 30 frames (images) per second, which is fast enough for good CRT temporal resolution. Since the finger **10** is pressed against the camera **204,** the acquired "images" are not actually in-focus; however, the integrated intensity per frame (for example, computed as the average pixel intensity per frame) is a suitable metric for the skin color and can be used to characterize the color return.

With reference to FIGURE 2(c), in a variant embodiment, a patient's CRT is calculated using the hardware described with reference to FIGURE 2(a) and further including a cuff **212** (shown in dashed outline form in FIGURE 2(c)) that is clipped over the light source **202** and the camera **204** of the mobile device **200** prior to the CRT measurement. The patient slips his or her finger into the cuff **212,** which shields it from environmental light during the measurement. In one embodiment, the cuff **212** is a passive cuff that is non-transparent and flexible, the latter in order to allow the clinician to squeeze the finger while in the cuff. The passive cuff provides finger alignment, and may include a soft material to cushion and distribute the applied pressure on the finger.

In another embodiment, the cuff **212** is a rigid or inflatable cuff that also serves as a mechanical device for applying pressure to the finger. In this approach, a patient's CRT is calculated using the rigid or inflatable cuff **212** for shielding the finger from environmental light during CRT measurement. In a rigid cuff embodiment, the cuff includes one or more built-in servos motors (not shown) that perform the squeeze-and-release actions, allowing for standardized pressures. In an inflatable cuff embodiment the cuff is inflatable, for example using a diaphragm pump built into the cuff, to apply the pressure to the finger in the inflated state. In either a rigid or inflatable embodiment, pressure sensors (not shown) are optionally included to provide positive feedback regarding the applied pressure.

Advantageously, servo motors of the rigid cuff **212** (or the inflation unit of an inflatable cuff) are controlled by the CRT app **206** allowing the app **206** to know the exact release time.

Although the cuff **212** is described as non-transparent or opaque, this is not necessarily required. Ambient light is problematic insofar as it may include transients that can interfere with the capillary refill monitoring, or may be so bright as to reduce sensitivity of the capillary refill monitoring. Typically ambient light intensity is essentially constant in a doctor's office or hospital over the time frame of the CRT measurement, so cuff opacity may not be essential, or a translucent cuff may be sufficient. Even if the cuff **212** is not designed to block ambient light, it may be useful to guide the patient's finger into the proper position for the CRT measurement, and as already described in some embodiments the cuff **212** also provides the active pressure for the CRT measurement.

With reference to FIGURE 3, in another illustrative embodiment the device **102** of FIGURE 1 is a wearable device, such as an illustrative optical head-mounted display (OHMD) **300** having the form of eyeglasses (i.e. spectacles). The OHMD **300** includes a camera **302,** and the display of the OHMD **300** serves as a monitor for feedback. The device **300** further includes a microprocessor or microcontroller running an application program ("app") **306** to perform the capillary refill time (CRT) measurement. In one contemplated embodiment, the OHMD **300** is a Google Glass unit (available from Google, Mountain View, CA, USA) running an application program ("app") **306** under a Google Glasses-specific version of the Android mobile operating system. To perform a CRT measurement, the clinician wears the OHMD **300** and views the hand **304** of the patient whereby the camera **302** is focused on the hand **304.** The CRT measurement may be initiated in various ways, such as by an instruction provided to the clinician via the display of the OHMD **300** or via a simulated voice generated by the OHMD unit **300,** or by a verbal command spoken by the clinician and detected by a voice recognition component of the OHMD **300,** or by automatic detection of the hand **304** in the field-of-view of the camera **304** identified using suitable image segmentation techniques, or so forth. The camera **302** detects the fingernail of interest (or alternatively views the finger pad side of the finger), performs a baseline color assessment, and provides a baseline color index (e.g. peak intensity or AUC of the finger nail intensity histogram of the red channel). Then, the clinician applies pressure to the finger nail of interest for a few seconds. When the physician releases the finger, the camera **302** re-detects the finger and records its color in each video frame, for example, over ten seconds at 30 frames/sec. The camera **302** can capture the color changes in the patient's finger using video recording or a time sequence of still images (i.e. photographs) to be analyzed. After

completion of the recording, the CRT is determined by determining the video frame or still photo where the finger nail regained its baseline color, or by fitting a mathematical function to the measured color in the sequential video frames for more reproducible determination of the capillary refill time.

