

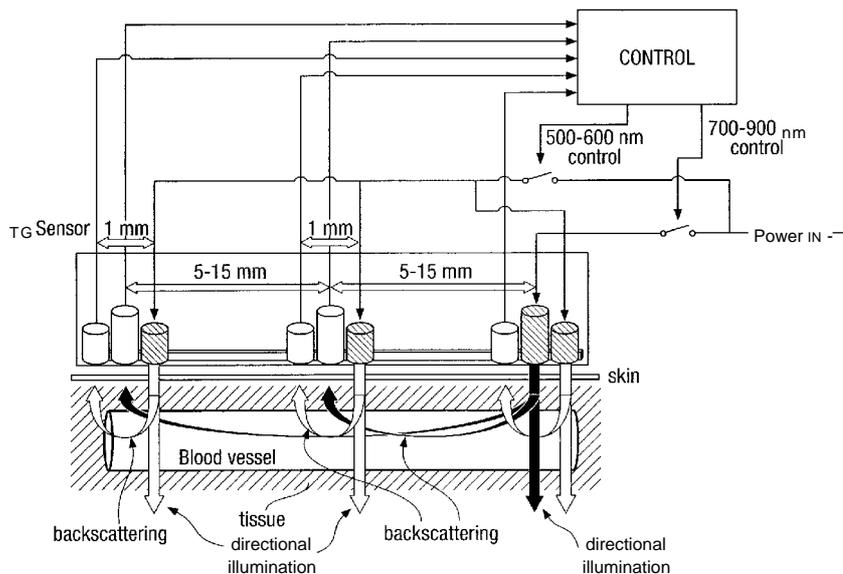


- (51) **International Patent Classification:**  
A61B 5/1455 (2006.01) A61B 5/145 (2006.01)  
A61B 5/00 (2006.01)
- (21) **International Application Number:**  
PCT/CA20 15/050897
- (22) **International Filing Date:**  
16 September 2015 (16.09.2015)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**  
62/05 1,341 17 September 2014 (17.09.2014) US
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- (81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Published:**  
— with international search report (Art. 21(3))

(54) **Title:** DEVICE AND METHOD FOR MONITORING FAT BALANCE



**FIG. 4D**

(57) **Abstract:** A Device and method for monitoring the balance between the amount and type of food consumed versus the physical activity.



## DEVICE AND METHOD FOR MONITORING FAT BALANCE

### BACKGROUND

[0001] Many Individuals both adults and children worldwide (especially in the industrialized societies) are overweight or obese. Overweight and obesity are major risk factors for cardiac diseases, cancer, diabetes and other diseases. Obesity is due to a sustained positive energy balance, i.e. in which an individual energy intake is greater than his energy expenditure for long time periods (weeks, months, years). Weight gain is typically coupled with low levels of physical activity and sedentary lifestyles, together with over consumption of food containing high levels of carbohydrates and fats. In order to maintain weight, one have to balance his energy intake versus energy expenditure, and in order to lose weight one have to keep his energy intake lower than his energy expenditure for long time period (weeks to months). In order to do so there is a need for providing an objective and continues feedback to the person regarding his energy balance during each day, and at the end of each day enabling him manage his food consumption versus his activity, for achieving an energy gap or the balance needed for weight loss or control.

[0002] Due to the importance of the problem, many solutions were suggested; however no good solution has been founded yet. Current solutions are based on using a wearable device that estimates user's energy expenditure 24/7, using an accelerometer. The accelerometer identifies body movements and estimation of energy expenditure is done, based on movement's pattern. Devices that provide energy expenditure estimation based

on heart rate pulse, and/or Global Positioning Systems are also available. For estimating energy intake, the user has to log manually the amount and type of food he consumed and to estimate the caloric value of the food consumed. Since both estimations of energy expenditure and energy consumption are extremely non accurate, it is prohibit calculating the true caloric balance on a daily or an hourly interval, thus prohibiting from providing the needed feedback for managing the energy balance. Therefore, a method, and a wearable device, that can provides an objective and accurate data regarding user caloric balance, in real time, is highly needed. This data will enable the user to control his food amount and type for the day, and to know whether he had burned more energy than consumed. The real time daily feedback is a powerful tool for changing habits and acquiring a healthier life style regarding nutrition and physical activity.

#### **BRIEF SUMMARY OF THE INVENTION**

[0003] This invention provides a new method and device for providing a real time feedback to an individual regarding the balance between the amount and type of food consumed, and his physical activity intensity and duration, in order to reduce the access amount of fat stored in the body or to prevent accumulation of fat.

[0004] The new method is based on continues or sequential measurement or estimation of triglycerides (TG) concentration in blood or total triglycerides (TTG) concentration in blood or TG-rich lipoproteins (TRL) particles ( e.g. chylomicrons (CM), very low density lipoproteins (VLDL)) concentration in blood. Blood TTG are known to be a surrogate for TRL. Consumption of excess fat increases TRL and TTG blood levels, the increase start about 1 hour after fat consumption, and reach to a peak value after 2-3 hours (Richard B

et al. 2003). Consumption of excess carbohydrate or alcohol increases TRL levels by increasing the liponeogenesis (Regina M McDevitt et al. 2001, Kevin Jacheson et al. 1988). Liponeogenesis is the conversion of the carbohydrate excess, mainly by the liver, to TG, and its secretion as VLDL to the blood circulation system for transfer to long term storage in fat tissue. Increase in physical activity causes faster clearance of TRL from the blood vessels and reduced VLDL production. Increase in physical activity causes a decrease in the fasting TTG level in the morning after the day where the activity was performed (Elena Bellou et al. 2013), see figure 1 A and B. The TRL and TTG blood levels at any given time represent the bottom line of the excess fats and carbohydrate consumed, that are about to be cleared from the blood circulation and stored in the fat tissue. When there is a need for using the fat as energy, the triglycerides in the fat tissue are firstly degrade to a small fatty acid fragment that travel in the circulation, not as lipoprotein particles, and later oxidized in the cells. Therefore, continues monitoring of TTG or TRL levels in the blood can be used as biomarker for the balance between the amount carbohydrate and fats consumed and physical activity intensity and duration. This biomarker assists in preventing accumulation of fat in the body, or reducing the amount of fat stored in the fat tissues.

**[0005]** The measurement of TTG or TRL in this invention can be done at least once in 24 hours, or at least twice in 24 hours, or at least every 6 hours, or at least every 3 hours. The results are recorded and analyzed as follows: The baseline level of the TTG or TRL is defined as TTG or TRL level that is measured in the early morning time before wake up, or before the first meal of the day during the morning time, for example, at between 2 am to 6am. In another embodiment of the invention the first baseline measurement is

done after the user was in fasting of at least 6 hours or at least 8 hours, or at least 10 hours before the baseline measurement, and this value can be further used as a reference baseline for comparison to the following baseline measurements. In each of the following days, a baseline level is measured and set at early morning time. The baseline value is then subtracted from the following measurements of the day, and the net TTG values (TTG value after subtraction of the baseline) for the following measurement are accumulated, i.e. an integral is calculated of the area confined between the net TTG and the baseline level, see figure 2. This net accumulated TTG value (NATTG), is affected by the daily food consumption and activity balance and acts as a biomarker for food versus activity balance.

[0006] In yet another embodiment of the invention the NATTG is calculated over the baseline value that is zero. In yet another embodiment of the invention the NATTG is calculated based on a reference baseline values that was measured after fasting. A reference NATTG accumulation graph for every time of the day is set by calculation of the average NATTG values recorded in a group of apparently healthy individuals, during at least one full day, in which they were balanced regarding the caloric intake and caloric expenditure. A reference baseline value is set by calculation of the average baseline values recorded in a group of apparently healthy individuals, during at least one full day, in which they were balanced regarding the caloric intake and caloric expenditure. By comparing the individual NATTG value of the user, as measured in a certain time point to a reference NATTG value measured in the same time, the user gets a feedback for the given time, regarding how far he is from a balance point for the time passed from setting the baseline value. In yet another embodiment of the invention the reference is set as the

NATTG profile of the user in a former day, in yet another embodiment as an average value of the user for past several days, at least 3 days, at least 10 days, at least 30 days or at least 365. In yet another embodiment of the invention the user is comparing the daily baseline value to a reference baseline TTG value that was calculated as the average TTG value of a group of apparently healthy individuals that were balanced in the day before measurement regarding caloric intake and expenditure. In yet another embodiment the value is calculated based on the average baseline of the user in former day, in the former days for at least 3 days, at least 10 days, at least 30 days, or at least 365.

[0007] The measured baseline and NATTG values are used to direct the user how to manage his food consumption versus his physical activity in order to maintain or lose weight by maintaining or decreasing the amount of fat tissue in his body. The objective of the user is to achieve NATTG value that will not be higher than the reference value. If the NATTG is above reference value, the user has to increase his physical activity and/or decrease his fats and carbohydrates consumption. If the user wants to reduce weight he has to maintain NATTG values lower than the NATTG reference value for at least one day, or at least one week or at least one month. In yet another embodiment of the invention the objective of the user is to achieve baseline TTG value that will not be higher than the reference baseline TTG value. If the baseline TTG is above reference value in the following day, the user has to increase his physical activity and/or decrease his fats and carbohydrates consumption during the following day. If the user wants to maintain weight he has to maintain, each day, baseline TTG values that are similar to the reference baseline. If the user wants to reduce weight he has to maintain each day, a

lower baseline TTG than the reference baseline TTG. Figure 3 describes the flowchart of the method.

