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(54) DETECTION OF ANISOTROPIC BIOLOGICAL TISSUE

NACHWEIS VON ANISOTROPEM BIOLOGISCHEM GEWEBE

DÉTECTION DE TISSU BIOLOGIQUE ANISOTROPE

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(73) Proprietor: **Koninklijke Philips N.V.**
5656 AE Eindhoven (NL)

(72) Inventors:
- **MUELLER, Manfred**
  5656 AE Eindhoven (NL)
- **HENDRIKS, Bernardus Hendrikus Wilhelmus**
  5656 AE Eindhoven (NL)
- **LUCASSEN, Gerhardus Wilhelmus**
  5656 AE Eindhoven (NL)
- **BYDLON, Torre Michelle**
  5656 AE Eindhoven (NL)

(74) Representative: **Fairley, Peter Douglas**
Philips Intellectual Property & Standards
High Tech Campus 5
5656 AE Eindhoven (NL)

(56) References cited:
WO-A2-99/02956 **US-A1- 2003 135 122**

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Description

FIELD OF THE INVENTION

[0001] The invention generally relates to a system for detection of optically anisotropic biological tissue in optical spectroscopy. The invention further relates to a computer program allowing steps of a process resulting in a detection of optically anisotropic biological tissue to be performed automatically.

BACKGROUND OF THE INVENTION

[0002] In various clinical interventions, it is important that nerves can be localized accurately. For example, detecting nerves may preserve nerves or prevent resection during surgical procedures and allows for localized injection of pain relieving medicaments nearby nerves. Currently localization procedures consist of localizing nerves in imaging modalities such as ultrasound or magnetic resonant imaging (MRI), whereby it may be sometimes difficult to find and identify tissue as being nerves.

[0003] There is a clinical desire for confirmation of the presence of the nerve in order to prevent complications. The gold standard for confirmation of this presence is stimulation of the nerves by using electrical stimulation.

[0004] US 5,284,154 describes a method and apparatus for locating and identifying the function of specific peripheral nerves. The apparatus of US 5,284,154 includes a stimulus delivery means and a response-detecting means. Electrical stimulation is used for example to locate, identify the function of, and guard against the inadvertent cutting of specific nerves during surgical procedures.

[0005] Electrical stimulation has several disadvantages, for example it may induce electrical burns in patients, which if unseen by surgeons can result in perforated organs and can also lead to peritonitis. Electrical stimulation also has a low sensitivity.

Recently, stimulation of nerves using optical energy has received increased attention in the literature. A practical device for in- vivo application is suggested in WO 2012/123869 which relates to the identification and stimulation of nerve tissues, and more in particular to a method, apparatus and probe for optical nerve localization and optical nerve stimulation. It is suggested to combine in a single apparatus the localization and the verification of the presence of nerve tissue by optical stimulation. The stimulation is detected by monitoring the variations based on thermal sensitive spectroscopic features of light scattering from the area of the stimulated nervous tissue.

[0006] WO 99/02956 A2 discloses a system for the detection of anisotropy of a tissue where the light paths emitted by the source are partially parallel to each other.

SUMMARY OF THE INVENTION

[0007] The invention is defined by the appended claims. It may be seen as an object of the invention to improve the discrimination of nerve tissue (and other anisotropic tissues like tendons) from other biological tissue types. This and other objects are solved by the system and the computer program according to the independent claims, respectively. Further embodiments are described in the dependent claims.

[0008] In general, a tissue classification system is suggested which is configured to discriminate/detect an optical anisotropic tissue (like nerve) using diffuse reflectance spectroscopy (DRS) that measures the DRS spectrum under two or more different directions (either simultaneously or sequentially) at the same location. The detection algorithm then uses the differences between these different spectra to discriminate/detect the desired tissue.

[0009] The measurement under different directions/angles can be facilitated by the hardware (e.g. by using multiple source and/or detection optical fibers under significantly different angles and not averaging).

[0010] The detection algorithm will typically start by determining whether the tissue at the current location is isotropic or not. If the tissue is isotropic, then it is not nerve, tendon, etc. If the tissue is anisotropic then the algorithm will determine from the spectra whether it is the desired or another anisotropic tissue.

[0011] According to an embodiment, a system for detection of optically anisotropic tissue may comprise an optical source, an optical detector, a probe and a processing unit. Either the optical source or the optical detector may be wavelength-selective. The probe may have a shaft with a longitudinal axis and a front end, and a plurality of optical fibers, wherein an end of each of the optical fibers is arranged at the front end of the shaft. At least one of the optical fibers may be a source optical fiber adapted to transmit optical radiation emitted from the optical source to a tissue adjacent to the front end of the shaft and another one of the optical fibers may be a detector optical fiber adapted to transmit optical radiation reflected from the tissue to the optical detector, so that an optical path through the tissue is defined. The processing unit may be configured (i) to control the optical source to emit optical radiation, (ii) to receive a signal generated by the optical detector based on the optical radiation reflected by the tissue, (iii) to determine an optical spectrum of the reflected optical radiation, based on the received signal, and (iv) to compare at least two spectra, wherein the spectra relate to optical radiation with different optical paths, wherein the optical paths differ from each other with respect to their spatial orientation.

[0012] It is noted that an optical spectrum may encompass one or more discrete wavelengths or wavelength regions, that the optical source may be a broadband optical source, i.e. including wavelengths within the visible to infrared spectral region, or a visible white light source and that the detector optical fiber may be connected to a spectrometer.

[0013] In the following, geometrical aspects will be defined for a better understanding. First of all, the probe may include a longitudinal main axis, usually the center axis of a rotationally symmetrical shaft. If the probe is a needle or another intrusive probe the longitudinal main axis will be along the direction of movement inside the biological tissue. Further, the tip portion of the probe may be cut at an angle to the main axis. The angle may be substantially perpendicular to the main axis (forming a blunt probe end) but may also be inclined to the main axis (forming a bevel). The pointed tip of a bevel may be considered as being directed to the 'front' of the needle and may form an acute angle with the shaft. Looking from the 'side', i.e. 'laterally', it is possible to recognize the angle between the bevel and the main axis.

[0014] It should be noted that the end surface of an optical fiber at an opening in the front surface may have a circular shape or a more or less oval shape in case of a substantially circular cross section of the fiber in an inclined front surface. Depending on the angle at which the optical fiber ends at the bevel surface, the shape of the end surface of the optical fiber will be affected and therefore also the direction of the emitted or received optical radiation. For a needle the optical path may be substantially in the direction of movement of the needle through the tissue, enabling the needle to 'look ahead'.

[0015] A pair of optical fiber ends may define an optical path, with optical radiation emitted from a first optical fiber, reflected in tissue and received in a second optical fiber of the pair. Depending on the position of the respective optical fiber ends, the optical path will have a spatial orientation relative to the shaft of the probe. Consequently, each pair of optical fibers will define an optical path, wherein the spatial orientation will differ as soon as different optical fibers form a pair or as soon as the probe is rotated. The optical path may be ahead in the direction where nerve detection may be intended.