It will be noted that the embodiment of FIGURE 3 differs from the embodiments of FIGURES 2(a), (b), (c) in that there is no analog to the camera light source **202.** The embodiment of FIGURE 3 relies on ambient light in order to acquire images of the fingernail. Additionally or alternatively, it is contemplated to include a light source or other light source on the OHMD **300.**

With reference to FIGURE 4 a process flowchart is shown diagramming an illustrative method **400** for measuring a patient's capillary refill time. The method **400** is suitable for devices, such as the camera-equipped device **200** of FIGURES 2(a), 2(b), 2(c), that have a camera and light source that are close enough to cover with a single finger digit. In an operation **402,** the CRT app **206** is started on the mobile device **200.** The CRT app **206** turns on the light source **202** in an operation **404** and activates the camera **204** in an operation **406.** In an operation **408,** the patient's finger is pressed to the camera, and the camera calculates the baseline color of the patient's finger in an operation **410.** The baseline color is the starting point from which the camera will detect the patient's capillary refill time. After baseline measurement operation **410,** a clinician (or the automatic cuff **212** in embodiments including same) squeezes or presses (i.e. applies pressure to) the patient's finger for a defined amount of time in an operation **412.** For example, the patient's finger is pressed for 3 seconds in some suitable embodiments. At the end of the operation **412,** the clinician or the automatic cuff then releases the patient's finger. In an operation **414** the camera takes video images (frames) or a time series of still images of the patient's finger as the capillaries refill with blood, and the CRT app **206** calculates the patient's CRT as the amount of time elapsed until the patient's finger returns to its baseline color after being squeezed. Optionally, in an operation **416** the CRT app **206** classifies the data into a classification group for the clinician. For example, the classification groups could be classified as 'very low' (e.g. CRT<1 sec), 'low' (e.g. CRT=l-2 sec), 'normal' (e.g. CRT=2-3 sec), 'high' (e.g. CRT=3-4 sec), or 'very high' (e.g. CRT>4 sec). In an operation **418,** the CRT value and/or the optional CRT classification information is sent to the user interface for the clinician to review.

CRT measurement using the OHMD **300** of FIGURE 3 can be similarly performed. Here there is no analog to the operation **404,** and the operation **408** corresponds to focusing the camera **302** onto the fingernail, for example by having the clinician wearing the

OHMD 300 look at the fingernail. An image segmentation algorithm may optionally be applied to more particularly identify the fingernail region in the image.

With reference to FIGURE 5 an illustrative example of the optical signal acquired by the camera 204 of the mobile device 200, or by the camera 302 of the OHMD 300, during the CRT measurement is shown. This diagram is generated by the CRT app 206, 306, and may in some embodiments be displayed for the clinician on the user interface. A region 502 of the diagram indicates the baseline optical signal before any pressure is applied 502. When pressure is applied (indicated by arrow 504), the optical signal undergoes a rapid transient 504. The nature of this transient depends upon the specific arrangement of the camera, illumination, and source of pressure. FIGURE 5 shows the transient 504 as a sharp decrease in signal, which may occur because the clinician's hand applying the pressure occludes view of the fingernail. On the other hand, for the embodiment of FIGURES 2(a), 2(b), 2(c) the transient may be different since the view of the camera 204 is never occluded. When the pressure from either the clinician or the pressure cuff is released, a further transient 508 may be observed. Thereafter, as the capillaries refill with blood, the camera captures the corresponding color change and the time is recorded in the integrated application 410. When the color returns to the baseline color, the integrated application stops recording and calculates the CRT.

It will be appreciated that the capillary refill time (CRT) may be quantified in various ways. In one approach, the CRT is taken as the time at which the rising signal in region 510 returns to the baseline signal level observed in the region 502. However, this approach can be prone to some error - for example, in some cases, it has been observed that the signal may briefly overshoot or undershoot the baseline. Improved accuracy can be obtained by characterizing the shape of the recovery curve in the region 510, for example by determining a time constant assuming an exponential shape in the recovery region 510. Another approach is to take the CRT as the 90% recovery time (or some other designated point), that is, the time for the optical signal to reach 90% of the baseline value, which can reduce the impact of overshoot or undershoot on the accuracy of the CRT measurement.

The CRT measurement process also includes determining the "start" time, that is, the time at which the pressure applied to the finger is removed. This can be done in various ways. In prospective approaches, a control signal is provided in real-time to indicate removal of the pressure. For example, in embodiments in accord with FIGURE 2(c) that include an actuated cuff 212, the control signal suitably corresponds to removal of the applied pressure by the cuff 212. In manual pressure approaches, a prospective start time can

be taken as a time that the physician is instructed to release the pressure, but this assumes the physician promptly does so. In retrospective approaches, a time series of images/frames, or a camera channel (e.g. red, green, or blue channel) signal measured as a function of time, is acquired over a time interval sufficient to encompass the capillary refill time interval. For example, start of the acquisition of the video stream may be triggered by a signal to the clinician to begin the CRT test, and the video stream may be stopped after a fixed time interval of several seconds to tens of seconds or by a stopping criterion applied to the measured images/frames/signal. In these retrospective approaches, signal processing is applied to detect the release of pressure corresponding to the "start" time. To illustrate, in the example of FIGURE 5 the "start" time can be detected by detecting the signal loss during occlusion **506** followed by the (near instantaneous) signal jump when the occlusion is removed - the latter is a suitable definition of the "start" time.

