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(54) DEPTH CONTROLLED PHOTOABLATION OF HUMAN OR ANIMAL TISSUE

TIEFENGESTEUERTE PHOTOABLATION VON MENSCHLICHEM ODER TIERISCHEM GEWEBE
PHOTO-ABLATION CONTRÔLÉE EN PROFONDEUR POUR TISSU HUMAIN OU ANIMAL

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Description

Technical Field

[0001] The present invention relates to a method in which a focused laser beam with a beam waist is provided to a human or animal tissue and more particularly to a device with which such a method can be implemented and a computer program controlling such a device. Such methods, devices and computer programs can be used for photoablating and thereby cutting human or animal tissue.

Background Art

[0002] For cutting human or animal hard tissue such as bone or nail tissue various methods and devices are applied today. Thereby, in recent years photoablation by means of laser beams turned out to be a feasible alternative to known tools and methods. Particularly, in osteotomy laser induced photoablation became of increasing interest as an alternative to known mechanical tools such as saws, chisels or drills. The aim of such laser induced photoablation is to increase preciseness and operability while decreasing collateral damages, e.g. caused by direct contact of the mechanical tools with the bone.

[0003] For example, in WO 2011/035792 A1 a computer assisted and robot guided laser osteotome medical device is described. This medical device comprises a laser head mounted to a robotic arm. The robotic arm has several degrees of freedom such that the laser head can be precisely adjusted in preferred positions and orientations. Like this, it is possible to precisely provide a laser beam onto bone tissue and to photoablate the bone such that it is cut along a predefined osteotomic line. For determining and adjusting the beam position in relation to the bone, the medical device has an autotracking system. By means of the autotracking system the position and orientation of the bone can be monitored and the laser head can be adjusted in order to prevent a deviation of the cutting from the predefined osteotomic line.

[0004] A common problem in known laser induced photoablation of human or animal hard tissue relates to controlling cutting depth and beam intensity. In contrast to laser induced photoablation widely used in micromachining of non-biological materials such as metals and plastics, issues with respect to collateral damages are of crucial importance when photoablating human or animal hard tissue. Such collateral damages can occur, e.g. as carbonization, due to heating caused by inappropriate laser beam intensities in tissue neighboring the osteotomic or cutting line. Or, they can also occur due to photoablation beyond the depth of the targeted hard tissue. Making these problems even more difficult to handle, in contrast to the mentioned non-biological materials, human or animal hard tissues of the same type usually are differing from one individual to the other. Furthermore, human or animal hard tissues usually are not homoge-

neous such that the photoablation properties of the tissue can vary within one single tissue target particularly depending on the cutting depth. For preventing such excess or unwanted photoablation, depth of the photoablation in the tissue is usually optically monitored, e.g., by means of optical coherence tomography (OCT). However, such monitoring is on one hand usually rather complicated and can on the other hand be impaired by other factors of the photoablation such as by debris or by water or blood.

[0005] Therefore, there is a need for a method and device allowing convenient improved photoablation of human or animal tissue by means of a laser beam particularly in terms of collateral damages caused to the tissue by the laser beam.

Disclosure of the Invention

[0006] According to the invention this need is settled by a method of depth controlled photoablation of human or animal tissue as it is defined by the features of independent claim 8 and by a photoablation device as it is defined by the features of independent claims 1. Preferred embodiments are subject of the dependent claims.

[0007] In particular, the gist of the invention is the following: A method of depth controlled photoablation of human or animal tissue comprises the steps of: providing a focused laser beam with a beam waist, wherein a radius of the laser beam increases from the beam waist into a direction of propagation of the laser beam; defining a photoablation zone of the laser beam, wherein the photoablation zone ends in a cutting face which is located offset from the beam waist into the direction of propagation of the laser beam; adjusting the laser beam such that an intensity at the cutting face of the photoablation zone is too low to photoablate the tissue; moving the laser beam in relation to the tissue such that the cutting face of the photoablation zone is arranged at a surface of the tissue; continuously increasing intensity of the laser beam until the intensity at the cutting face of the photoablation zone is sufficiently high to photoablate the tissue; and moving the laser beam towards the tissue. The method according the invention is performed to the human or animal tissue in vitro.