[0016] According to an embodiment, the probe may comprise one detector optical fiber and at least two source optical fibers, wherein a first optical path is defined from a first source optical fiber to the detector optical fiber and a second optical path is defined from a second source optical fiber to the detector optical fiber. In this embodiment, the optical path from the first source optical fiber to the detector optical fiber is oriented transversely to the optical path from the second source optical fiber to the detector optical fiber.

[0017] According to another embodiment, the probe may comprise at least two detector optical fibers and at least two source optical fibers, wherein a first optical path is defined from a first source optical fiber to a first detector optical fiber and a second optical path is defined from a second source optical fiber to a second detector optical fiber. In this embodiment, the optical path from the first source optical fiber to the first detector optical fiber is oriented transversely to the optical path from the second source optical fiber to the second detector optical fiber.

[0018] The first optical path may be oriented relative to the second optical path with an angle of at least 60 degrees. According to an embodiment, the angle between the first and second optical paths may be at least 70 degrees.

[0019] Furthermore, it is advantageous if the two optical paths cross each other.

[0020] According to another embodiment, the system comprises two optical sources. In addition or alternatively, the system may further comprise an optical switch or modulator, to distribute the optical radiation of one optical source to different optical fibers.

[0021] As described in more detail below, the invention is based on the idea that a biological tissue is measured with differently oriented optical paths. This may also be achieved with a probe including one pair of optical fibers, wherein the probe is rotated between two measurements. Consequently, the system may further comprise a means for actively and/or automatically rotating the probe about its longitudinal axis. It is noted that a rotation of the probe may also be of advantage, with two optical paths being provided by the probe.

[0022] According to another embodiment, the system may further comprise a means for polarizing the optical radiation emitted from the optical source. The means for polarizing may be capable of changing the polarization direction, i.e. may be capable of polarizing the optical radiation with different polarization directions. With such an embodiment, two different (for example orthogonal) polarization measurements may be employed. When the tissue is anisotropic, the two measurements will be different. A detection algorithm is employed to detect the difference between the spectra measured for the different polarization directions and uses this information to discriminate/detect the desired tissue.

[0023] According to an embodiment, the probe may further comprise a channel for injecting or extracting a fluid. For example, an injection of a narcotic fluid may be possible in a direct vicinity of a nerve, as soon as the nerve has been detected by means of the probe, with the effect that a smaller amount of the narcotic fluid may have the intended anaesthetic effect on the nerve.

[0024] According to an embodiment, the system may further comprise a console including the optical source, the optical detector and the processing unit for processing the signals provided by the optical detector, the console being adapted for in-vivo tissue inspection. The optical source or the optical detector may provide wavelength selectivity. The optical source may be one of a laser, a light-emitting diode or a filtered optical source or a broad-band optical source, and the console may further comprise one of an optical fiber switch, a beam splitter or a dichroic beam combiner. Furthermore, the device may be adapted to perform at least one out of the group consisting of diffuse reflectance spectroscopy, diffuse optical tomography, differential path length spectroscopy, fluorescence spectroscopy, and Raman spectroscopy. The console may comprise at least one spectrometer.

[0025] According to an embodiment, the probe may further comprise a coil for electromagnetic tracking. For example, the tip of the probe may be equipped with such a small coil. This offers the capability of controlled navigation of the probe and, at the same time, it also offers an on-the-spot tissue confirmation using spectral sensing as described herein.

[0026] According to an embodiment, the probe may further comprise a radiopaque material at the distal end portion of the shaft for enhancing the visibility of that portion in a fluoroscopic image. Furthermore, the distal end portion of the shaft of the probe may be configured for cauterization. This would prevent the risk of excessive bleeding at the insertion site.

[0027] According to another aspect, a method for detecting optically anisotropic tissue in a portion of tissue. The method comprises the steps of:

A1) controlling a light source to emit light having two different optical paths, wherein the optical paths cross each other;

A2) receiving a signal which has been generated by an optical detector based on light reflected by the portion of tissue;

A3) determining a plurality of optical spectra (Sp1, Sp2) of the reflected light based on the received signal, wherein the optical spectra are obtained from at least two different directions at the same location , wherein the measurement is performed either simultaneously or sequentially;

A4) comparing the plurality of optical spectra (Sp1, Sp2), wherein the optical spectra relate to optical radiation of the different optical paths (Lp1, Lp2).

[0028] According to another aspect, a computer program is suggested to be executed on a processing unit of a system as described above so as to automatically perform steps of a method for detection of optically anisotropic biological tissue. The computer program may comprise instructions for (i) controlling the optical source to emit optical radiation, (ii) receiving a signal generated by the optical detector based on the optical radiation reflected by the tissue, (iii) determining an optical spectrum of the reflected optical radiation, based on the received signal, and (iv) comparing at least two spectra, wherein the spectra relate to optical radiation with different optical paths, wherein the optical paths differ from each other with respect to their spatial orientation.

[0029] According to an embodiment, the computer program may further comprise instructions for controlling a rotational orientation of the probe. For example, the system may comprise a means for driving a rotation of the probe mechanically, pneumatically, hydraulically or otherwise. Those means may be controlled by the processing unit when executing corresponding instructions of a computer program.

In addition or alternatively, the computer program may comprise instructions for controlling a polarization direction of the emitted optical radiation.

[0030] The aspects defined above and further aspects, features and advantages of the present invention may also be derived from the examples of embodiments to be described hereinafter and are explained with reference to examples of embodiments. The invention will be described in more detail hereinafter with reference to examples of embodiments but to which the invention is not limited.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031]

Figure 1 shows a hierarchical structure of tendon.

Figure 2 shows DRS spectra of a nerve in dependence of the angle between the optical path at the probe and the nerve axis.

Figure 3 shows a system including a probe, a console and a processing unit.

Figure 4 is a view of the front surface of a probe of Figure 3.

Figure 5 is a view of the front surface of a probe according to another embodiment.

Figure 6 is a view of the front surface of a probe according to yet another embodiment.

Figure 7 is a view of the front surface of a probe according to a further embodiment.

Figure 8 is a flow chart illustrating steps of a method executable by a computer program.

[0032] The illustration in the drawings is schematically only and not to scale. It is noted that similar elements are provided with the same reference signs in different figures, if appropriate.

DETAILED DESCRIPTION OF EMBODIMENTS

[0033] Spectra from a given tissue type tend to look similar. The respective tissue "fingerprint" (characteristic spectrum) is used to discriminate between tissue types. Typically, the fingerprint is first extracted/enhanced (for example by fitting the concentration of characteristic chromophores or by calculating principal components) and then these derived features are used to discriminate tissues based on typical machine learning methods such as SVM, CART, cut-off values, or k-nearest-neighbors. For example, it is clear that fat spectra have a different characteristic shape (or fingerprint) than the muscle tissue. For example the fat dip at 1200 nm is nearly always deeper for subcutaneous fat tissue than for muscle tissue.