The optical signal that is monitored to assess the capillary refill process can also be variously chosen. As some illustrative examples, the optical signal may be a color value (e.g., measured using suitable color coordinates in CIE coordinate space or another color space), a tint or shade value, an intensity value (for a particular color channel or for the measured light without any spectral decomposition), or so forth.

In the illustrative embodiments, the CRT is measured for a finger, and conventionally CRT is measured for a finger. However, it is also contemplated to employ the disclosed CRT measurement devices to measure capillary recovery time for skin in other anatomical regions, such as the earlobe or forearm. In general, the CRT measurement entails applying pressure to the skin of the finger (or earlobe, or forearm, et cetera) to blanch the skin at the point of pressure, and then optically measuring the capillary recovery time for the skin at the point of pressure upon removal of that pressure.

The invention has been described with reference to the preferred embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be constructed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS:

1. A capillary refill time (CRT) measurement device operative to measure CRT for a finger upon release of pressure applied to the finger, the CRT measurement device comprising:

a mobile or wearable device **(102, 200, 300)** including a camera **(204, 302),** a display component **(114),** and an electronic processor **(104)** programmed to perform a CRT measurement by operations including:

operating the camera to measure an optical signal from the finger over a time interval encompassing the CRT,

determining a CRT value based on analysis of the measured optical signal, and

displaying the determined CRT value on the display component.

2. A (CRT) measurement device of claim 1, wherein the mobile or wearable device **(102, 200, 300)** is one of a cellphone **(200)** or an optical head-mounted display **(300).**

3. The CRT measurement device of any one of claims 1-2 wherein the mobile or wearable device includes a camera light source **(202)** offset laterally from the camera **(204, 302)** and operating the camera includes operating the camera light source to illuminate the finger at least during the time interval encompassing the CRT.

4. The CRT measurement device of any one of claims 1-3, wherein operating the camera **(204, 302)** comprises operating the camera to acquire video or a time sequence of still images of the finger, and the determining comprises determining the CRT value based on the acquired video or time sequence of still images.

5. The CRT measurement device of any one of claims 1-4 further including a cuff **(212)** clipped over the camera **(204)** to shield the finger **(210)** from environmental light.

6. The CRT measurement device of claim 5, wherein the cuff **(212)** is non-transparent and flexible.

7. The CRT measurement device of claim 5, wherein the cuff is a rigid or inflatable cuff **(212)** and the electronic processor **(104)** is programmed to perform the CRT measurement by the further operation of operating the rigid or inflatable cuff to apply pressure to the finger.

8. The CRT measurement device of claim 7, wherein the rigid or inflatable cuff **(212)** is a rigid cuff that includes one or more built in servo motors for applying standardized pressure to the subject's finger **(210)** wherein the one or more built in servo motors are controlled by the electronic processor.

9. The CRT measurement device of any one of claims 1-8, wherein the electronic processor **(104)** is programmed by an integrated CRT application **(206, 306)** to perform a CRT measurement.

10. The CRT measurement device of any one of claims 1-9, wherein the operation of determining the CRT value based on analysis of the measured optical signal includes identifying the beginning of a capillary refill time interval by one of an instruction provided by the clinician, or by automatic detection of the hand **304** in the field-of-view of the camera **(204, 302).**

11. The CRT measurement device of any one of claims 1-10, wherein the operation of determining the CRT value based on analysis of the measured optical signal uses Red and/or Green and/or Blue component of a camera image stream generated by the operation of operating the camera **(204, 302)** to detect signal distortions to calculate the CRT.

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12. A non-transitory storage medium storing instructions readable and executable by the processor of a mobile or wearable device that further includes a camera and a display component to perform a method comprising:

operating the camera of the mobile or wearable device to detect a signal indicating a subject's finger;

monitoring the signal to detect addition and removal of pressure applied to the subject's finger;

analyzing the signal to detect a recovery time; and

displaying a capillary refill time (CRT) value based on the recovery time on the display component of the mobile or wearable device.

13. The non-transitory storage medium of claim 12, wherein the method further includes operating a transmitter **(106)** of the mobile or wearable device to communicate the CRT value over a communication network **(110)** to a user interface **(112)** for use by a clinician for analysis and treatment of the subject.