[0008] In the context of the invention, human or animal tissue relates to any tissue suitable for being cut or drilled by laser induced photoablation. The tissue can be a hard tissue such as nail tissue, tooth tissue or the like and particularly bone tissue. The term "intensity" in connection with the laser beam relates to energy per time per area. In order that photoablation of the tissue is possible with the laser beam, its intensity has to be above a specific threshold. Beyond others, this threshold depends on the properties of the tissue. The term "continuously" with regard to the increasing of the laser beam intensity relates to fluent increasing as well as to iterative or stepwise increasing. The term "photoablation" or laser ablation generally relates to a process of removing material from a solid or sometimes liquid surface by irradiating the ma-

terial with a laser beam. With the photoablation according to the invention slits, cuts and/or holes can be provided in the tissue. The steps of adjusting the laser beam such that the intensity at the cutting face of the photoablation zone is too low to photoablate the tissue and continuously increasing the intensity of the laser beam until the intensity at the cutting face of the photoablation zone is sufficiently high to photoablate the tissue can be called calibration. The direction of propagation of the laser beam can also be referred to as a distal direction.

[0009] In some embodiments, and in the absence of supplementary optical elements, the laser beam increases over essentially its whole extent, i.e. it diverges. In such cases, the beam waist can be located at or near a laser source propagating the laser beam. However, typically for focused laser beams, the radius of the laser beam also increases from the beam waist against the direction of propagation of the laser beam such that the beam waist defines a narrowest section or focal point of the laser beam.

[0010] Within the method according to the invention, the depth of the photoablation into the tissue can conveniently be controlled and determined by the movement of the laser beam towards the tissue. In particular, the depth can correspond to the movement of the laser beam towards the tissue. Furthermore, the photoablation energy or intensity can precisely be adjusted in accordance with the properties of the tissue. Like this, it is possible to take account of the individual properties of the tissue and to minimize collateral damages and particularly heating of the tissue such that, e.g., carbonization of the tissue can be prevented.

[0011] Preferably, the photoablation zone of the laser beam corresponds to a Raleigh zone of the laser beam. Defining the photoablation zone to correspond to the Raleigh zone of the laser beam allows for implementing the photoablation zone in a well-established fashion and to precisely define the cutting face of the laser beam at the distal end of the Raleigh zone. Also, as the laser beam increasingly diverges outside the Raleigh zone the intensity correspondingly decreases. Therefore, defining the cutting face to be at the distal end of the Raleigh zone allows for an efficient photoablation, e.g. in terms of energy consumption, in terms of delimitation of the cutting face and in terms of cutting or drilling abilities.

[0012] Preferably, the intensity of the laser beam is adjusted by adjusting current and/or voltage provided to a laser source propagating the laser beam and/or by adjusting a length of a pulse of the laser beam. Such adjustment of the laser beam allows for a comparably simple, precise and efficient implementation.

[0013] Preferably, it is continuously sensed if the tissue is photoablated and the increasing of the intensity of the laser beam is stopped when it is sensed that the photoablation of the tissue starts. Like this, the threshold of the intensity required for photoablating the tissue can precisely and conveniently be determined. By stopping the increasing of the intensity once the threshold is reached,

the intensity can be exactly adjusted to the properties of the tissue and any unnecessary heating of the tissue can be prevented.

[0014] Thereby, it preferably is acoustically sensed if the tissue is photoablated or not. Such acoustical sensing can, e.g., be performed by positioning a microphone, particularly a laser microphone, and/or a piezoelectric pressure transducer near or at the tissue. Like this, the threshold of the laser beam intensity necessary for photoablating the tissue can precisely be detected in a comparably simple manner.