[0034] On the one hand, biological tissues may be optically isotropic, wherein optical isotropy means in this context that the DRS spectrum does not depend on the direction in which the spectrum has been measured. If one source optical fiber and one detector optical fiber is used, the direction in which the spectrum may be measured is the direction from the exit facet of the source optical fiber to the entrance facet of the detector optical fiber. Most biological tissues like fatty tissue and connective tissue are inherently isotropic (that is the cells have no preferred direction or orientation) and are therefore optically isotropic. Even biological tissues whose cells have a preferred direction, like muscle, are often still optically isotropic.

[0035] On the other hand, some biological tissues are anisotropic. This includes nerves but also tendons and ligaments. That is because tendons/ligaments and nerves are ordered bundles of fibers as shown in Figure 1. A tendon/ligament consists primarily of collagen. The structure of nerves is similar, with a strong principal axis. As a consequence, the spectrum of nerve or tendon tissue depends strongly on the direction (from the nerve or tendon axis) at which it is measured. There is no longer a single tissue type fingerprint/characteristic spectrum.

[0036] Figure 2 illustrates DRS spectra of the same pig nerve (same location) in dependence of the angle between the source/detector optical fiber pair, i.e. the optical path of the probe and the nerve axis. The right graph was measured with the probe perpendicular to the nerve and the probe being rotated around its axis. An angle of 0° or 180° means the direction of the optical path at which the spectrum was measured is parallel to the nerve fibers, at 90° and 270° it is perpendicular. The left spectrum was measured with the probe angled 60° from the perpendicular direction and being rotated around the perpendicular direction.

[0037] A DRS system as described herein typically consists of three main components, namely a probe (e.g. a needle) with at least one source optical fiber and one detector optical fiber, a console with at least one optical source and at least one spectrometer including an optical detector, and a processing unit on which a discrimination software may run that makes a tissue classification depending on the optical spectra. In the following description it is assumed that the system is supposed to detect nerves. The same principle applies for detecting any other anisotropic type of tissue.

[0038] In a first embodiment, as shown in Figure 3, a special fiber optic probe 300 is used that can measure spectra under at least two different directions without the need to rotate the probe. Two source (S1, S2) and two detector (D1, D2) optical fibers together with two optical sources 10, 20 and two spectrometers 30, 40 are used to measure the DRS spectrum at two perpendicular directions Lp1, Lp2. The data processing unit 200 has the (at least) two spectra Sp1, Sp2 as input and a tissue classification (e.g. Nerve or NonNerve) as an output. By using at least two spectra it is easy to distinguish isotropic from non-isotropic tissues. Also it is easier to distinguish different types of non-isotropic tissues. Various ways may be implemented to do the actual processing and classification. For example, the two spectra may be subtracted from each other and the difference spectrum may be used as an input for a classification method like PLS-DA, SVM or adaboost.

As shown in Figure 3, the optical fibers of the probe are connected to an optical console 100. The optical fibers can be understood as optical guides or optical waveguides. The console 100 may comprise at least one optical source 10, 20 in the form of a halogen broadband optical source with a shutter, and at least one optical detector 30, 40. The optical detector providing the functionality of a spectrometer can resolve optical radiation with a wavelength substantially in the visible and infrared regions of the wavelength spectrum, such as from 400 nm to 1700 nm. The combination of optical source and optical detector allows for diffuse reflectance measurements.

[0039] Optionally it is also possible that the console is coupled to an imaging modality capable of imaging the interior of the body, for instance when a biopsy is taken under image guidance. On the other hand, also other optical methods can be envisioned like diffuse optical tomography by employing a plurality of optical fibers, differential path length spectroscopy, fluorescence and Raman spectroscopy to extract tissue properties.

[0040] A processor transforms the measured spectrum into physiological parameters that are indicative for the tissue state and a monitor may be used to visualize the results. A computer program executable on the processor unit 200 may be provided on a suitable medium such as an optical storage medium or a solid-state medium supplied together with or as part of the processor, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems.

[0041] For fluorescence measurements the console must be capable of providing excitation optical radiation to at least one source optical fiber while detecting tissue-generated fluorescence through one or more detection optical fibers. The excitation optical source may be a laser (e.g. a semiconductor laser), a light-emitting diode (LED) or a filtered optical source, such as a filtered mercury lamp. In general, the wavelengths emitted by the excitation optical source are shorter than the range of wavelengths of the fluorescence that is to be detected. It is preferable to filter out the excitation optical radiation using a detection filter in order to avoid possible overload of the detector by the excitation optical radiation. A wavelength-selective detector, e.g. a spectrometer, is required when multiple fluorescent entities are present that need to be distinguished from each other.

[0042] In case fluorescence measurements are to be combined with diffuse reflectance measurements, the excitation optical radiation for measuring fluorescence may be provided to the same source optical fiber as the optical radiation for diffuse reflectance. This may be accomplished by, e.g., using an optical fiber switch, or a beam splitter or dichroic beam combiner with focusing optics. Alternatively, separate optical fibers may be used for providing fluorescence excitation optical radiation and optical radiation for diffuse reflectance measurements.

[0043] Figure 4 is a detailed view of the front surface of the probe of Figure 3. It is possible to distinguish non-isotropic tissues from isotropic tissues, for most orientations of the probe. However, when the (projected) angle between measurement direction along optical path Lp1 and the nerve axis, α, is (nearly) equal to the (projected) angle between measurement direction along optical path Lp2 and the nerve axis, β, both spectra may be the same. In such a case, a non-isotropic tissue may appear isotropic. This issue can be resolved in various ways. Firstly, instructions for use may be provided for a physician who will typically know the general direction of the nerve he/she is looking for. The incidence of a $\alpha \approx \beta$ situation can be reduced by marking the direction of one measurement on the probe and instructing the user to rotate the probe in such a way that the marked direction aligns with the expected direction of the nerve. Secondly, at least three directions may be measured, as an $\alpha \approx \beta$ situation can only occur if exactly two directions are measured. Thirdly, source and detector optical fibers may be cross-switched.

[0044] In the situation in Figure 4, if one measures one spectrum Sp1 between source optical fiber S1 and detector optical fiber D2 and spectrum Sp2 between detector optical fiber D1 and detector optical fiber D2 one gets again maximum contrast between the spectra. For this to work, one of the optical fibers in the probe has to be connected in such a way that it can be used as either a source or a detector optical fiber.

[0045] Figure 5 shows a variation with two source optical fibers and a common detector optical fiber. For example, the two source optical fibers may be the optical fibers denoted with 2 and 3 and the detector optical fiber may be the optical fiber denoted with 1 in Figure 5. It will be understood that the same output can be achieved with just a single spectrometer and/or a single optical source, for example by using optical switches or modulators. In any case, it is intended to measure at least two spectra at different angles, for example at approximately right angle. A common detector optical fiber can measure the optical DRS spectrum under two different directions. Using a common detector optical fiber allows the use of a single optical detector and spectrometer.