[0008] In one embodiment of this invention the estimation of TTG blood level can be done non-invasively by measurement of light scattering coefficient of the blood in a blood vessel near the skin. Increase in concentration and size TRL particles increases the blood light scattering coefficient. In yet another embodiment the measurement of the blood light scattering coefficient can be done by an implemented device located under the skin near a blood vessel.

[0009] The estimation of the blood light scattering coefficient can be done by illuminating continuous light at a point on the skin just above a blood vessel that is close to the skin surface, and measuring the intensity of the backscattered light at another point with the distance p from the light source, above the same blood vessel. The backscattered light detection point is located above the same blood vessel, in such a way the backscatter light passed mostly through the interior of the said blood vessel.

[00010] From the diffusion equation, the distribution of the backscattered light detected at distance p, ( R(p)) from the light source, is given by:

$$R(\rho) = \frac{S_0 z_0}{2\pi} \left( \mu_{eff} + \frac{1}{\sqrt{\rho^2 + z_0^2}} \right) \frac{\exp \left( -\mu_{eff} \sqrt{\rho^2 + z_0^2} \right)}{\rho^2 + z_0^2}$$

Where

$$z_0 = \frac{1}{\mu_s'} - H_{eff} = \sqrt{3\mu_a(\mu_s' + \mu_a)}$$

[00011]  $S_0, \mu'_s, \mu_a$  are the intensity of the light source, the (reduced) scattering coefficient and the absorption coefficient of the blood, respectively. If  $S_0, \mu_a$  and  $p$  are fixed during repeated measurements, the changes in  $R(p)$  correlated to the changes in the light scattering coefficient of the blood. Increase in  $R(p)$  indicates decrease in the  $\mu'_s$  and vice versa. In one embodiment of the invention the measurement of the changes in the blood scattering coefficient is done by using one light source and one detector at distance of 3-30 mm, or 5-15mm between them. See figure 4 A.

[00012] Using some algebra and approximation, the previous equation is reduced to

$$R(p) = \frac{S_0}{4\pi} \frac{3\mu_a}{\mu_{eff}} \frac{\exp(-\mu_{eff} p)}{p^2}$$

[00013] Now, if we take two independent measures from two distinct distances from the light source  $R(p_1), R(p_2)$ , we can estimate the scattering coefficient as described in (Kazuya Inaga et al. 2013):

$$\mu'_s = \frac{1}{3\mu_a} \left( \frac{1}{p_2 - p_1} \ln \frac{p_1^2 R(p_1)}{p_2^2 R(p_2)} \right)^2$$

[00014] Therefore, in yet another embodiment of the invention, the estimation of blood scattering coefficient will be achieved by taking two measurement at once from two different detectors placed at different distances from one light source, See figure 4 B.

[00015] In yet another embodiment of the invention, the estimation will be achieved by taking two measurements using one detector and two light sources each placed at different distance from the detector. The measurements from each light source is

separated by time, e.g, the light sources are illuminating at different times, and the measurements recorded using the same light detector but in different times, see figure 4C.

[00016] In one embodiment of the invention the noninvasive measurement of TTG or TRL can done by a wearable device, which contains a light source that produces light at defined wave length of 700nm to 900nm (in the near infra-red band) with a directional light emission. The light source can be a light emitting diode (LED), a laser, or a laser diode. The light detector can be a photo diode. In yet another embodiment of the invention, the light emission is directed to the blood vessel, or to the skin. The wearable device is located on the body in such a way that the light source is located above a blood vessel near the skin. In yet another embodiment of the invention the blood vessel is a vein, in yet another embodiment the device is worn as a bracelet. The device includes a first light detector with a detection range of 700nm-900nm, located above the said blood vessel that the light source is located on, at a distance of 5- 15 mm from the light sources. In yet another embodiment the device includes as well a second light detector at a distance of 15-25 mm from the first light detector. In yet another embodiment the device includes two light sources and one detector and the measurements are separated by time. The light source and the light detectors are located in such a way that the light that is detected by the detectors passes mostly through the interior of the blood vessel (figure 4).

[00017] The device includes a control unit that includes memory device, an electric power source, a clock and a communication module that is used to transmit the processed data to a smart phone or computer. Alternatively the device can have a display unit to display the accumulated fat balance factor and the baseline TTG level (see Figure 4 D).

[00018] In another embodiment of the invention the device includes as well a 3 dimensional accelerometer to identify the time periods where the user does not move in order to allow starting a new measurement. See figure 4 D.

[00019] In yet another embodiment the device is an implantable device and is implanted in the body, in parallel to a blood vessel in such a way that the scattered light detected by the detector passes through the interior of the blood vessel.

[00020] In yet another embodiment of the invention the light scattering sensor includes another set light sources (500-600 nm wavelength) and light detector (500-600 nm wavelength) used to verify that the light sources and detectors (700-900 nm wavelength) are located exactly above the said blood vessel, in such a way that the light emitted from the light source passes through the blood vessel and scattered within it before it is detected by the detectors. This is done to make sure that the light source (700-900 nm wavelength) and the light detector (700-900 nm wavelength) or, the light source (700-900 nm wavelength) and the two detectors (700-900 nm wavelength), or the 2 light sources (700-900 nm wavelength) and one detector (700-900 nm wavelength) are located exactly above the said blood vessel, in such a way that the light emitted from the light source (700-900 nm wavelength) passes through the blood vessel and scattered within it before it is detected by the detectors (700-900 nm wavelength). See figure 4 E.

[00021] In another embodiment of the invention a second directional light source emitting light at 500-600 nm wavelength is located adjacent to the first light source at a distance of no more than 0.5mm or 1 mm from it, and a light detector unit that detects the scattered light at 500-600 nm wavelength is located adjacent to the first light detector unit of 700-900nm at a distance of no more than 0.5mm or ] mm from it. The second set of

light sources and detectors at 500-600nm is used to identify if a blood vessel is located just below the light source. The absorbance coefficient of blood at 500-600nm wave length range is extremely high, thus allowing only low amount of backscattering light to be detected, if the light source and the light detector are above a blood vessel having diameter of at least 0.5mm, or at least 1mm, or at least 2 mm, or at least 5 mm. If the backscattering light (level at 500-600nm wave length range, detected by the detector is below certain trash hold, the trash hold was set by measurement the backscattering when the light source and detector were located directly above a blood vessel. In yet another embodiment the levels is compared to the backscattering light from an adjacent set of light source, that is not located above a blood vessel having diameter of at least 1 mm than it means that the first light source and detectors are located directly above the blood vessel. (Figures 4 E and 5).

**[00022]** In yet another embodiment the device is an implantable device and is implanted in parallel to a blood vessel in such a way that the scattered light that detected by the detector passed through the interior of the blood vessel.

**[00023]** In yet another embodiment of the invention the blood light scattering sensor is an array of 2 or more sensors each sensor includes at least one light detector and one light source (See figure 5).

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[00024]** **Figure 1.** Figure 1A illustrates the sources and path of carbohydrate and TTG in the blood circulation system; Figure 1 B illustrates the factors that affect TTG blood levels.

[00025] **Figure 2.** Shows regular profile of TTG during 2 days, and the base line, and how the NATTG is calculated.

[00026] **Figure 3.** Presents block diagram describing the flow chart of the method for daily management of food consumption vs physical activity based on sequential measurements of TTG blood concentration.

[00027] **Figure 4.** Presents schematic blocks diagram of the device and sensor for non-invasive or implanted measurement of TTG concentrating in blood based on light scattering.

[00028] **Figure 5.** Presents schematic description of the different option for arrangement of the light sources and detectors in sensor for noninvasive measurement of blood light scattering.

[00029] **Figure 6.** Presents flow chart for overcoming movement artifacts in measurement blood light scattering coefficient.

#### **DETAILED DESCRIPTION AND BEST MODE OF IMPLEMENTATION**

[00030] Lipoproteins are complex aggregates of lipids and proteins that render the lipids compatible with the aqueous environment of body fluids and enable their transport throughout the body of all vertebrates via blood circulation system to tissues where they are required. The most abundant lipid constituents are triacylglycerol (that are named triglycerides as well), free cholesterol, cholesterol esters and phospholipids. Lipoproteins particles are classified as chylomicrons (CM), very-low-density lipoproteins (VLDL), low-density lipoproteins (LDL) and high-density lipoproteins (HDL), Compositional details are listed in Table 1.

**Table 1. Physical properties and lipid compositions of lipoprotein classes.**

	CM	VLDL	LDL	HDL
<b>Density (g/ml)</b>	< 0.94	0.94-1 .006	1.006-1 .063	1.063-1 .210
<b>Diameter (Å)</b>	6000-2000	600	250	70-1 20
<b>Total lipid (wt%) *</b>	99	91	80	44
<b>Triacylglycerols</b>	85	55	10	6
<b>Cholesterol esters</b>	3	18	50	40
<b>Cholesterol</b>	2	7	11	7
<b>Phospholipids</b>	8	20	29	46

[00031] Lipoproteins particles are synthesized mainly in intestine and the liver and transported to the blood circulations system. Within the circulation, these aggregates are in a state of constant flux, changing in composition and physical structure as the peripheral tissues take up the various components before the remnants return to the liver, a reference is made to figure 2 A. The main macronutrient types in the human food are proteins, carbohydrate and fats. In the intestine, food is processed, and degraded to the basic building blocks: protein to amino acids, carbohydrate to mono saccharides (mainly glucose and fructose), and fats to fatty acids, all transported to the blood circulation. CM transport dietary lipids from the intestine to storage in the fat tissues throughout the body, CM half life time in the circulation is about 1 hour. VLDL particles are assembled in the liver from endogenous lipids (mainly triglycerides) and transported via blood circulation

to the fat tissues. VLDL particles have a half life time of several hours. CM and VLDL metabolism and regulation is affected by the amount of carbohydrate consumed. High levels of carbohydrate Triglyceride levels vary quite a bit over short time periods. A meal containing high levels of sugar, fat, or alcohol can raise the triglyceride level drastically.