[0015] Thereby, a frequency spectrum of an acoustically sensed wave preferably is monitored. The frequency spectrum depends on the acoustic impedance of the tissue. For example, applying laser beams with identical properties, comparably hard materials generate comparably high acoustic frequencies whereas comparably soft materials generate comparably low acoustic frequencies. Thus, monitoring the acoustically sensed signal allows for recognizing changing properties of the tissue. Accordingly, suitable measures can be taken based on the monitored acoustic signal. For example, propagation of the laser beam can be stopped or recalibrated as described in the following section if it is detected that the tissue is getting softer such that the beam intensity should preferably be reduced.

[0016] Generally, optical coherence tomography (OCT) is an interferometric technique used as an optical signal acquisition and processing method. It captures micrometer-resolution, one- two and three-dimensional images from within optical scattering media such as biological tissue, e.g., the human or animal tissue. The use of relatively long wavelength light allows it to penetrate into the scattering medium. Depending on the properties of the light source superluminescent diodes, ultrashort pulsed lasers and supercontinuum lasers are employed. A relatively recent implementation of OCT which is called frequency-domain OCT provides advantages in signal-to-noise ratio, permitting faster signal acquisition. OCT systems are employed in diverse applications, including diagnostic medicine, ophthalmology and cardiology to help diagnose coronary artery disease. OCT can also be used in conjunction with the present method to monitor the depth of the cut or drill by photoablation in real-time. Thereby, as an alternative to the acoustic sensing described hereinbefore or in addition to such acoustic sensing, it preferably is optically sensed if the tissue is photoablated by applying OCT. In particular, OCT can be used to anticipate outer bone-soft tissue interface or any intermediate position with high precision. Such sensing with OCT can allow for an efficient high precision control of the photoablation.

[0017] Preferably, the method further comprises decreasing intensity of the laser beam such that the intensity at the cutting face of the photoablation zone is too low to photoablate the tissue again and continuously increasing intensity of the laser beam again until the intensity at the cutting face of the photoablation zone is sufficiently high

to photoablate the tissue. Like this, the laser beam can be recalibrated during the photoablation process. This can particularly be helpful in cases where properties of the tissue are changing, e.g. with increasing depth of the photoablation. For example, human bone tissue usually is not fully homogenous and photoablation properties often change inwards a bone. In particular, in consideration of the frequency spectrum acoustically sensed as described above, this allows for ongoing recalibration of the laser beam as soon as a change of tissue properties are detected by changing frequency spectrum.

[0018] Preferably, properties of the tissue are determined prior to continuously increasing the intensity of the laser beam wherein the properties are considered when photoablating the tissue. In this context, properties can relate to dimensions, structure and/or composition of the tissue. They can particularly comprise a thickness of the tissue. By considering the properties of the tissue the photoablation process can be tailored and optimized to the given situation. Furthermore, these pre-determined properties can be combined with properties measured in an ongoing manner and determined such that the photoablation process can additionally be tailored and optimized to the given situation.

[0019] As mentioned hereinbefore, the human or animal tissue is photoablated in vitro.

[0020] A further aspect of the invention relates to a photoablation device for photoablation of human or animal tissue. The photoablation device comprises: a laser source being arranged to propagate a focused laser beam with a beam waist, wherein a radius of the laser beam increases from the beam waist into a direction of propagation of the laser beam, an adjusting structure being arranged for adjusting an intensity of the laser beam; a position detector for detecting a position of the laser source in relation to the tissue; a positioning device being arranged to move the laser source in relation to the tissue; and a controller unit being arranged to define a photoablation zone of the laser beam, wherein the photoablation zone ends in a cutting face which is located offset from the beam waist into the direction of propagation of the laser beam, to adjust an intensity at the cutting face of the photoablation zone of the laser beam by means of the adjusting structure, and to move the laser beam towards the tissue by means of the positioning device, wherein the position of the laser source detected by the position detector is evaluated.