[0046] It is noted that the area denoted with the reference sign 50 in Figures 5 and 6, and consequently also in Figure 7, may either be a channel for injection or resection of a fluid through the probe or be a further optical fiber which may serve as a source or a detector optical fiber.

[0047] Figures 6 and 7 show alternative embodiments of probes having at least one detector optical fiber and up to 5 or 6 source optical fibers.

[0048] For example, the embodiments of Figures 6 and 7 may show a probe with multiple source optical fibers (1, 2, 3, 4, 5 and 6) arranged around a single detector optical fiber 50. These embodiments measure DRS spectra under different angles sequentially by sequentially illuminating individual optical fibers and taking a spectrum. If source optical fibers are arranged on opposite sides of the detector optical fiber, these sources optical fibers can be illuminated at the same time. Ideally subsequent spectra are taken nearly at right angles, to maximize contrast between subsequent spectra. The probe as shown in Figure 6 could work by illuminating optical fiber 1, then optical fiber 3, then optical fiber 5, then optical fiber 2, then optical fiber 4, then optical fiber 1 again. If one spectrum is measured per illumination, then subsequent spectra are measured at 72 degree angles. Possible switching patterns may be for the embodiment of Figure 7, first illuminating optical fibers 1 and 4, then optical fibers 2 and 5, then optical fibers 3 and 6, then optical fibers 1 and 4 again. If one spectrum is measured per illumination, then subsequent spectra are measured at 60 degree angles. The switching should be fast enough so that the classification algorithm can make use of at least 3 subsequent spectra to avoid the $\alpha \approx \beta$ problem.

[0049] With reference to Figure 8, a software solution is described. The flowchart in Figure 8 illustrates the principles of anisotropic tissue detection. It will be understood that the steps described with respect to the automatically performed method are major steps, wherein these major steps might be differentiated or divided into several sub steps. Furthermore, there might also be sub steps between these major steps. A sub step is only mentioned if that step is important for the understanding of the principles of the method according to the invention.

[0050] A demand for an anisotropic detection can be initiated by a user or by the system. The user can initiate an anisotropic detection, when the probe tip is at a location where the user needs to classify the type of tissue with a high degree of certainty. This could for example be just before an injection. The user may initiate an anisotropic detection for example by pressing a button. Otherwise, the system can automatically initiate an anisotropic detection, when the standard classification suspects a nerve, but when the uncertainty is still too high.

[0051] According to another aspect of the invention, there is provided a method for detecting optically anisotropic tissue in a portion of tissue, comprising the steps of:

A1) controlling a light source to emit light having two different optical paths, wherein the optical paths cross each other;
A2) receiving a signal which has been generated by an optical detector based on light reflected by the portion of tissue;
A3) determining a plurality of optical spectra (Sp1, Sp2) of the reflected light based on the received signal, wherein the optical spectra are obtained from at least two different directions at the same location , wherein the measurement is performed either simultaneously or sequentially;
A4) comparing the plurality of optical spectra (Sp1, Sp2), wherein the optical spectra relate to optical radiation of the different optical paths (Lp1, Lp2), thus allowing the detection of anisotropic tissue using the differences between the optical spectra.

[0052] When performing an anisotropic detection, the at least one optical source is controlled so as to emit optical radiation, in step A1.

[0053] In step A2, a signal is received which has been generated by the optical detector based on the optical radiation reflected by tissue.

[0054] Based on the received signal, an optical spectrum of the reflected optical radiation is determined in step A3.

[0055] At least two of the determined spectra are compared in step A4.

[0056] Based on the comparison of the spectra, the system may alert the user to the need to rotate the probe e.g. by a sound signal.

[0057] In step A5, if necessary, the probe may be rotated. For example, the probe may be rotated with a rotation by 90° around the axis of the probe, wherein a rotation by 180° or more may be preferred because then the contrast between the spectra is maximized. The rotation may be done slowly so that spectra at different angles are taken more reliably. A marking on the probe can help a user in following the rotation angle. When the probe is not being rotated, the system may utilize different optical paths which are possible with at least three optical fibers.

[0058] If the probe is rotated manually the classification unit will acquire a number of spectra measured under different angles, but it will not be obvious which spectra was acquired at which angle. This is not necessary, however. The classification unit can simply pick the two spectra which exhibit the biggest differences. In general these two spectra will have been measured roughly at perpendicular directions.

[0059] Additionally, polarization of the emitted optical radiation may be employed in step A6. By employing polarization the anisotropy in the medium, i.e. the inspected tissue can be detected from the difference in signal when optical radiation with different polarization is sent into the optical fiber. Preferably polarization maintaining fibers are used. It is also possible to use normal multimode fibers. In this case the polarization is not fully maintained and only the difference between the two states can be measured and are indicative for an isotropic medium in front of the needle. Furthermore, the optical console contains an optical source and a switch between two states with two different polarizers. A controller may be used to switch the polarization state from state one to the second state and two different measurements may be made. An algorithm then determines whether the medium in front is isotropic. If so the tissue classification algorithm then makes use of this input.

[0060] In general, the process is based on the steps A1 to A4. The steps A5 and A6 may be performed additionally or alternatively, if necessary.

[0061] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. The present invention is defined solely by the appended claims.

[0062] In the claims, the word "comprising" does not exclude other elements and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measured cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

LIST OF REFERENCE SIGNS:

[0063]

10	optical source
20	optical source
30	spectrometer
40	spectrometer
50	channel (with or without optical fiber)
100	console
200	processing unit
300	probe
D1	first detector optical fiber
D2	second detector optical fiber
Lp1	optical path 1
Lp2	optical path 2
N	nerve
S1	first source optical fiber
S2	second source optical fiber
Sp1	optical spectrum 1
Sp2	optical spectrum 2

Claims

1. A system for detecting optical anisotropy of a tissue disposed in front of the ends of a plurality of optical fibers, the system comprising:

    an optical source (10, 20);
    an optical detector (30, 40);
    a processing unit (200); and
    a probe (300);
    wherein the probe has a shaft with a longitudinal axis and a front end, and a plurality of optical fibers; an end of each of the optical fibers being arranged at the front end of the shaft;
    wherein at least two of the optical fibers are source optical fibers (S1, S2) adapted to transmit optical radiation emitted from the optical source to a corresponding end of the source optical fiber (S1, S2) for irradiating a tissue adjacent to the front end of the shaft; and
    wherein at least two of the optical fibers are detector optical fibers (D1, D2) adapted to transmit optical radiation reflected from the tissue to the optical detector (30, 40);

wherein the ends of the optical fibers are arranged to define at least two optical paths (Lp1, Lp2) between the at least two source optical fibers (S1, S2) and the at least two detector optical fibers (D1, D2), wherein said at least two optical paths (Lp1, Lp2) intersect each other for probing at the point of the intersection a same location within the tissue from a plurality of transversely-oriented directions; and
wherein the processor is configured:

- to control the optical source (10, 20) to emit optical radiation,
- to receive signals generated by the optical detector (30, 40),
- to determine from the received signals at least two optical spectra (Sp1, Sp2), each spectrum of the at least two optical spectra (Sp1, Sp2) corresponding to one of the at least two optical paths (Lp1, Lp2), the measurement of the at least two optical spectra being performed either simultaneously or sequentially; and
- to determine the anisotropy of the tissue based on differences between the at least two optical spectra (Sp1, Sp2).