14. A method for measuring capillary refill time, the method comprising:

starting an integrated application **(206, 306)** on a mobile or wearable device **(102, 200, 300),** the integrated application programming the mobile or wearable device to:

detect a subject's finger using a camera **(204, 302)** of the mobile or wearable device;

prompt a clinician to press or squeeze the subject's finger **(210)** and then to release the pressure on the subject's finger;

measure an optical signal from the subject's finger using the camera of the mobile or wearable device;

calculate the capillary refill time based on analysis of the measured optical signal; and

display the capillary refill time to the clinician on a display component **(114)** of the mobile or wearable device.

15. The method according to claim 14, wherein the integrated application **(206, 306)** uses at least one of red, green, and blue component of the camera image stream to determine color changes in the patient's finger.

16. The method according to any one of claims 14-15, wherein the mobile device **(200, 300),** includes a camera light source **(202)** offset laterally from the camera **(204, 302)** and the measurement of the optical signal from the subject's finger using the camera further includes illuminating the subject's finger during the measurement using the camera light source.

17. The method according to any one of claims 14-16, wherein the integrated application **(206, 306)** is configured to control a rigid cuff with at least one integrated servo motor to depress the patient's finger with a specified amount of force.

18. The method according to any one of claims 14-17, wherein the integrated application **(206, 306)** is configured to control an inflatable cuff to depress the patient's finger with a specified amount of force.

19. The method according to any one of claims 14-18, wherein the optical signal is measured by acquiring video images or still images of the subject's finger using the camera

and the capillary refill time is calculated by analyzing the video images or still images of the subject's finger and calculating the CRT as an amount of time elapsed until the subject's finger returns to its baseline color after being squeezed.

20. The method according to any one of claims 14-19, wherein the integrated application **(206, 306)** classifies the CRT data into a classification group as 'very low', 'low', 'normal', 'high', or 'very high'.

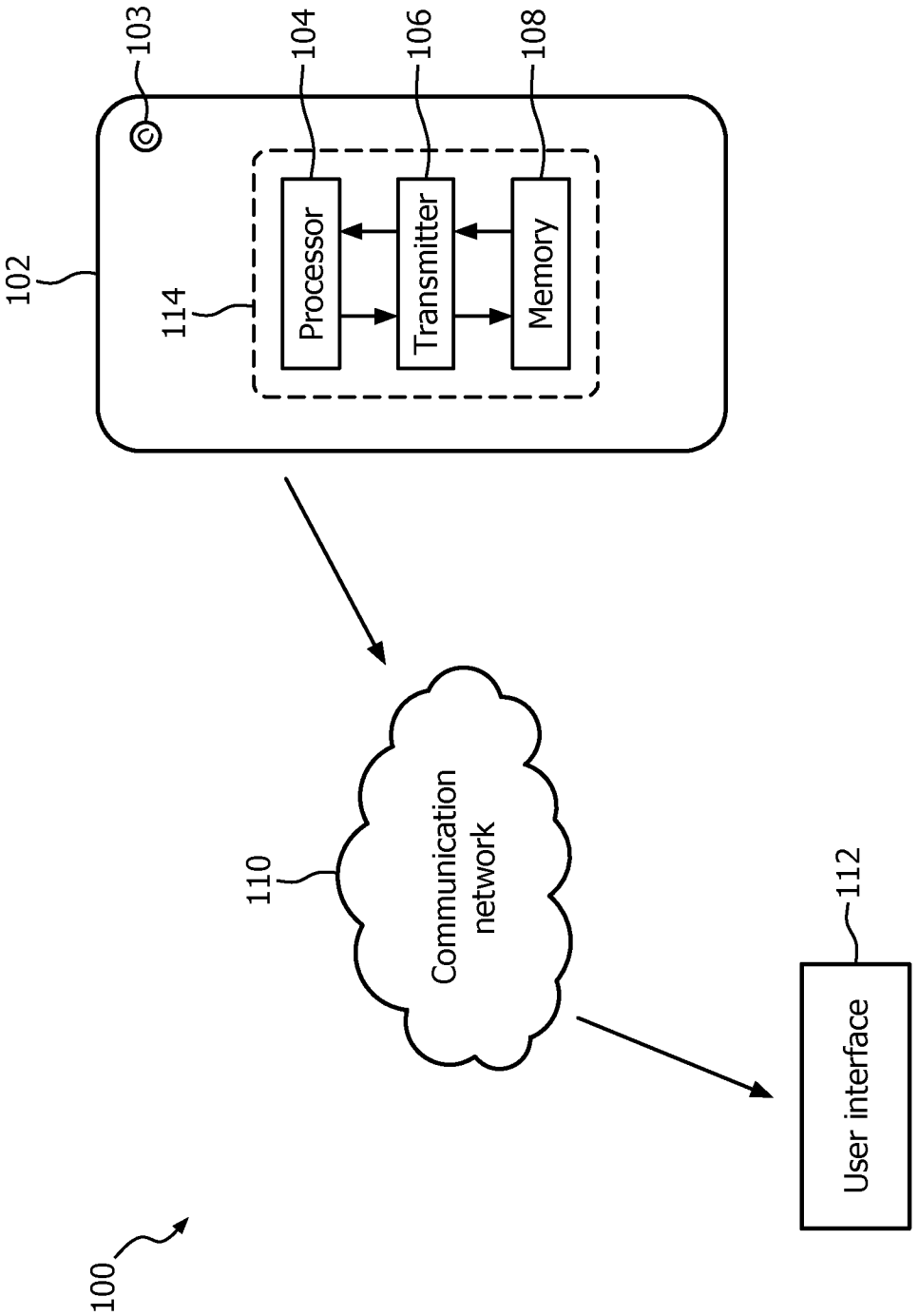
100
102
103
104
106
108
114
Processor
Transmitter
Memory
110
Communication network
112
User interface