[0021] In the context of the invention the term "position" can relate to location and orientation of the laser source. The photoablation device allows for efficiently and conveniently implementing the method described above thereby implementing the aspects and preferred effects as described in connection with the method.

[0022] The laser source can, e.g., be arranged to emit at wavelengths where water has strong absorption bands and can preferably comprise an Erbium solid state laser such as Er:YAG, Er/Pr:YAG, Ho:YAG or Er/Cr:YSGG, a holmium solid state laser such as Ho/Nd:YAG or Ho:YS-

GG, a diode laser, and/or a fiber laser. For example, the photoablation laser can have a pulse temporal width which is between 10 femtoseconds and 1 millisecond, preferably, between 10 nanoseconds and 800 microseconds. It can also be arranged to deliver a laser beam with an energy density between 1 millijoule per square centimeter and 100'000 joule per square centimeter, in particular, between 10 millijoule per square centimeter and 5 joule per square centimeter.

[0023] Preferably, the adjusting structure comprises a current adjuster for adjusting current or voltage or both, current and voltage simultaneously, provided to the laser source propagating the laser beam and/or a pulse adjuster for adjusting a length of a pulse of the laser beam. With such an adjusting structure, the photoablation device can be capable of efficiently and precisely adjusting intensity of the laser beam.

[0024] Preferably, the photoablation device further comprises an acoustic sensor being arranged to sense an acoustic wave generated by the laser beam hitting the tissue and to provide a corresponding signal. Thereby, the controller unit preferably is arranged to evaluate the signal provided by the acoustic sensor in order to detect photoablation of the tissue. Like this, the threshold of the laser beam intensity necessary for photoablating the tissue can precisely be detected in a comparably simple manner. Thereby, the controller unit preferably is arranged to continuously increase intensity of the laser beam until photoablation of the tissue is detected by evaluating the signal provided by the acoustic sensor. Such controller unit allows for precisely and conveniently adjusting the laser beam appropriately.

[0025] Preferably, the controller unit is arranged to monitor a frequency spectrum of the acoustic wave by evaluating the signal provided by the acoustic sensor. As described in more detail above in connection with the method according to the invention such monitoring allows for recognizing changing properties of the tissue. Accordingly, suitable measures can be taken based on the monitored acoustic signal.

[0026] Preferably, the acoustic sensor is a microphone and/or a piezoelectric pressure transducer and/or a laser microphone. Such an acoustic sensor allows for a comparably simple implementation with appropriate precision and efficiency. As an alternative or in addition to the acoustic sensor, the photoablation device preferably further comprises an optical coherence tomography structure with an optical sensor. Such OCT structure can be arranged to apply OCT as described above in connection with the method wherein, in particular, the controller unit can be arranged to be involved in the OCT.

[0027] Another further aspect of the invention relates to a computer program comprising program code being arranged to implement a controller unit of a photoablation device as described hereinbefore when being executed. Such a computer program allows for efficiently and conveniently implementing the method described above and controlling the device described above thereby imple-

menting the aspects and preferred effects as described in connection with the method and the device.

[0028] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter.

Brief Description of the Drawings

[0029] The photoablation device and the method according to the invention are described in more detail hereinbelow by way of an exemplary embodiment and with reference to the attached drawings, in which:

- Fig. 1 shows an embodiment of a photoablation device according to the invention;
 Fig. 2 shows a focused laser beam with a photoablation zone defined in accordance with the invention; and
 Fig. 3 shows the focused laser beam of Fig. 2 applied to a bone tissue.

Description of Embodiments

[0030] In the following description certain terms are used for reasons of convenience and are not to be interpreted as limiting. The terms "right", "left", "up" and "down" refer to directions in the figures. The terminology comprises the explicitly mentioned terms as well as their derivations and terms with a similar meaning.