2. The system of claim 1, wherein an angle is defined between two optical paths (Lp1, Lp2) of at least 60 degrees.

3. The system of claim 1, wherein an angle is defined between two optical paths (Lp1, Lp2) of at least 70 degrees.

4. The system of any one of claims 1 to 3, wherein the system comprises two optical sources (10, 20).

5. The system of any one of the preceding claims, wherein the system comprises an optical switch or modulator configured to distribute the optical radiation of one optical source (10, 20) to different optical fibers (S1, S2).

6. The system of any one of the preceding claims, further comprising means for rotating the probe (300) about its longitudinal axis.

7. The system of any one of the preceding claims, further comprising means for polarizing the optical radiation emitted from the optical source (10, 20).

8. The system of any one of the preceding claims, wherein the probe (300) further comprises a channel (50) for injecting or extracting a fluid.

9. The system of any of the preceding claims, wherein the system is a diffuse reflectance spectroscopy system.

10. A computer program to be executed on a processing unit of a system according to claim 1, the computer program comprising instructions to:

- control the optical source (10, 20) to emit optical radiation;
- receive signals generated by the optical detector (30, 40);
- determine from the received signals the at least two optical spectra (Sp1, Sp2); and to
- determine the anisotropy of the tissue based on differences between the at least two optical spectra (Sp1, Sp2).

11. The computer program of claim 10, further comprising instructions to control a rotational orientation of the probe (300).

12. The computer program of any one of claims 10 and 11, further comprising instructions to control a polarization direction of the emitted optical radiation.

Patentansprüche

1. System zum Detektieren optischer Anisotropie von Gewebe, eingerichtet vor den Enden einer Vielzahl von Lichtwellenleitern, wobei das System Folgendes umfasst:

eine optische Quelle (10, 20);
einen optischen Detektor (30, 40);
eine Verarbeitungseinheit (200); und
eine Sonde (300);
wobei die Sonde einen Schaft mit einer Längsachse und einem vorderen Ende sowie eine Vielzahl von Lichtwellenleitern aufweist; wobei ein Ende jedes der Lichtwellenleiter am vorderen Ende des Schafts angeordnet ist;
wobei mindestens zwei der Lichtwellenleiter Quellenlichtwellenleiter (S1, S2) sind, die angepasst sind, von der optischen Quelle emittierte optische Strahlung zum Bestrahlen eines an das vordere Ende des Schafts angrenzenden Gewebes auf ein entsprechendes Ende des Quellenlichtwellenleiters (S1, S2) zu übertragen; und wobei mindestens zwei der Lichtwellenleiter Detektorlichtwellenleiter (D1, D2) sind, die angepasst sind, von dem Gewebe reflektierte optische Strahlung auf den optischen Detektor (30,40) zu übertragen;
wobei die Enden der Lichtwellenleiter angeordnet sind, mindestens zwei Strahlengänge (Lp1, Lp2) zwischen den mindestens zwei Quellenlichtwellenleitern (S1, S2) und den mindestens zwei Detektorlichtwellenleitem (D1, D2) zu de-

finieren, wobei die mindestens zwei Strahlengänge (Lp1, Lp2) einander schneiden, um am Schnittpunkt eine gleiche Stelle innerhalb des Gewebes von einer Vielzahl quer orientierter Richtungen zu untersuchen; und
wobei der Prozessor konfiguriert ist,

- um die optische Quelle (10, 20) zu steuern, um optische Strahlung zu emittieren,
- um von dem optischen Detektor (30, 40) erzeugte Signale zu empfangen,
- um aus den empfangenen Signalen mindestens zwei optische Spektren (Sp1, Sp2) zu ermitteln, wobei jedes Spektrum der mindestens zwei optischen Spektren (Sp1, Sp2) einem der mindestens zwei Strahlengänge (Lp1, Lp2) entspricht, wobei die Messung der mindestens zwei optischen Spektren entweder simultan oder nacheinander durchgeführt wird; und
- um die Anisotropie des Gewebes basierend auf Unterschieden zwischen den mindestens zwei optischen Spektren (Sp1, Sp2) zu ermitteln.

2. System nach Anspruch 1, wobei zwischen zwei Strahlengängen (Lp1, Lp2) ein Winkel von mindestens 60 Grad definiert ist.

3. System nach Anspruch 1, wobei zwischen zwei Strahlengängen (Lp1, Lp2) ein Winkel von mindestens 70 Grad definiert ist.

4. System nach einem der Ansprüche 1 bis 3, wobei das System zwei optische Quellen (10, 20) umfasst.

5. System nach einem der vorstehenden Ansprüche, wobei das System einen optischen Schalter oder Modulator umfasst, der konfiguriert ist, die optische Strahlung einer optischen Quelle (10, 20) auf verschiedene Lichtwellenleiter (S1, S2) zu verteilen.

6. System nach einem der vorstehenden Ansprüche, weiter umfassend Mittel zum Drehen der Sonde (300) um ihre Längsachse.

7. System nach einem der vorstehenden Ansprüche, weiter umfassend Mittel zum Polarisieren der von der optischen Quelle (10, 20) emittierten optischen Strahlung.

8. System nach einem der vorstehenden Ansprüche, wobei die Sonde (300) weiter einen Kanal (50) zum Injizieren oder Extrahieren eines Fluids umfasst.

9. System nach einem der vorstehenden Ansprüche, wobei das System ein Spektroskopiesystem mit diffuser Reflexion ist.

10. Computerprogramm, das auf einer Verarbeitungseinheit eines Systems nach Anspruch 1 auszuführen ist, wobei das Computerprogramm Anweisungen umfasst,

- um die optische Quelle (10, 20) zu steuern, um optische Strahlung zu emittieren;
- um von dem optischen Detektor (30, 40) erzeugte Signale zu empfangen;
- um aus den empfangenen Signalen die mindestens zwei optischen Spektren (Sp1, Sp2) zu ermitteln;
und
- um die Anisotropie des Gewebes basierend auf Unterschieden zwischen den mindestens zwei optischen Spektren (Sp1, Sp2) zu ermitteln.

11. Computerprogramm nach Anspruch 10, weiter umfassend Anweisungen, um eine Drehorientierung der Sonde (300) zu steuern.

12. Computerprogramm nach einem der Ansprüche 10 und 11, weiter umfassend Anweisungen, um eine Polarisierungsrichtung der emittierten optischen Strahlung zu steuern.