FIG. 1

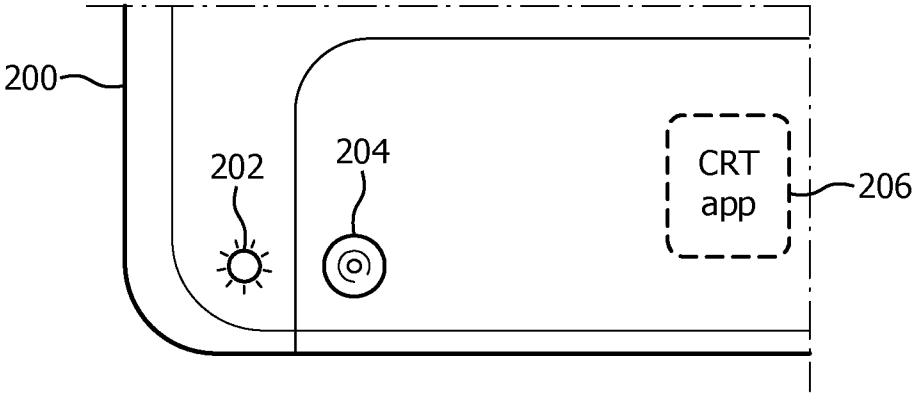

FIG. 2A

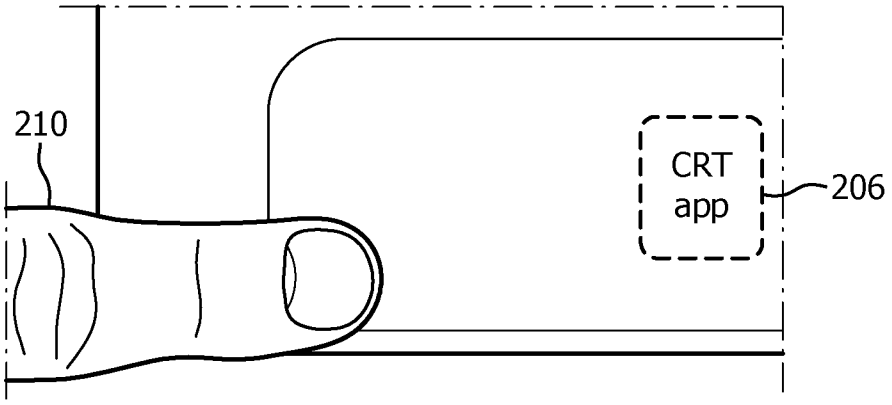

FIG. 2B

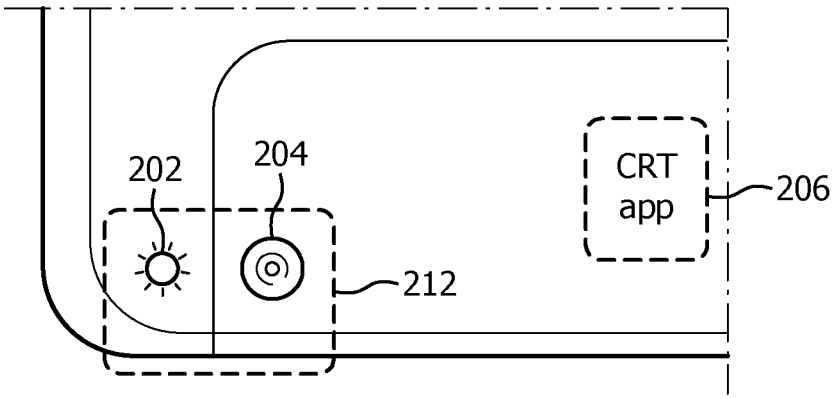

FIG. 2C