[00032] Light scattering coefficient is the fractional rate in the transmission of radiation through a scattering medium (as of light through fog) at which the flux density of radiation decreases by scattering in respect to the thickness of the medium traversed.

The scattering properties are mainly determined by the size of the scattering particles relative to the wavelength of light, and by the refractive index mismatch between the scattering particles and the surrounding medium. In biological tissues, the scattering centers are cells and cellular organelles. In the medical spectral window (700-900 nm), cellular organelles have dimensions comparable to the wavelength, and their index of refraction is relatively close to that of the cytosol and extracellular fluid. As a result, light scattering in tissue is mainly forward directed (i.e. the scattering angle  $\theta$  is less than  $90^\circ$ ) and shows a weak wavelength dependence. The scattering properties of tissues are described by two parameters; (1) the scattering coefficient ( $\mu_s$ ), defined as the inverse of the average photon path length between successive scattering events, and (2) the average cosine of the scattering angle ( $\mu_s = \langle \cos\theta \rangle$ ). From the definition of  $\mu_s$ , it follows that  $1/\mu_s$  is the average distance traveled by a photon between successive scattering events. Even though each scattering event is mainly forward directed, after a number of collisions a photon loses its original direction of propagation. Under these conditions, we can say that the photon has experienced an effectively isotropic scattering event.

Lipoprotein particles have a major effect on the blood light scattering coefficient. The higher the number of this particle and the larger their size is, light passing through the blood will be more scattered, and the blood scattering coefficient will be larger. The CM and VLDL are the largest type of lipoproteins particle and therefore have the largest effect on the blood scattering coefficient.

**[00033]** This invention provides a new method and device for providing a real time feedback to an individual regarding the balance between the amount and type of food consumed, and his physical activity intensity and duration, in order to reduce the access amount of fat stored in the body or to prevent accumulation of fat.

**[00034]** This invention provides a new method and device for providing a real time feedback to an individual regarding the balance between the amount and type of food consumed, and his physical activity intensity and duration, in order to reduce the access amount of fat stored in the body or to prevent accumulation of fat.

**[00035]** The new method is based on continues or sequential measurement or estimation of triglycerides (TG) concentration in blood or total triglycerides (TTG) concentration in blood or TG-rich lipoproteins (TRL) particles (e.g. chylomicrons (CM), very low density lipoproteins (VLDL)) concentration in blood. Blood TTG are known to be a surrogate for TRL. Consumption of excess fat increases TRL and TTG blood levels, the increase start about 1 hour after fat consumption, and reach to a peak value after 2-3 hours (Richard B et al. 2003). Consumption of excess carbohydrate or alcohol increases TRL levels by increasing the liponeogenesis (Regina M McDevitt et al. 2001, Kevin Jacheson et al. 1988). Liponeogenesis is the conversion of the carbohydrate excess, mainly by the liver, to TG, and its secretion as VLDL to the blood circulation system for transfer to long term

storage in fat tissue. Increase in physical activity causes faster clearance of TRL from the blood vessels and reduced VLDL production. Increase in physical activity causes a decrease in the fasting TTG level in the morning after the day where the activity was performed (Elena Bellou et al. 2013), see figure 1 A and B. The TRL and TTG blood levels at any given time represent the bottom line of the excess fats and carbohydrate consumed, that are about to be cleared from the blood circulation and stored in the fat tissue. When there is a need for using the fat as energy, the triglycerides in the fat tissue are firstly degraded to a small fatty acid fragment that travel in the circulation, not as lipoprotein particles, and later oxidized in the cells. Therefore, continuous monitoring of TTG or TRL levels in the blood can be used as biomarker for the balance between the amount carbohydrate and fats consumed and physical activity intensity and duration. This biomarker assists in preventing accumulation of fat in the body, or reducing the amount of fat stored in the fat tissues.

**[00036]** The measurement of TTG or TRL in this invention can be done at least once in 24 hours, or at least twice in 24 hours, or at least every 6 hours, or at least every 3 hours. The results are recorded and analyzed as follows: The baseline level of the TTG or TRL is defined as TTG or TRL level that is measured in the early morning time before wake up, or before the first meal of the day during the morning time, for example, at between 2am to 6am. In another embodiment of the invention the first baseline measurement is done after the user was in fasting of at least 6 hours or at least 8 hours, or at least 10 hours before the baseline measurement, and this value can be further used as a reference baseline for comparison to the following baseline measurements. In each of the following days, a baseline level is measured and set at early morning time. The baseline

value is then subtracted from the following measurements of the day, and the net TTG values (TTG value after subtraction of the baseline) for the following measurement are accumulated, i.e. an integral is calculated of the area confined between the net TTG and the baseline level, see figure 2. This net accumulated TTG value (NATTG), is affected by the daily food consumption and activity balance and acts as a biomarker for food versus activity balance.

[00037] In yet another embodiment of the invention the NATTG is calculated over the baseline value that is zero. In yet another embodiment of the invention the NATTG is calculated based on a reference baseline values that was measured after fasting. A reference NATTG accumulation graph for every time of the day is set by calculation of the average NATTG values recorded in a group of apparently healthy individuals, during at least one full day, in which they were balanced regarding the caloric intake and caloric expenditure. A reference baseline value is set by calculation of the average baseline values recorded in a group of apparently healthy individuals, during at least one full day, in which they were balanced regarding the caloric intake and caloric expenditure. By comparing the individual NATTG value of the user, as measured in a certain time point to a reference NATTG value measured in the same time, the user gets a feedback for the given time, regarding how far he is from a balance point for the time passed from setting the baseline value. In yet another embodiment of the invention the reference is set as the NATTG profile of the user in a former day, in yet another embodiment as an average value of the user for past several days, at least 3 days, at least 10 days, at least 30 days or at least 365. In yet another embodiment of the invention the user is comparing the daily baseline value to a references baseline TTG value that was calculated as the average TTG

value of a group of apparently healthy individuals that were balanced in the day before measurement regarding caloric intake and expenditure. In yet another embodiment the value is calculated based on the average baseline of the user in former day, in the former days for at least 3 days, at least 10 days, at least 30 days, or at least 365 .

**[00038]** The measured baseline and NATTG values are used to direct the user how to manage his food consumption versus his physical activity in order to maintain or lose weight by maintaining or decreasing the amount of fat tissue in his body. The objective of the user is to achieve NATTG value that will not be higher than the reference value. If the NATTG is above reference value, the user has to increase his physical activity and/or decrease his fats and carbohydrates consumption. If the user wants to reduce weight he has to maintain NATTG values lower than the NATTG reference value for at least one day, or at least one week or at least one month. In yet another embodiment of the invention the objective of the user is to achieve baseline TTG value that will not be higher than the reference baseline TTG value. If the baseline TTG is above reference value in the following day, the user has to increase his physical activity and/or decrease his fats and carbohydrates consumption during the following day. If the user wants to maintain weight he has to maintain, each day, baseline TTG values that are similar to the reference baseline. If the user wants to reduce weight he has to maintain each day, a lower baseline TTG than the reference baseline TTG. Figure 3 describes the flowchart of the method.

**[00039]** In one embodiment of this invention the estimation of TTG blood level can be done non-invasively by measurement of light scattering coefficient of the blood in a blood vessel near the skin. Increase in concentration and size TRL particles increases the

blood light scattering coefficient. In yet another embodiment the measurement of the blood light scattering coefficient can be done by an implemented device located under the skin near by a blood vessel.

[00040] The estimation of the blood light scattering coefficient can be done by illuminating continuous light at a point on the skin just above a blood vessel that is close to the skin surface, and measuring the intensity of the backscattered light at another point with the distance  $p$  from the light source, above the same blood vessel. The backscattered light detection point is located above the same blood vessel, in such a way the backscatter light passed mostly through the interior of the said blood vessel.

[00041] From the diffusion equation, the distribution of the backscattered light detected at distance  $p$ , ( $R(p)$ ) from the light source, is given by:

$$R(p) = \frac{S_0 z_0}{2\pi} \left( \mu_{eff} + \frac{1}{\sqrt{\rho^2 + z_0^2}} \right) \frac{\exp\left(-\mu_{eff} \sqrt{\rho^2 + z_0^2}\right)}{\rho^2 + z_0^2}$$

Where,

$$z_0 = \frac{1}{\mu'_s}, \quad \mu_{eff} = \sqrt{3\mu_a(\mu'_s + \mu_a)}.$$

[00042]  $S_0, \mu'_s, \mu_a$  Are the intensity of the light source, the (reduced) scattering coefficient and the absorption coefficient of the blood, respectively. If  $S_0, \mu_a$  and  $p$  are fixed during repeated measurements, the changes in  $R(p)$  correlated to the changes in the light scattering coefficient of the blood. Increase in  $R(p)$  indicates decrease in the  $\mu'_s$  and vice versa. In one embodiment of the invention the measurement of the changes in the

blood scattering coefficient is done by using one light source and one detector at distance of 3-30 mm, or 5-15mm between them. See figure 4 A.

[00043] Using some algebra and approximation, the previous equation is reduced to

$$R(\rho) = \frac{S_0}{2\pi} \frac{3\mu_a}{\mu_{eff}} \frac{\exp(-\mu_{eff}\rho)}{\rho^2}.$$

[00044] Now, if we take two independent measures from two distinct distances from the light source  $R(\rho_1), R(\rho_2)$ , we can estimate the scattering coefficient as described in (Kazuya linaga et al. 2013):

$$\mu_s' = \frac{1}{3\mu_a} \left( \frac{1}{\rho_2 - \rho_1} \ln \frac{\rho_1^2 R(\rho_2)}{\rho_2^2 R(\rho_1)} \right)^2.$$

[00045] Therefore, in yet another embodiment of the invention, the estimation of blood scattering coefficient will be achieved by taking two measurements at once from two different detectors placed at different distances from one light source, see figure 4 B.