Revendications

1. Système de détection de l’anisotropie optique d’un tissu disposé en regard des extrémités d’une pluralité de fibres optiques, le système comprenant :

une source optique (10, 20) ;
un détecteur optique (30, 40) ;
une unité de traitement (200) ; et
une sonde (300) ;
dans lequel la sonde a un arbre avec un axe longitudinal et une extrémité frontale ainsi qu’une pluralité de fibres optiques ; une extrémité de chacune des fibres optiques étant agencée à l’extrémité frontale de l’arbre ;
dans lequel au moins deux des fibres optiques sont des fibres optiques de source (S1, S2) qui sont à même de transmettre un rayonnement optique émis par la source optique à une extrémité correspondante de la fibre optique de source (S1, S2) pour irradier un tissu adjacent à l’extrémité frontale de l’arbre ; et
dans lequel au moins deux des fibres optiques sont des fibres optiques de détecteur (D1, D2) qui sont à même de transmettre un rayonnement optique réfléchi par le tissu au détecteur optique (30, 40) ;
dans lequel les extrémités des fibres optiques sont agencées pour définir au moins deux trajets optiques (Lp1, Lp2) entre les au moins deux fi-

bres optiques de source (S1, S2) et les au moins deux fibres optiques de détecteur (D1, D2), dans lequel lesdits au moins deux trajets optiques (Lp1, Lp2) se coupent l'un l'autre pour sonder au point d'intersection un même emplacement au sein du tissu à partir d'une pluralité de directions transversalement orientées ; et
dans lequel le processeur est configuré pour :

- commander la source optique (10, 20) pour émettre un rayonnement optique,
- recevoir des signaux générés par le détecteur optique (30, 40),
- déterminer à partir des signaux reçus au moins deux spectres optiques (Sp1, Sp2), chaque spectre des au moins deux spectres optiques (Sp1, Sp2) correspondant à l'un des au moins deux trajets optiques (Lp1, Lp2), la mesure des au moins deux spectres optiques étant effectuée simultanément ou en séquence ; et
- déterminer l'anisotropie du tissu sur la base de différences entre les au moins deux spectres optiques (Sp1, Sp2).

2. Système selon la revendication 1, dans lequel un angle est défini entre deux trajets optiques (Lp1, Lp2) d'au moins 60 degrés.

3. Système selon la revendication 1, dans lequel un angle est défini entre deux trajets optiques (Lp1, Lp2) d'au moins 70 degrés.

4. Système selon l'une quelconque des revendications 1 à 3, dans lequel le système comprend deux sources optiques (10, 20).

5. Système selon l'une quelconque des revendications précédentes, dans lequel le système comprend un commutateur ou modulateur optique configuré pour distribuer le rayonnement optique d'une seule source optique (10, 20) à différentes fibres optiques (S1, S2).

6. Système selon l'une quelconque des revendications précédentes, comprenant en outre des moyens pour faire tourner la sonde (300) autour de son axe longitudinal.

7. Système selon l'une quelconque des revendications précédentes, comprenant en outre des moyens pour polariser le rayonnement optique émis par la source optique (10, 20).

8. Système selon l'une quelconque des revendications précédentes, dans lequel la sonde (300) comprend en outre un canal (50) pour injecter ou extraire un fluide.

9. Système selon l'une quelconque des revendications précédentes, dans lequel le système est un système de spectroscopie par réflectance diffuse.

10. Programme d'ordinateur à exécuter sur une unité de traitement d'un système selon la revendication 1, le programme d'ordinateur comprenant des instructions pour :

- commander la source optique (10, 20) pour émettre un rayonnement optique ;
- recevoir des signaux générés par le détecteur optique (30, 40) ;
- déterminer à partir des signaux reçus les au moins deux spectres optiques (Sp1, Sp2) ; et
- déterminer l'anisotropie du tissu sur la base de différences entre les au moins deux spectres optiques (Sp1, Sp2).

11. Programme d'ordinateur selon la revendication 10, comprenant en outre des instructions pour commander une orientation de rotation de la sonde (300).

12. Programme d'ordinateur selon l'une quelconque des revendications 10 et 11, comprenant en outre des instructions pour commander un sens de polarisation du rayonnement optique émis.

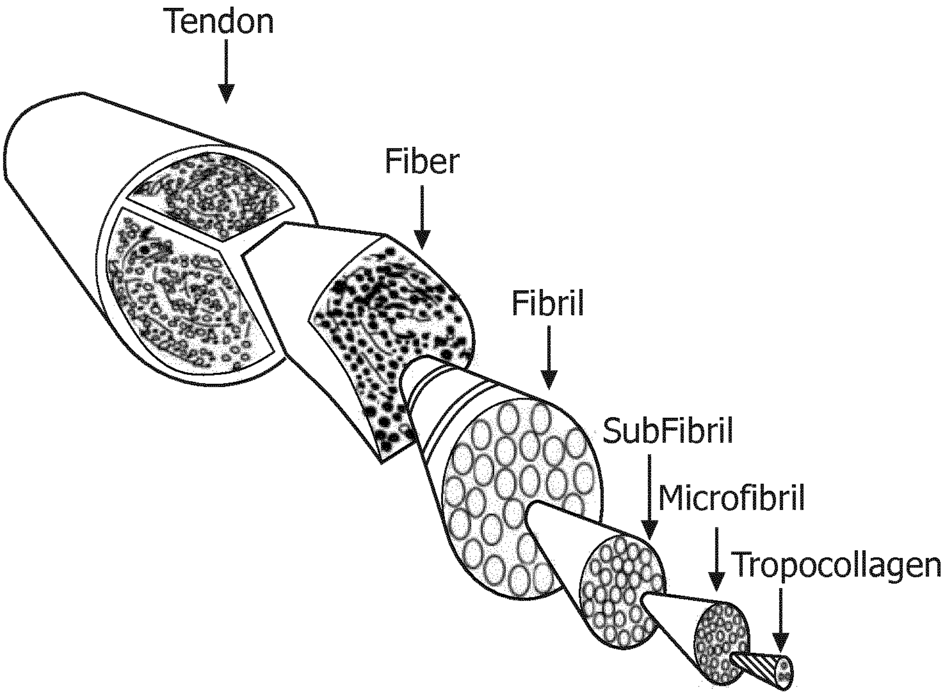
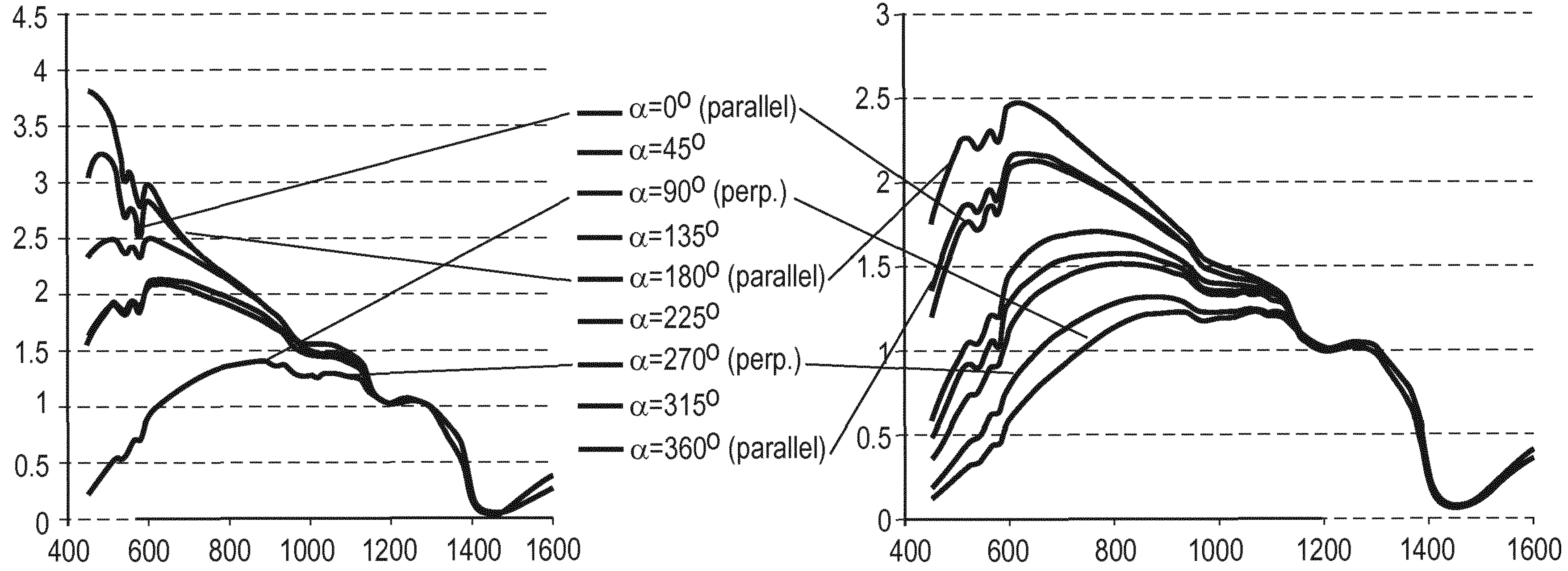