[0031] Fig. 1 shows an embodiment of a photoablation device 1 according to the invention for depth controlled photoablation of a target bone tissue 8. The photoablation device 1 comprises a robot arm 3 as positioning device, an evacuation supply system 5, an auto-tracker 6 as position detector, a laser source 2, a microphone 7 as acoustic sensor and a controller unit 4 having a computer 41.

[0032] The laser source 2 is fixedly mounted to a platform provided at a free end of the robot arm 3. It is arranged to propagate a focused laser beam 21 into a direction of propagation 213 which, in Fig. 1, is from left to right. The laser source 2 is connected to a current adjuster 47 of the controller unit 4 which allows the energy intensity of the laser beam 21 to be adjusted by adjusting the current provided to the laser source 2.

[0033] The bone tissue 8 is positioned to be reached and targeted by the laser beam 21 of the laser source 2. The robot arm 3 has several degrees of freedom such that the laser source 2 can be moved by the robot arm 3 in order to be accurately positioned and oriented to propagate the laser beam 21 to the bone tissue 8. For controlling the robot arm 3 and particularly its movements the robot arm 3 is connected to a robot interface 45 of the controller unit 4 such that the computer 41 can control and adjust the position and orientation of the laser source 2.

[0034] The auto-tracker 6 is arranged to detect and track the position of the laser source 2 in relation to the

bone tissue 8. For allowing three-dimensional detection of the position and orientation the laser source 2 is provided with at least three markers 22 and the bone tissue 8 is provided with at least three markers 84. The auto-tracker 6 is connected to an auto-tracker interface 43 of the controller unit 4 such that detected positions of the laser source 2 and the bone tissue 8 or particularly their markers 22, 84, respectively, can be gathered and evaluated by the computer 41.

[0035] On the bone tissue 8 an osteotomic line 81 is defined via the controller unit 4. In order to cut the bone tissue 8 along the osteotomic line 81 the laser source 2 is moved in relation to the bone tissue 8 such that the laser beam 21 is appropriately propagated. The osteotomic line 81 can be defined in the controller unit 4 by a dataset specifying a linear array of spots. The dataset can comprise the position of the spots where holes are to be perforated in the bone tissue 8 as well as striking angles of the laser beam 21 with respect to a surface of the bone tissue 8. In particular, the position of each spot can be defined by a set of space coordinates X, Y and Z and the striking angle on each spot can be defined by a pair of angles θ and Ω . Thus, the dataset can comprise XYZ- $\theta\Omega$ information for each spot together forming the osteotomic line 81.

[0036] The microphone 7 is fixedly located with regard to the laser source 2. It is arranged to sense an acoustic wave generated by the laser beam 21 hitting the bone tissue 8. The microphone 7 is connected to the computer 41 of the controller unit wherein a signal corresponding to the sensed acoustic wave is transmitted from the microphone 7 to the computer 41. Considering varying frequency spectra of the acoustic waves caused by photoablation in general and caused by photoablation of different tissue materials, the computer 41 can evaluate the signal transmitted by the microphone 7. Thereby, it can be detected on one hand if photoablation is performed or not and on the other hand if and when the target material or properties thereof change.

[0037] The controller unit 4 further has a joystick 41 connected to the computer 41 via an osteotomy design interface 46. By means of the joystick 41 a practitioner is allowed to design the osteotomic line 81 on the bone tissue 8 wherein the bone tissue 8 can be visually modelled or displayed by any suitable method and means. The evacuation supply system 5 is arranged to evacuate debris resulting from the photoablation of the bone tissue 8 and to supply a medium for keeping the bone tissue 8 clean particularly near the osteotomic line 81. For this purpose, the evacuation supply system 5 can be equipped with an aspirating pump and/or a water jet. The evacuation supply system 5 is connected to an evacuation supply interface 44 such that the computer 41 can monitor control appropriate supply and evacuation.