[00046] In yet another embodiment of the invention, the estimation will be achieved by taking two measurements using one detector and two light sources each placed at different distance from the detector. The measurements from each light source is separated by time, e.g, the light sources are illuminating at different times, and the measurements recorded using the same light detector but in different times, see figure 4C.

[00047] In one embodiment of the invention the noninvasive measurement of TTG or TRL can be done by a wearable device, which contains a light source that produces light at defined wave length of 700nm to 900nm (in the near infra-red band) with a directional light emission. The light source can be a light emitting diode (LED), a laser, or a laser diode. The light detector can be a photo diode. In yet another embodiment of the

invention, the light emission is directed to the blood vessel, or to the skin. The wearable device is located on the body in such a way that the light source is located above a blood vessel near the skin. In yet another embodiment of the invention the blood vessel is a vein, in yet another embodiment the device is worn as a bracelet. The device includes a first light detector with a detection range of 700nm-900nm, located above the said blood vessel that the light source is located on, at a distance of **5-15** mm from the light sources. In yet another embodiment the device includes as well a second light detector at a distance of 15-25 mm from the first light detector. In yet another embodiment the device includes two light sources and one detector and the measurements are separated by time. The light source and the light detectors are located in such a way that the light that is detected by the detectors passes mostly through the interior of the blood vessel (figure 4).

**[00048]** The device includes a control unit that includes memory device, an electric power source, a clock and a communication module that is used to transmit the processed data to a smart phone or computer. Alternatively the device can have a display unit to display the accumulated fat balance factor and the baseline TTG level (see Figure 4 D).

**[00049]** In another embodiment of the invention the device includes as well a 3 dimensional accelerometer to identify the time periods where the user does not move in order to allow starting a new measurement, see figure 4 D.

**[00050]** In yet another embodiment the device is an implantable device and is implanted in the body, in parallel to a blood vessel in such a way that the scattered light detected by the detector passes through the interior of the blood vessel.

**[00051]** In yet another embodiment of the invention the light scattering sensor includes another set light sources (500-600 nm wavelength) and light detector (500-600 nm

wavelength) used to verify that the light sources and detectors (700-900 nm wavelength) are located exactly above the said blood vessel, in such a way that the light emitted from the light source passes through the blood vessel and scattered within it before it is detected by the detectors. This is done to make sure that the light source (700-900 nm wavelength) and the light detector (700-900 nm wavelength) or, the light source (700-900 nm wavelength) and the two detectors (700-900 nm wavelength), or the 2 light sources (700-900 nm wavelength) and one detector (700-900 nm wavelength) are located exactly above the said blood vessel, in such a way that the light emitted from the light source (700-900 nm wavelength) passes through the blood vessel and scattered within it before it is detected by the detectors (700-900 nm wavelength). See figure 4 E.

[00052] In another embodiment of the invention a second directional light source emitting light at 500-600 nm wavelength is located adjacent to the first light source at a distance of no more than 0.5mm or 1 mm from it, and a light detector unit that detects the scattered light at 500-600 nm wavelength is located adjacent to the first light detector unit of 700-900nm at a distance of no more than 0.5mm or 1 mm from it. The second set of light sources and detectors at 500-600nm is used to identify if a blood vessel is located just below the light source. The absorbance coefficient of blood at 500-600nm wavelength range is extremely high, thus allowing only low amount of backscattering light to be detected, if the light source and the light detector are above a blood vessel having diameter of at least 0.5mm, or at least 1mm, or at least 2 mm, or at least 5 mm. If the backscattering light (level at 500-600nm wavelength range, detected by the detector) is below certain threshold, the threshold was set by measurement of the backscattering when the light source and detector were located directly above a blood vessel. In yet another

embodiment the levels is compared to the backscattering light from an adjacent set of light source, that is not located above a blood vessel having diameter of at least 1 mm than it means that the first light source and detectors are located directly above the blood vessel, (figures 4 E and 5).

[00053] The device also includes a control unit, an electric power source, a memory device, a clock and a communication module, used to transmit the processed data to a smart phone or computer. Alternatively the device can have a display unit to display the accumulated fat balance factor and the baseline TTG level (figure 4 - block diagram).

[00054] The control unit, e.g., a microprocessor, is responsible for real-time quantitative analysis of light scattering coefficient. Typically, the control unit drives light source to emit light in accordance with various emission parameters, such as duty cycle (e.g., number and/or timing of hours of operation per day) and amplitudes. In some applications of the present invention, light source is actuated by the control unit whenever a measurement take place and the light intensity measured at the detector is sampled by the control unit to gain a quantitative measurement of the light intensity in the detector position.

[00055] The power source is coupled to the device to supply power for the control units, light sources and detectors and additional modules attached (like 3D accelerometer). The power source can be a battery, a rechargeable battery, or a power source that harvest kinetic, thermal or solar energy.

[00056] The display unit, e.g. LCD is used to display primary measures and display alerts and status of the user's caloric balance.

[00057] A communication module, e.g., Bluetooth or wired interface, is able to transmit measures, alerts and statuses to an external display module or a PC. Also it able to receive relevant data needed to calibrate the analysis process in the control unit.

[00058] In some embodiment of the invention the device includes a support on which the light source and detectors are mounted, in another embodiment the control unit and electrical source power, the memory unit, and communication units are also attached to the support.

[00059] Any measurement that involves electromagnetic radiation into living bodies by a wearable device is prone to movement artifact. The two main sources are: 1, the relative movement of the device or sensor relatively to the body, and 2, changes in the tissue due to the body movement, e.g. pressure wave in the blood circulation system that affect volume and shape of blood vessels during the movement.

[00060] In yet another embodiment of the invention the device includes as well a 3 dimensional accelerometer to identify the time period where the user dose not moves his hand. If the acceleration values in all 3 axes shows very low variation, that can be quantified for example as the coefficient of variance ( $100 * \text{Standard deviation} / \text{Average}$ ) of the multiple reading within a certain time frame, that is below 10%, below 3% or below 1% this is an indication the device and the body are not moving.

[00061] Figure 6 describe the flowchart for identifying time period where the subject is not moving and the sensor is located above a suitable blood vessel for reliable measurement of the changes in blood scattering coefficient.

[00062] In yet another embodiment the device is an implantable device and is implanted in parallel to a blood vessel in such a way that the scattered light that detected by the detector passed through the interior of the blood vessel.

[00063] In yet another embodiment of the invention the blood light scattering sensor is an array of 2 or more sensors each sensor includes at least one light detector and one light source (see figure 5).

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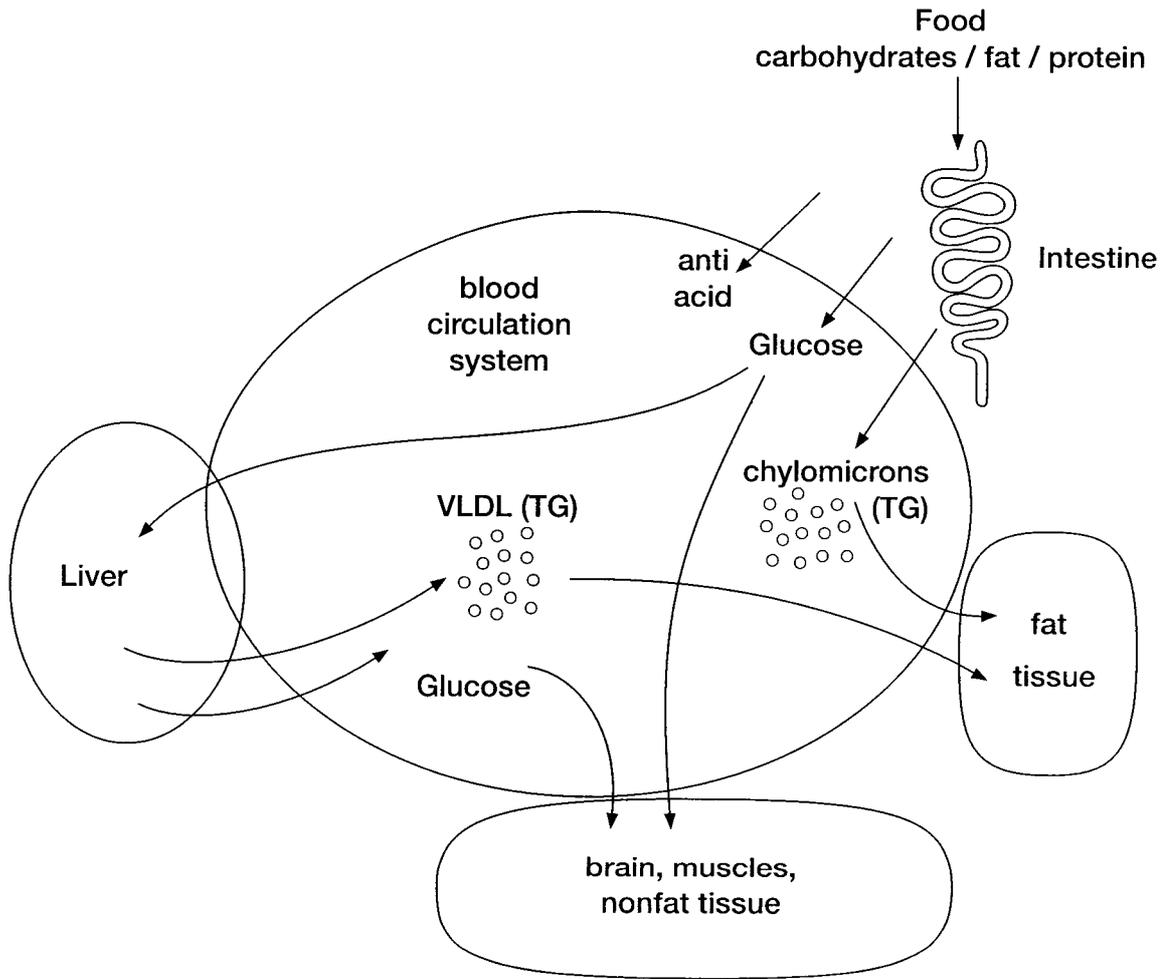
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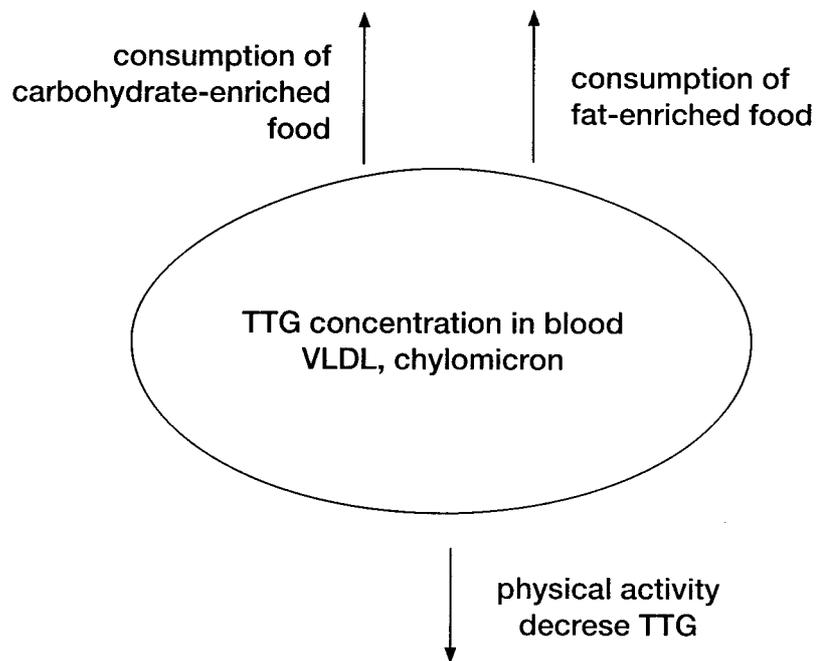
## CLAIMS