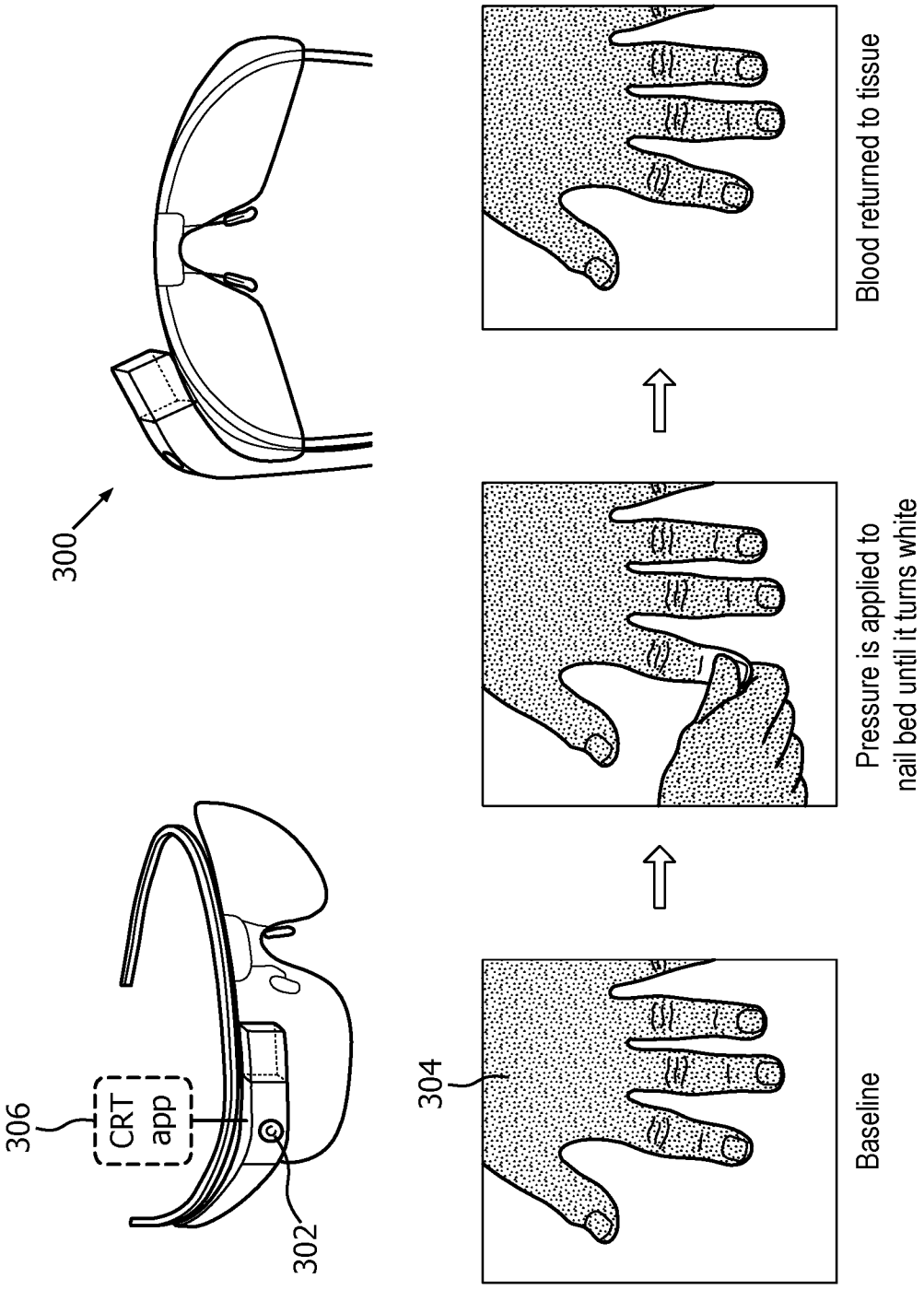
300
306
CRT app
302
304
Baseline
Pressure is applied to nail bed until it turns white
Blood returned to tissue