[0038] The following applies to the rest of this description. If, in order to clarify the drawings, a figure contains reference signs which are not explained in the directly associated part of the description, then it is referred to

previous description sections.

[0039] In Fig. 2 the focussed laser beam 21 provided by the laser source 2 in the direction of propagation 213 and its tailoring or application in accordance with the invention is shown in more detail. Generally, the shape of the laser beam 21 is known a priori to be similar as all focused laser beams and looks essentially like an ideal Gaussian laser beam 211 with $M^2=1$ or a non-ideal laser beam 212 with $M^2>1$. The ideal Gaussian laser beam 211 has a waist 2111 of smallest beam radius at which the photon-flux or photon density which corresponds to the energy density is highest. Starting from the waist 2111 the beam radius increases into and against the direction of propagation 213 as exemplified by beam radius 2114. Correspondingly, the photon or energy density decreases from the waist 2111 into and against the direction of propagation 213.

[0040] In accordance with the invention a photoablation zone 2112 of the ideal Gaussian laser beam 211 is defined. The photoablation zone 2112 corresponds to a Raleigh zone of the ideal Gaussian laser beam 211 at the end of which its photon and energy intensity drops to half compared to respective intensity at the waist 2111. Outside the Raleigh zone the so called far-field of the ideal Gaussian laser beam 211 is located. The distal end of the photoablation zone 2112 or the end into the direction of propagation 213 of the photoablation zone 2112 forms a cutting face 2113 of the ideal Gaussian laser beam 211.

[0041] Correspondingly, the non-ideal laser beam 212 has a waist 2121 of smallest beam radius which is bigger than and offset compared to the waist 2111 of the ideal Gaussian laser beam 211. Starting from the waist 2121 of the non-ideal laser beam 212 the photon or energy density decreases from the waist 2121 into and against the direction of propagation 213. A photoablation zone 2122 of the non-ideal laser beam 211 is defined corresponding to a Raleigh zone. At the end of the Raleigh zone of the non-ideal laser beam 212 its photon and energy intensity drops to half compared to respective intensity at the waist 2121. The distal end of the photoablation zone 2122 or the end into the direction of propagation 213 of the photoablation zone 2122 forms a cutting face 2123 of the non-ideal laser beam 212.

[0042] Fig. 3 shows the non-ideal laser beam 212 in two different situations with regard to the bone tissue 8 which has an upper cortical bone portion 82 and a lower spongy bone portion 83. The cortical bone portion 82 and the spongy bone portion 83 have different photoablation properties.

[0043] As can be seen in the left-hand situation of Fig. 3 the laser source 2 is positioned and oriented by means of the controller unit 4 and the robot arm 3 such that the cutting face 2123 of the non-ideal laser beam 212 is arranged at a top surface of the bone tissue 8. Initially, the current adjuster 47 of the controller unit 4 adjusts the current provided to the laser source 21 on a level such that the beam intensity is too low to initiate photoablation

of the bone tissue 8 at the cutting face 2123. In this status the microphone 7 provides a signal which is evaluated by the computer 41 of the controller unit 4 not to be induced by an acoustic wave of bone photoablation. Then, by increasing the current provided to the laser source 2 the intensity at the cutting face 2123 is increased until the computer 41 of the controller unit 4 evaluates that the respective signal provided by the microphone 7 is indicative for photoablation of the bone tissue 8 started. The current adjuster 47 of the controller unit 4 then holds the current provided to the laser source 21 at this level and the laser source 2 is calibrated. Like this, the laser beam intensity is selected such that the photon-flux only exceeds the threshold required for ablating the bone tissue inside photoablation zone 2122 of the non-ideal laser beam 212. As the robot arm 3 accurately controls the positioning and orientating of the laser beam 21 relative to the bone tissue 8, the cutting depth can thus be precisely controlled by moving the laser source 2 towards the bone tissue 8 as can be seen on the right-hand side of Fig. 3.