Tendon
Fiber
Fibril
SubFibril
Microfibril
Tropocollagen

FIG. 1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4
3.5
3
2.5
2
1.5
1
0.5
0
400
600
800
1000
1200
1400
1600
α=0° (parallel)
α=45°
α=90° (perp.)
α=135°
α=180° (parallel)
α=225°
α=270° (perp.)
α=315°
α=360° (parallel)
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2
1.5
1
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0
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600
800
1000
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1400
1600

FIG. 2

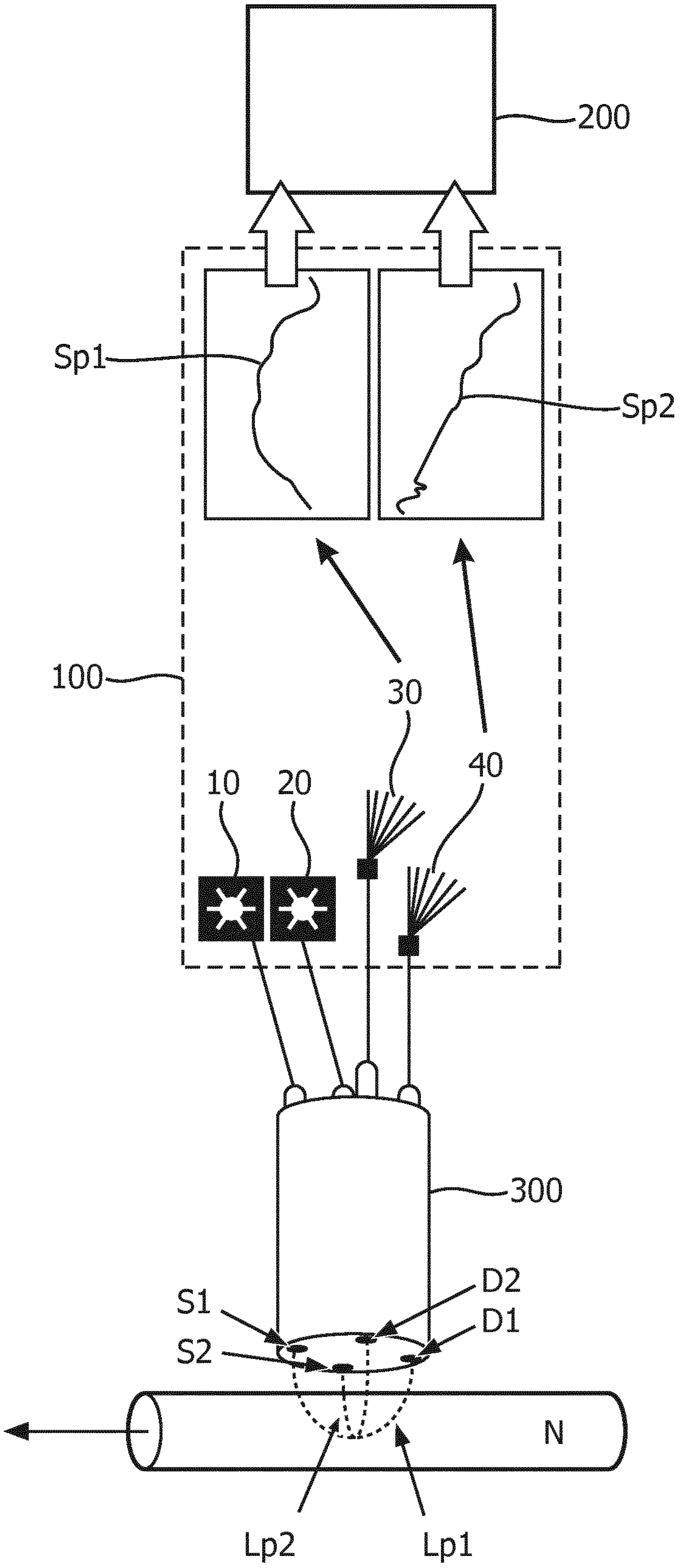

FIG. 3

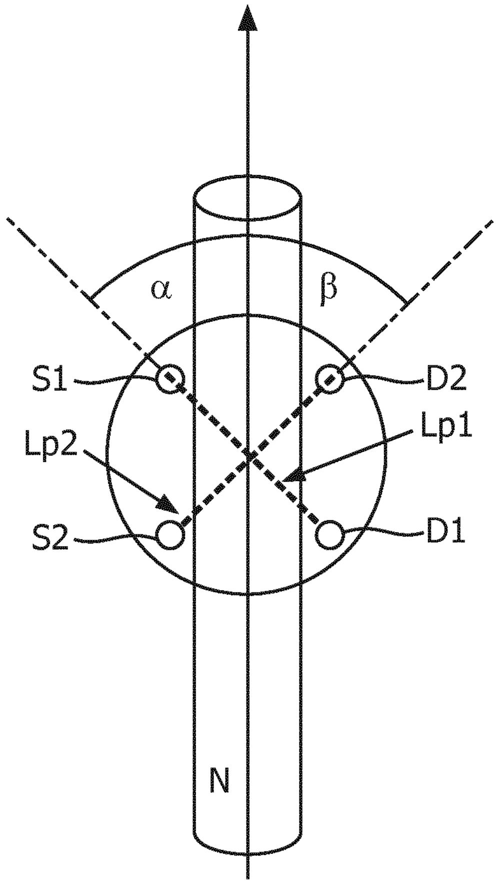

FIG. 4

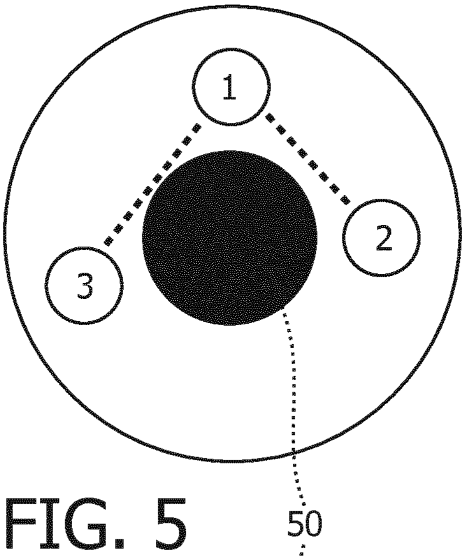

FIG. 5

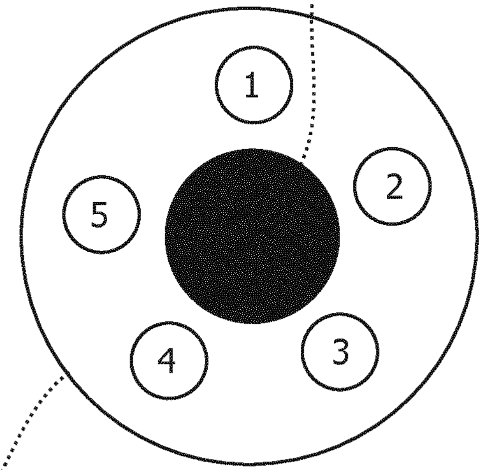

FIG. 6

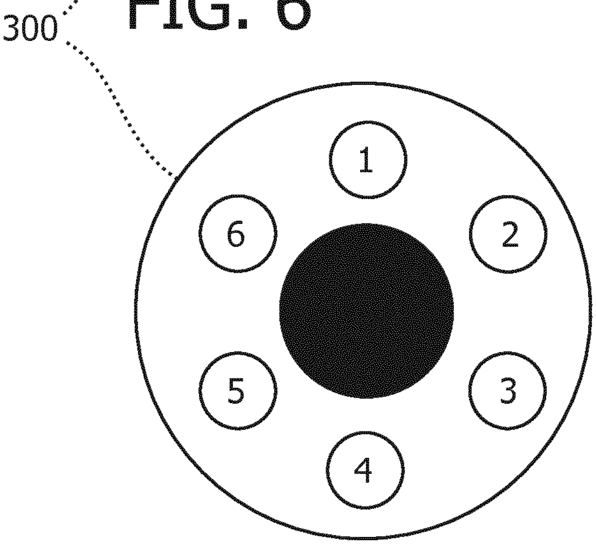

FIG. 7

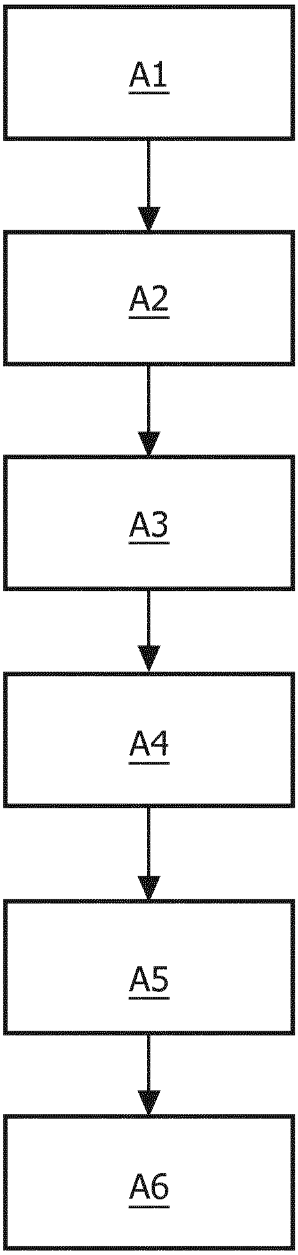

FIG. 8

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 5284154 A **[0004]**
- WO 2012123869 A **[0005]**