FIG. 3

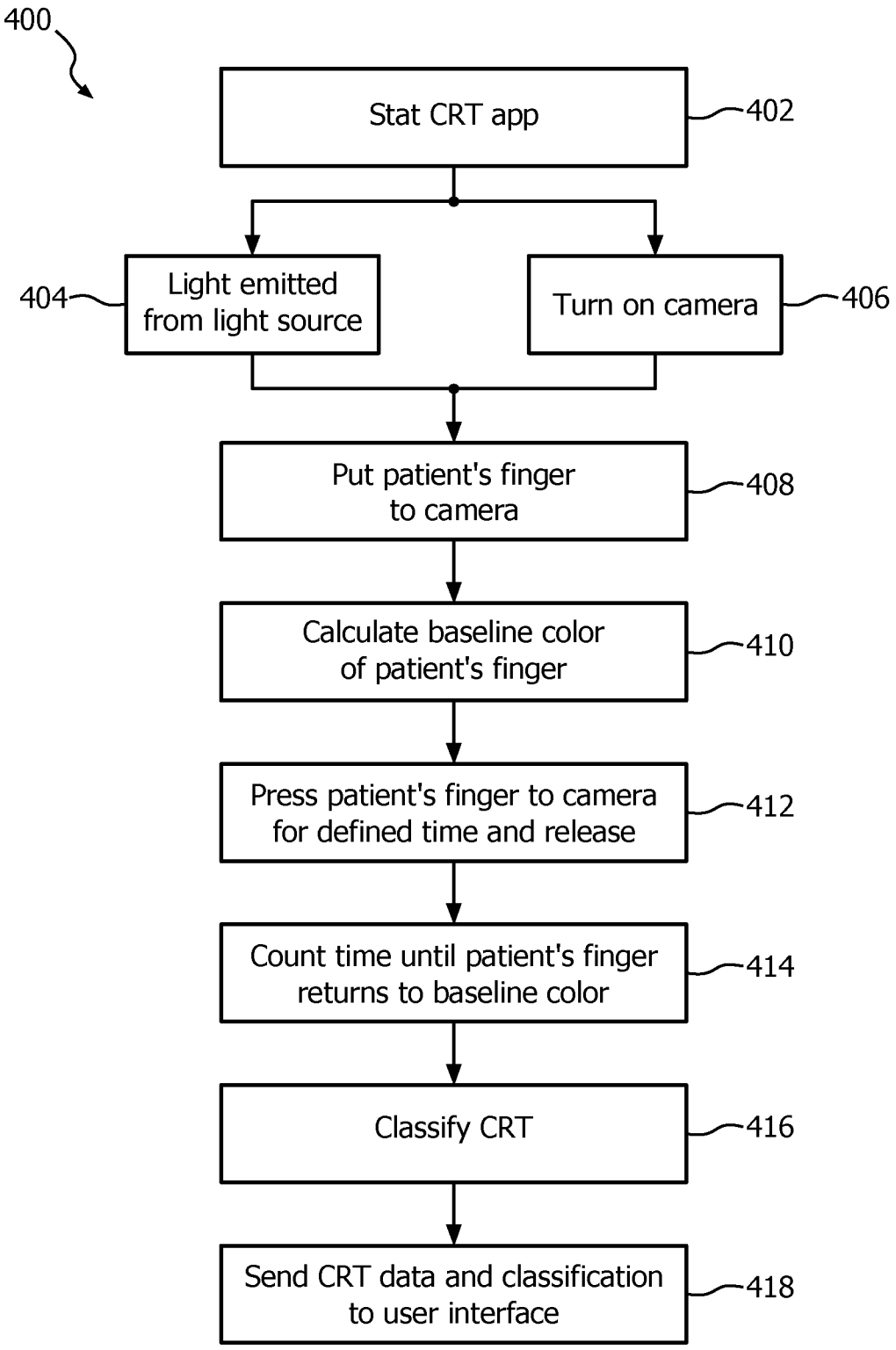
400
Stat CRT app
402
Light emitted from light source
404
Turn on camera
406
Put patient's finger to camera
408
Calculate baseline color of patient's finger
410
Press patient's finger to camera for defined time and release
412
Count time until patient's finger returns to baseline color
414
Classify CRT
416
Send CRT data and classification to user interface
418