What is claimed is:

1. A method for monitoring the balance between the amount and type of food consumed versus the physical activity based on level changes of TRL in the blood.
2. A wearable device for noninvasive monitoring the changes in blood TRL concentration based on changes in blood light scattering coefficient.



**FIG. 1A**



**FIG. 1B**

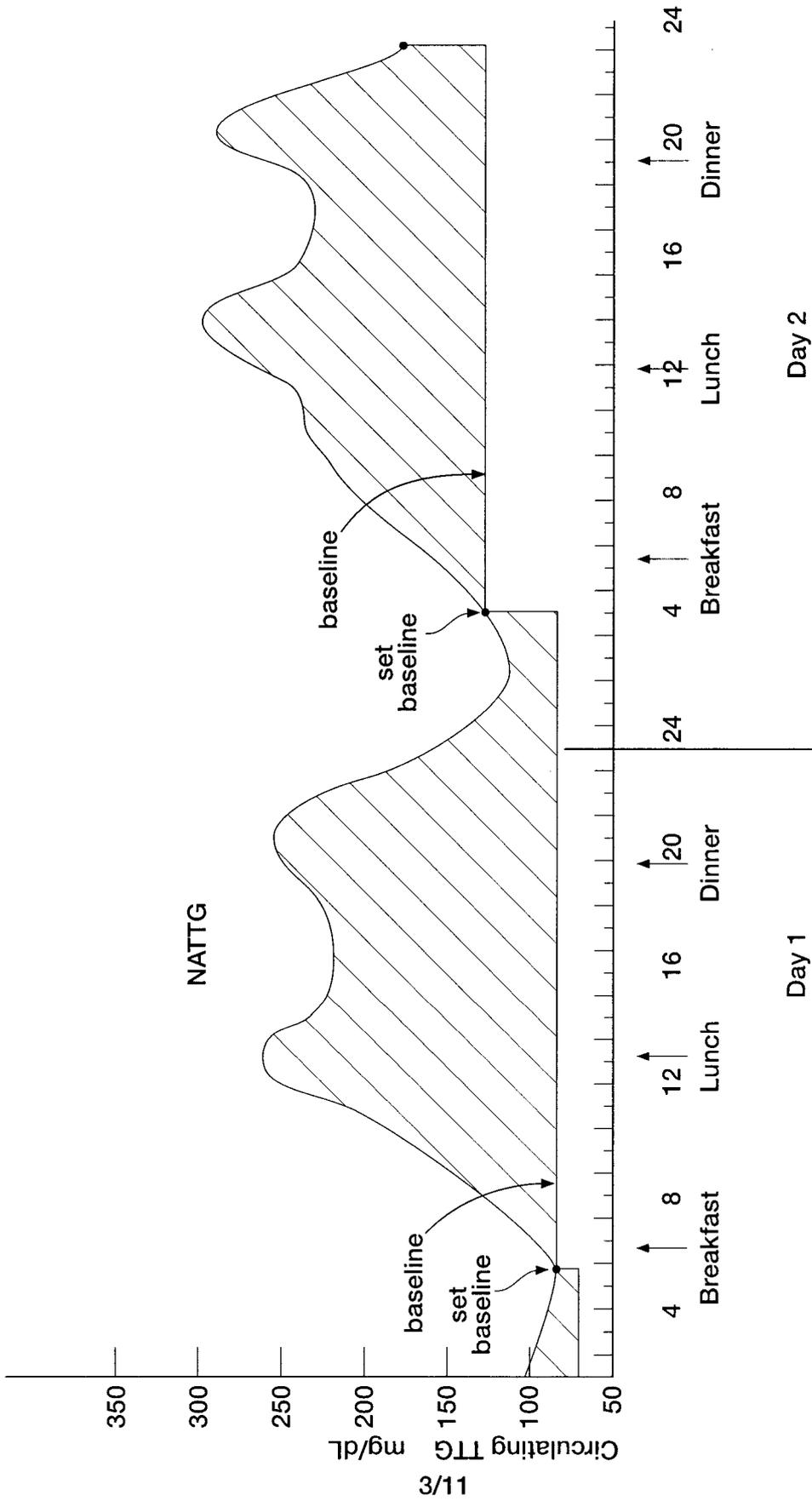
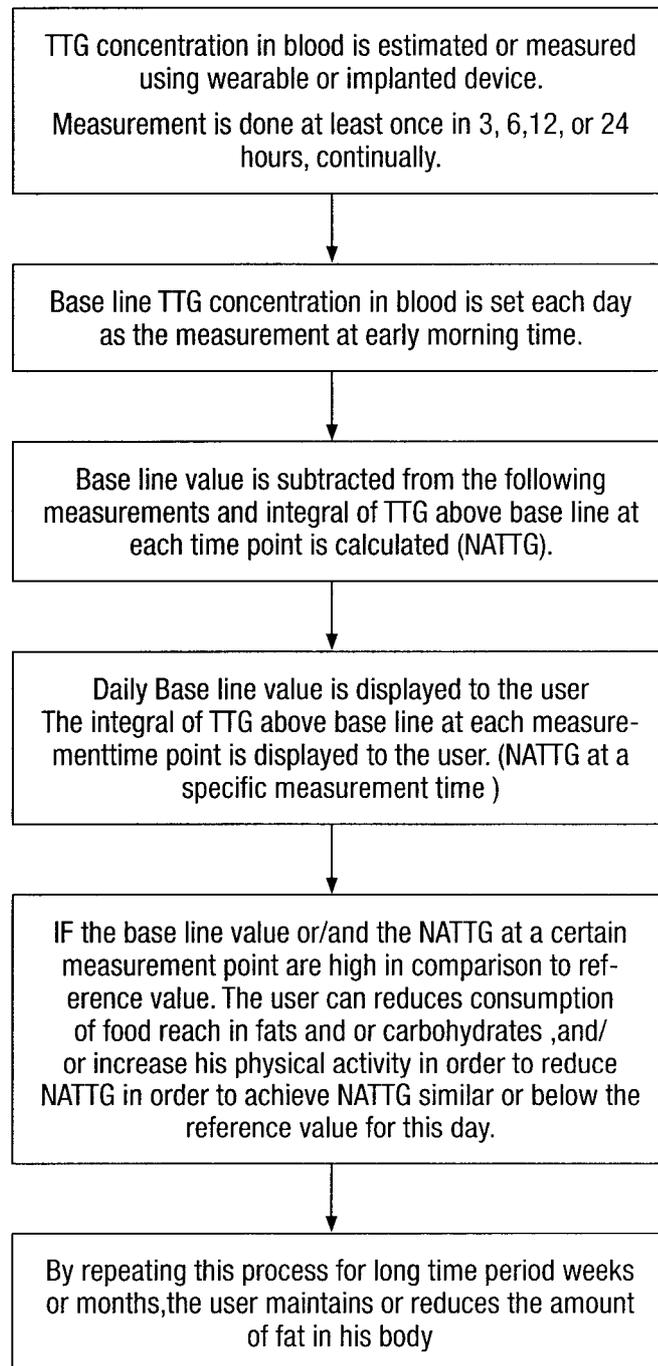
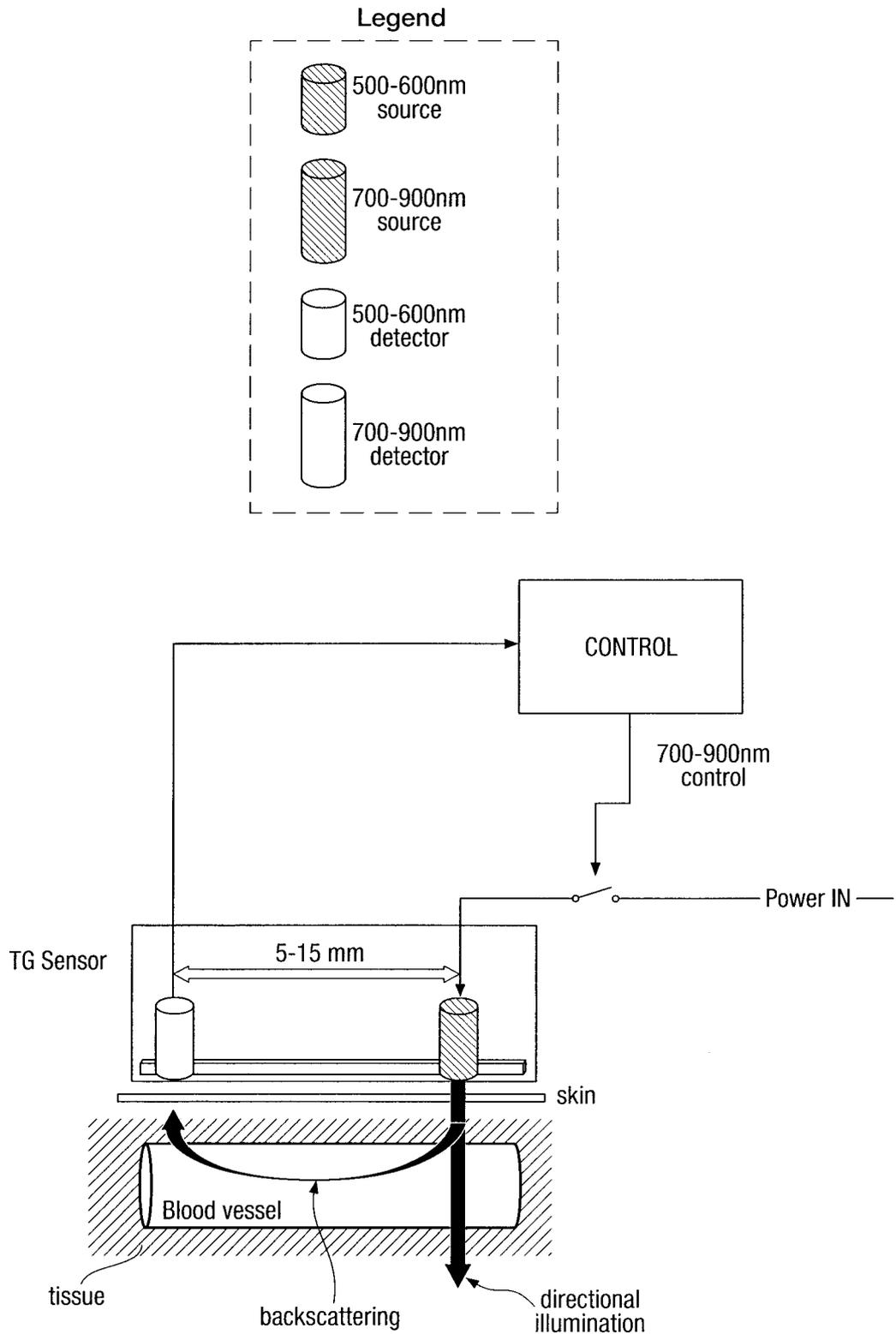
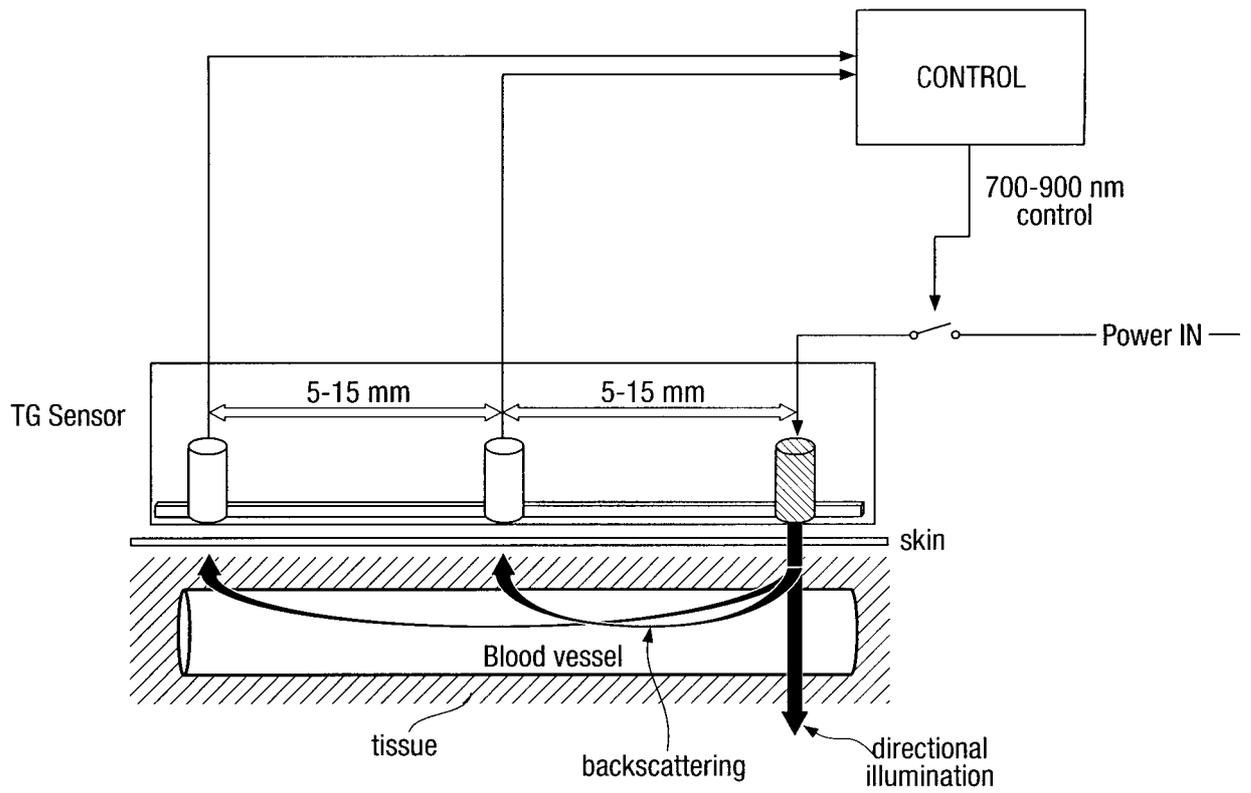