[0044] Thus, also considering that the bone thickness usually is known, the robot arm 3 can set the focal point of the optic such that the laser energy or density at the desired cutting depth just barely exceeds the required threshold for photoablation bone tissue 8, thus allowing efficient control over the ablation depth. As the photon-flux or laser beam intensity in the far field is below the required threshold, no ablation can happen. Thus, the cutting depth is limited and controlled by a comparably simple physical principle.

[0045] While photoablating the bone tissue 8, the microphone continuously provides the acoustic signal and the computer 41 of the controller unit 4 continuously monitors a frequency spectrum of the acoustically sensed wave corresponding to the acoustic signal. Once it is detected that frequency spectrum changes due to changing properties of the tissue being ablated, the laser beam intensity is decreased and photoablation is stopped. The laser beam 21 can then be recalibrated as described above. E.g., once the non-ideal laser beam 212 reaches the transition from the cortical bone portion 82 to the spongy bone portion 83 the acoustic signal provided by the microphone 7 changes. The computer 41 of the controller unit 4 evaluates that the frequency spectrum of a wave corresponding to this changed signal represents changed photoablating properties of the bone tissue 8 and the controller unit 4 decreases the current provided to the laser source 2 to a level at which no photoablation occurs. Now, similar to the initial calibration, the laser source is recalibrated in accordance with the properties of the spongy bone portion 83.

[0046] 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 defined in the claims, other embodiments being merely exemplary.

[0047] The disclosure comprises subject matter consisting of the features defined in the claims or the exemplary embodiments as well as subject matter comprising said features.

[0048] Furthermore, in the claims the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single unit or step may fulfil the functions of several features recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. The terms "essentially", "about", "approximately" and the like in connection with an attribute or a value particularly also define exactly the attribute or exactly the value, respectively. The term "about" in the context of a given numerate value or range refers to a value or range that is, e.g., within 20%, within 10%, within 5%, or within 2% of the given value or range. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems. In particular, e.g., a computer program can be a computer program product stored on a computer readable medium which computer program product can have computer executable program code adapted to be executed to implement a specific method such as the method according to the invention. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. Photoablation device (1) for photoablation of human or animal tissue (8), comprising
 - a laser source (2) arranged to propagate a focused laser beam (21) with a beam waist (2111, 2121), wherein a radius of the laser beam (21) increases from the beam waist (2111, 2121) into a direction of propagation (213) of the laser beam (21);
 - a position detector (6) for detecting a position of the laser source (2) in relation to the tissue (8); and
 - a positioning device (3) arranged to move the laser source (2) in relation to the tissue (8);**characterized by** further comprising
 - an adjusting structure (41, 47) arranged for adjusting an intensity of the laser beam (21); and
 - a controller unit (4) arranged

to define a photoablation zone (2112, 2122) of the laser beam (21), wherein the photoablation zone (2112, 2122) ends in a cutting face (2113, 2123) which is located offset from the beam waist (2111, 2121) into the direction of propagation (213) of the laser beam (21),
 to adjust an intensity at the cutting face (2113,

2123) of the photoablation zone (2112, 2122) of the laser beam (21) by means of the adjusting structure (41, 47), and

to move the laser beam (21) towards the tissue (8) by means of the positioning device (3), wherein the position of the laser source (2) detected by the position detector (6) is evaluated.