FIG. 4

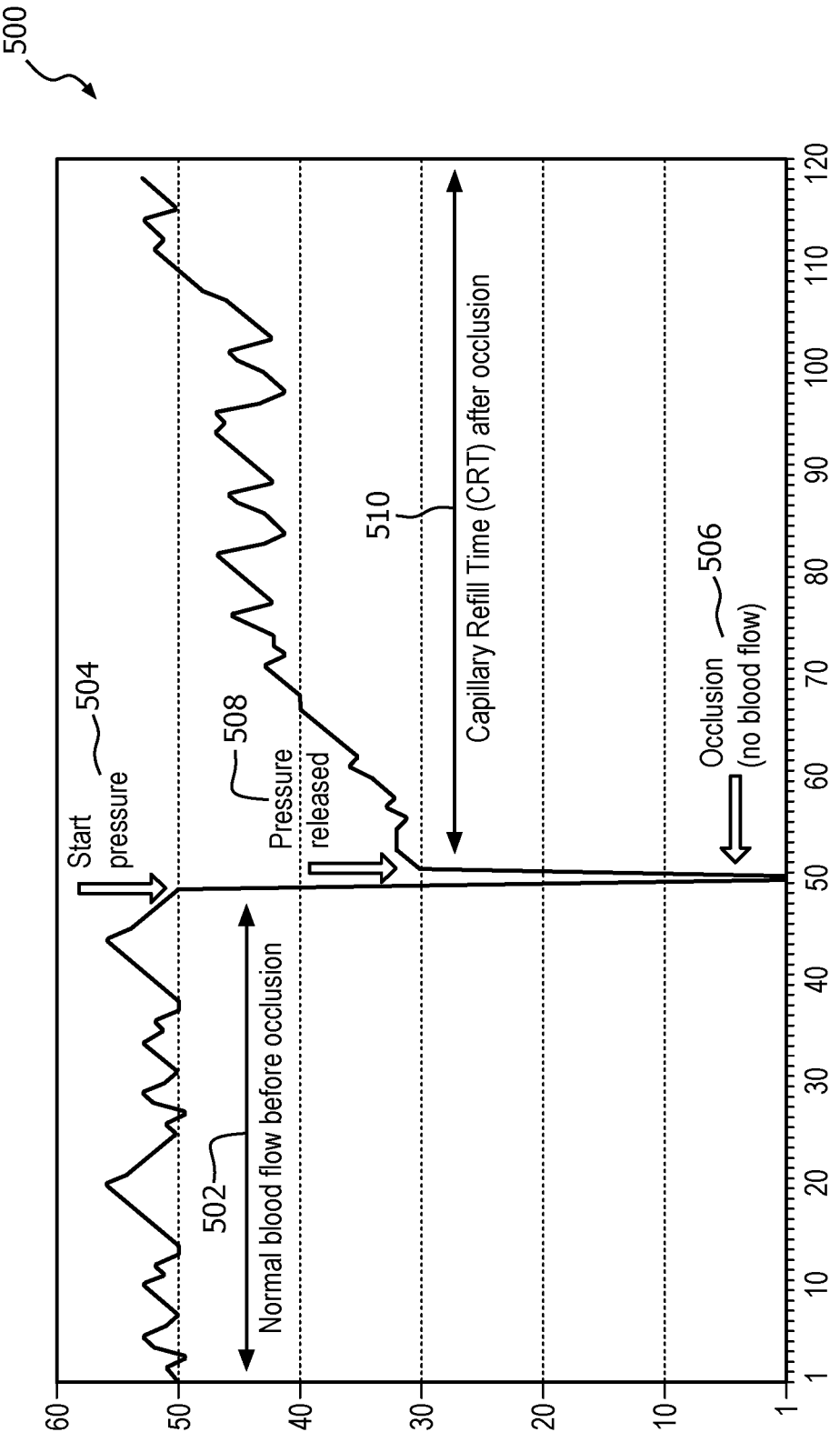
500
Start pressure
504
Pressure released
508
Capillary Refill Time (CRT) after occlusion
510
Occlusion (no blood flow)
506
Normal blood flow before occlusion
502
60
50
40
30
20
10
1
1
10
20
30
40
50
60
70
80
90
100
110
120

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/059596

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/00
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)
A61B

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 , INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 01/06926 Al (SHANI HAIM [IL] ; SHAVIT ITTAI [IL]) 1 February 2001 (2001-02-01) the whole document	1-20
Y	US 2014/018647 Al (SEGMAN YOSEF [IL]) 16 January 2014 (2014-01-16) the whole document	1-20
Y	US 2013/245396 Al (BERMAN DAVID [US] ET AL) 19 September 2013 (2013-09-19) paragraph [0017] - paragraph [0019] figure 1.2	2
A	US 2009/203998 Al (KLINGHULT GUNNAR [SE] ET AL) 13 August 2009 (2009-08-13) the whole document	1-20

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"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" documentwhich may throw doubts on priority claim(s) orwhich 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
22 February 2016	03/03/2016

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

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/059596

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/072145 A1 (DANTU RAMANAMURTHY [US]) 21 March 2013 (2013-03-21) paragraph [0013] - paragraph [0037] claims 1-3 figures 1-21	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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		US 2014018647 A1	16-01-2014
		WO 2014013387 A1	23-01-2014
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