- WO 9902956 A2 **[0006]**

专利名称(译)	检测各向异性生物组织		
公开(公告)号	EP3282928B1	公开(公告)日	2019-08-07
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[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦N.V.		
当前申请(专利权)人(译)	皇家飞利浦N.V.		
[标]发明人	MUELLER MANFRED HENDRIKS BERNARDUS HENDRIKUS WILHELMUS LUCASSEN GERHARDUS WILHELMUS BYDLON TORRE MICHELLE		
发明人	MUELLER, MANFRED HENDRIKS, BERNARDUS HENDRIKUS WILHELMUS LUCASSEN, GERHARDUS WILHELMUS BYDLON, TORRE MICHELLE		
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外部链接	Espacenet		

摘要(译)

提供了一种用于检测光学各向异性组织的系统。该系统包括光源，光学检测器，处理单元和探针。探针具有带纵轴和前端的轴，以及多根光纤;其中每根光纤的一端设置在轴的前端，并且至少一根光纤是源光纤，适于将从光源发出的光辐射传输到与前端相邻的组织。轴。另一个光纤是检测器光纤，其适于将从组织反射的光辐射传输到光检测器，从而限定通过组织的光路，其中光路相对于它们的空间取向彼此不同。 ，并且其中光路彼此交叉。处理器被配置为控制光源发射光辐射，以基于组织反射的光辐射接收由光检测器产生的信号，以基于接收的信号确定反射的光辐射的多个光谱。 ，其中从至少两个不同方向获得相同位置的光谱，其中光谱的测量同时或顺序进行，并比较多个光谱，其中光谱与光学辐射有关。因此，不同的光路允许使用光谱之间的差异来检测各向异性组织。

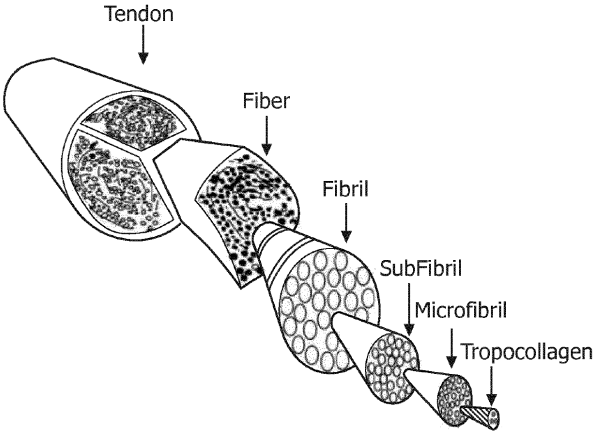

FIG. 1