FIG. 2

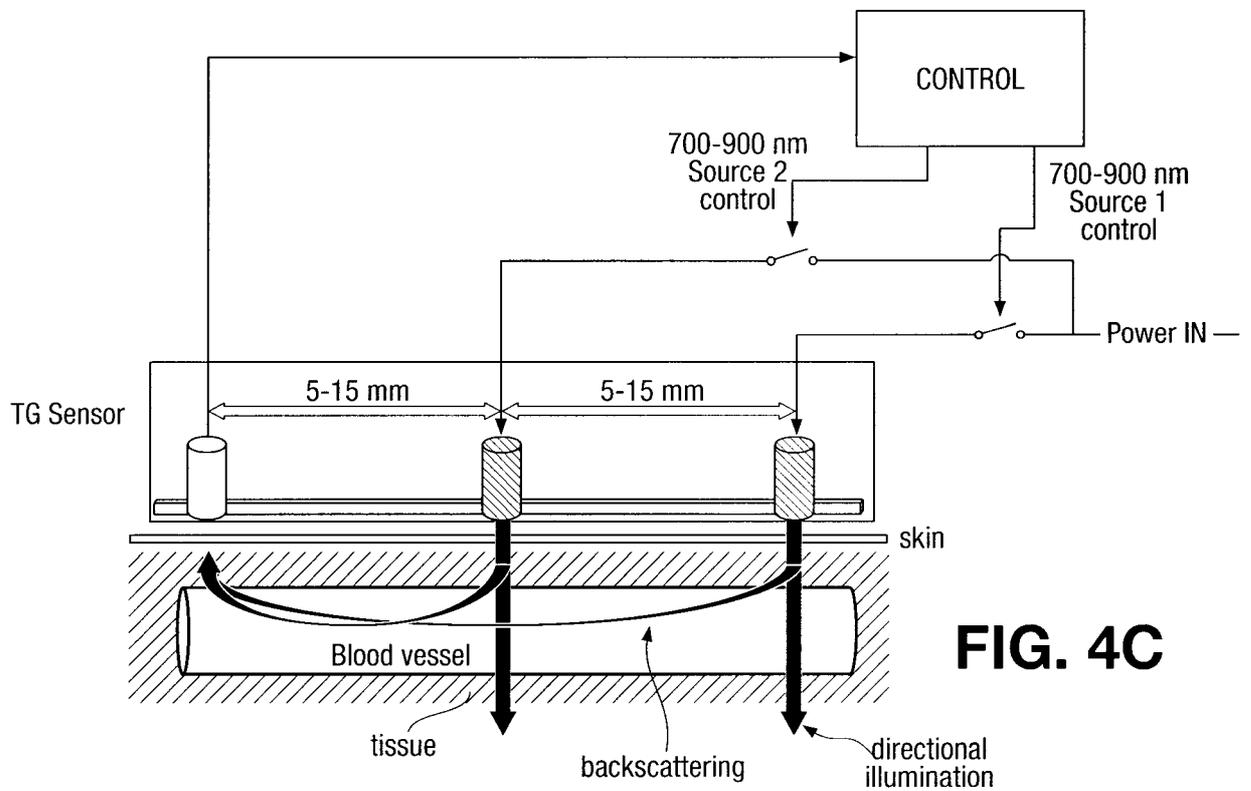
**FIG. 3**



**FIG. 4A**



**FIG. 4B**



**FIG. 4C**

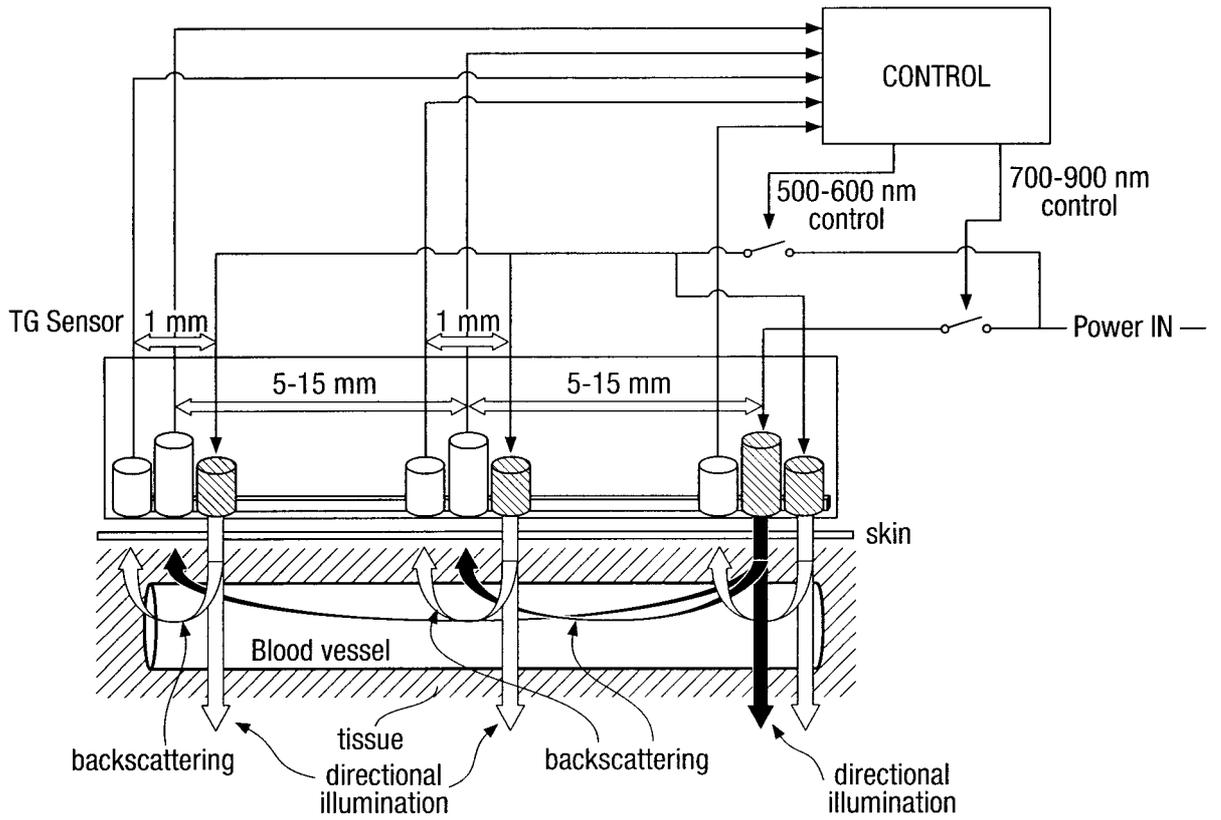
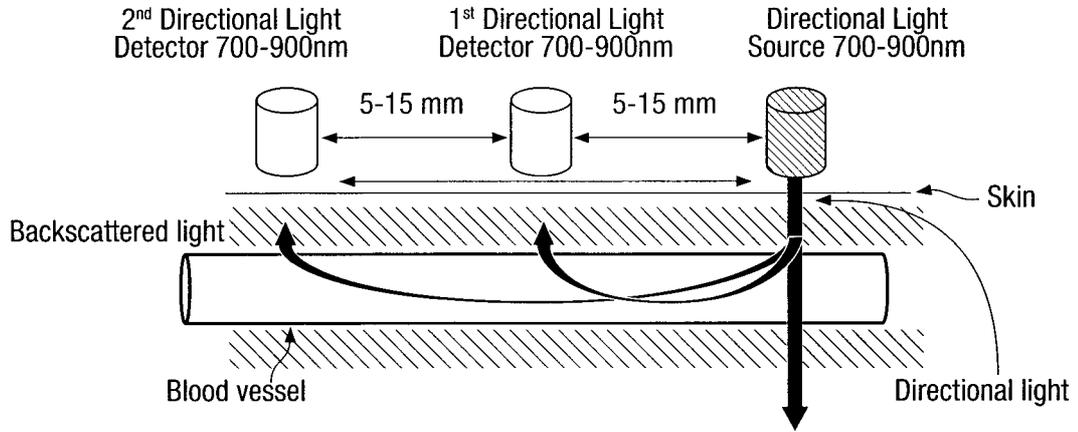
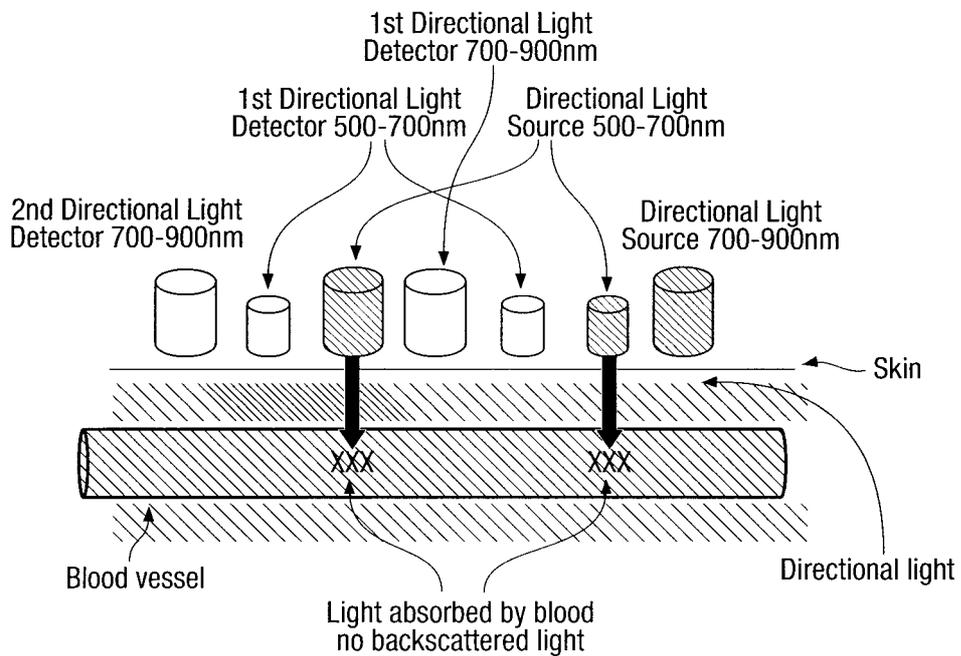


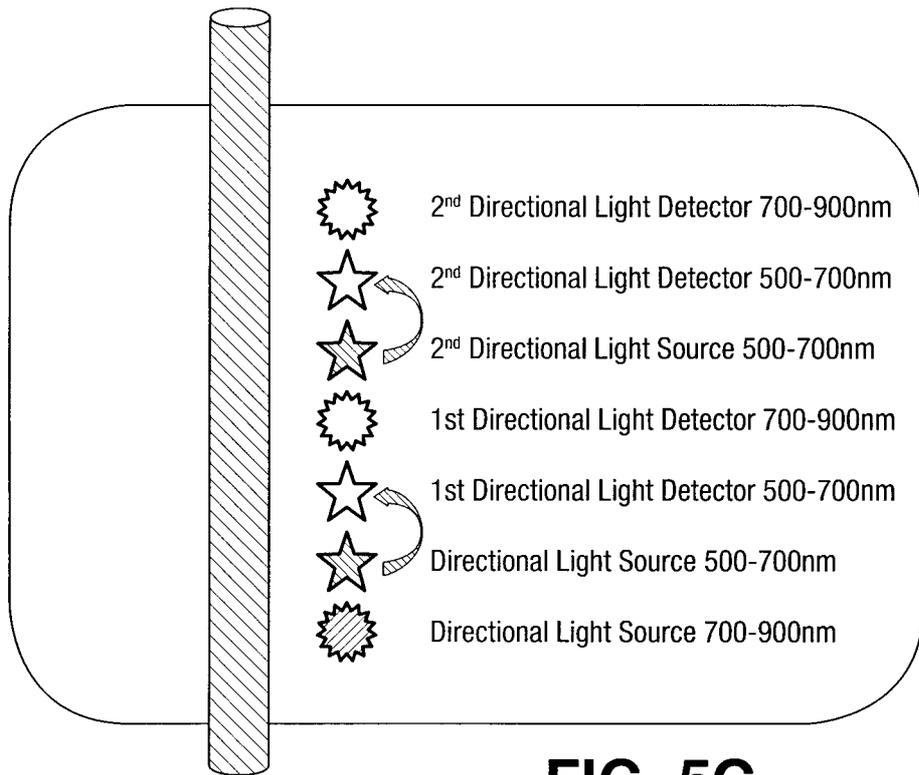
FIG. 4D



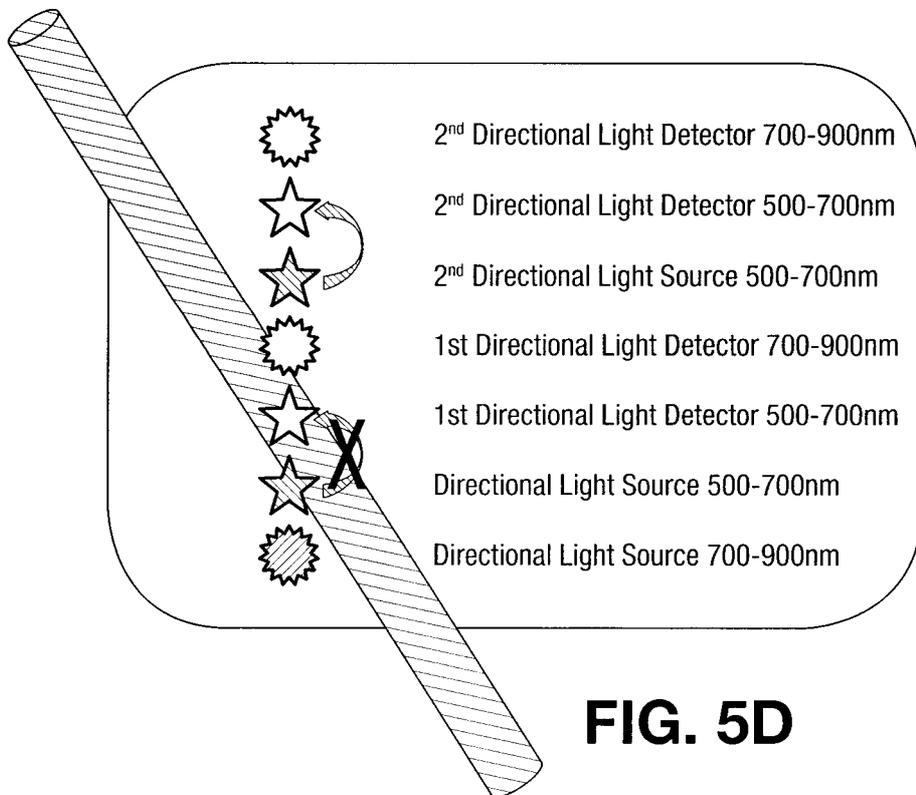
**FIG. 5A**



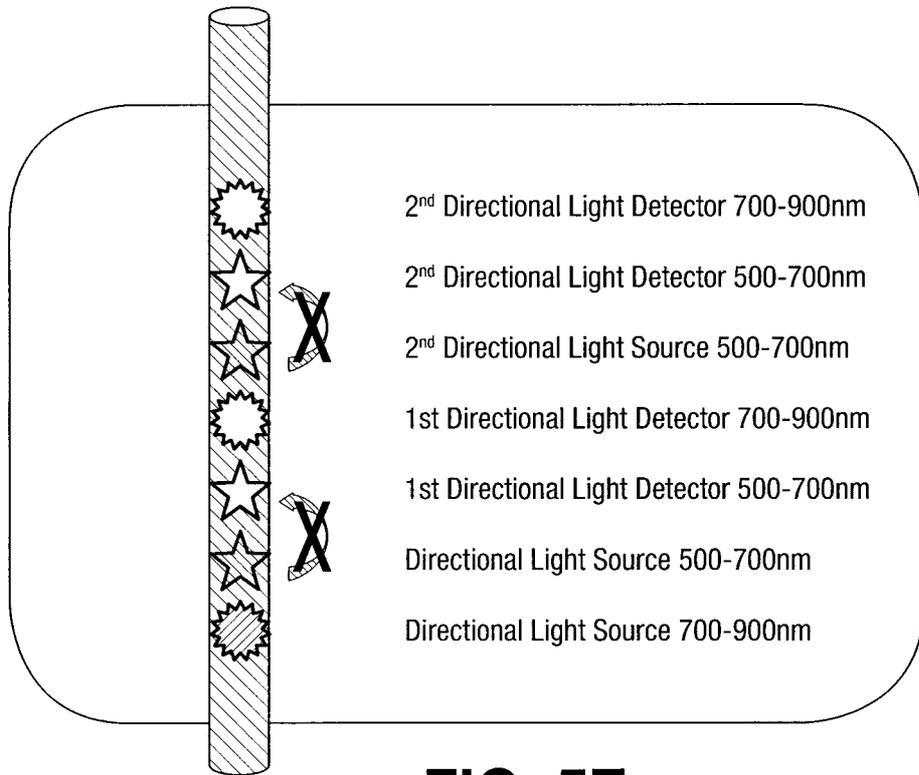
**FIG. 5B**



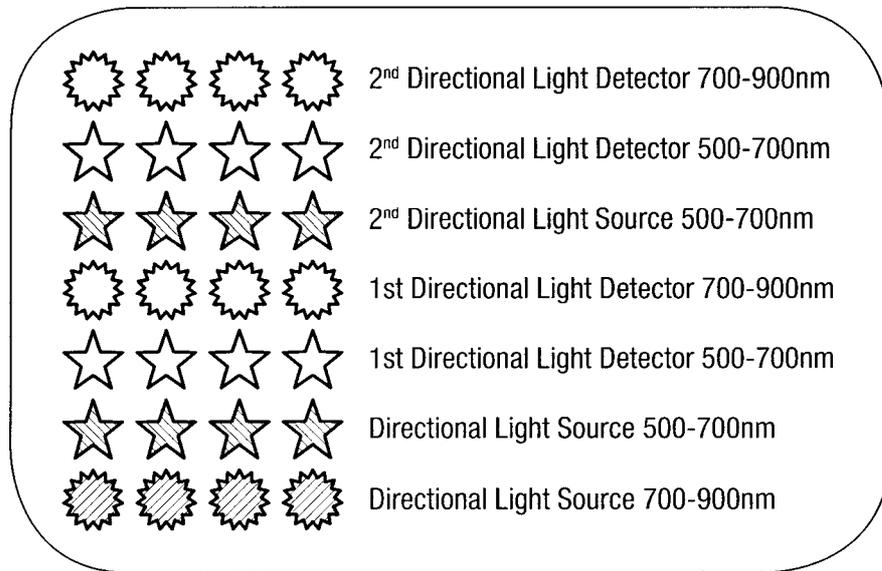
**FIG. 5C**



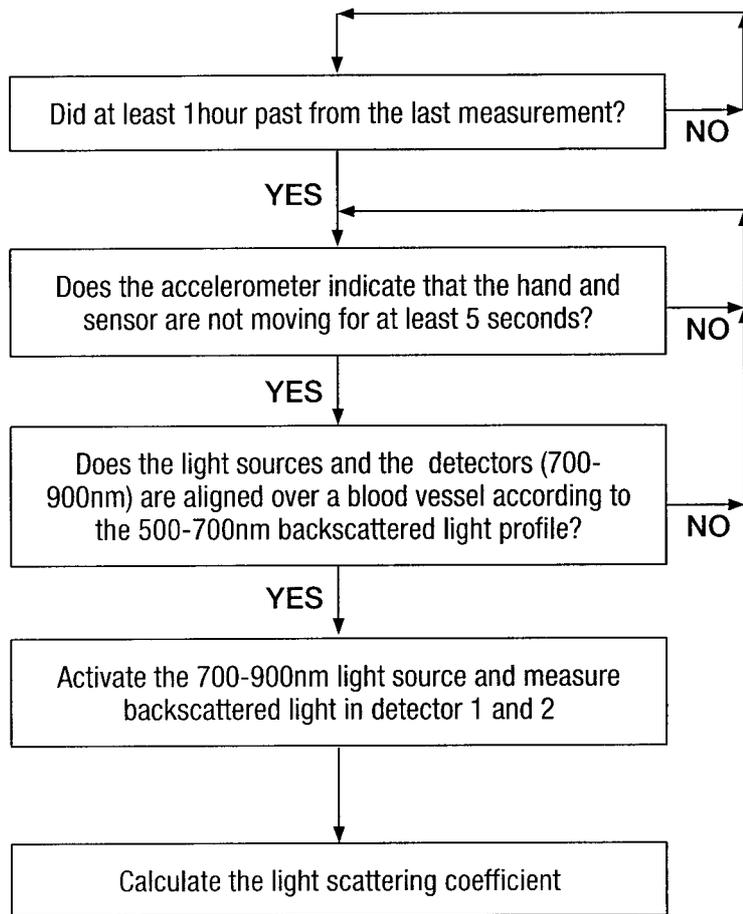
**FIG. 5D**



**FIG. 5E**



**FIG. 5F**



**FIG. 6**

## INTERNATIONAL SEARCH REPORT

International application No.

**PCT/CA2015/050897**

## A. CLASSIFICATION OF SUBJECT MATTER

IPC: **A61B 5/1455** (2006.01) , **A61B 5/00** (2006.01) , **A61B 5/145** (2006.01)

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)

IPC: A61B 5/1455, A61B 5/00, A61B 5/145

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Google, CIPO Resource Center, espacenet, Orbit

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See patent family annex.

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Date of the actual completion of the international search  
27 November 2015 (27-11-2015)Date of mailing of the international search report  
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