2. Photoablation device (1) according to claim 1, wherein the adjusting structure (41, 47) comprises a current adjuster for adjusting current and/or voltage provided to the laser source (2) propagating the laser beam (21) and/or a pulse adjuster for adjusting a length of a pulse of the laser beam (21).
3. Photoablation device (1) according to claim 1 or 2, comprising an acoustic sensor (7) arranged to sense an acoustic wave generated by the laser beam (21) hitting the tissue (8) and to provide a corresponding signal.
4. Photoablation device (1) according to claim 3, wherein the controller unit (4) is arranged to evaluate the signal provided by the acoustic sensor (7) in order to detect photoablation of the tissue (8).
5. Photoablation device (1) according to claim 4, wherein the controller unit (4) is arranged to continuously increase intensity of the laser beam (21) until photoablation of the tissue (8) is detected by evaluating the signal provided by the acoustic sensor (7).
6. Photoablation device (1) according to any one of claims 3 to 5, wherein the controller unit (4) is arranged to monitor a frequency spectrum of the acoustic wave by evaluating the signal provided by the acoustic sensor (7).
7. Photoablation device (1) according to any one of claims 3 to 6, wherein the acoustic sensor (7) is a microphone and/or a piezoelectric pressure transducer and/or a laser microphone.
8. Method of depth controlled photoablation of human or animal tissue (8), comprising
 - providing a focused laser beam (21) with a beam waist (2111, 2121), wherein a radius of the laser beam (21) increases from the beam waist (2111, 2121) into a direction of propagation (213) of the laser beam (21);
 - defining a photoablation zone (2112, 2122) of the laser beam, wherein the photoablation zone (2112, 2122) ends in a cutting face (2113, 2123) which is located offset from the beam waist (2111, 2121) into the direction of propagation (213) of the laser beam (21);
 - adjusting the laser beam (21) such that an intensity at the cutting face (2113, 2123) of the photoablation

- zone (2112, 2122) is too low to photoablate the tissue (8);
 moving the laser source (2) in relation to the tissue (8) such that the cutting face (2113, 2123) of the photoablation zone (2112, 2122) is arranged at a surface of the tissue (8);
 continuously increasing intensity of the laser beam (21) until the intensity at the cutting face (2113, 2123) of the photoablation zone (2112, 2122) is sufficiently high to photoablate the tissue (8); and
 moving the laser source (2) towards the tissue (8) wherein the human or animal tissue (8) is photoablated in vitro.
9. Method according to claim 8, in which the photoablation zone (2112, 2122) of the laser beam (21) corresponds to a Raleigh zone of the laser beam (21).
10. Method according to claim 8 or 9, wherein the intensity of the laser beam (21) is adjusted by adjusting current and/or voltage provided to a laser source (2) propagating the laser beam (21) and/or by adjusting a length of a pulse of the laser beam (21).
11. Method according to any one of claims 8 to 10, wherein it is continuously sensed if the tissue (8) is photoablated and the increasing of the intensity of the laser beam (21) is stopped when it is sensed that the photoablation of the tissue (8) starts.
12. Method according to claim 11, wherein it is acoustically sensed if the tissue (8) is photoablated wherein, preferably, a frequency spectrum of an acoustically sensed wave is monitored.
13. Method according to any one of claims 8 to 12, wherein it is optically sensed if the tissue (8) is photoablated by applying optical coherence tomography.
14. Method according to any one of claims 8 to 13, comprising decreasing intensity of the laser beam (21) such that the intensity at the cutting face (2113, 2123) of the photoablation zone (2112, 2122) is too low to photoablate the tissue (8) and continuously increasing intensity of the laser beam (21) again until the intensity at the cutting face (2113, 2123) of the photoablation zone (2112, 2122) is sufficiently high to photoablate the tissue (8).
15. Method according to any one of claims 8 to 14, in which properties of the tissue (8) are determined prior to continuously increasing the intensity of the laser beam (21) wherein the properties are considered when photoablating the tissue (8).

Patentansprüche

1. Photoablationsvorrichtung (1) zur Photoablation von menschlichem oder tierischem Gewebe (8), umfassend
 eine Laserquelle (2), die eingerichtet ist, um einen fokussierten Laserstrahl (21) mit einer Strahltaile (2111, 2121) auszubreiten, wobei ein Radius des Laserstrahls (21) von der Strahltaile (2111, 2121) aus in einer Ausbreitungsrichtung (213) des Laserstrahls (21) zunimmt;
 einen Positionsdetektor (6) zum Erkennen einer Position der Laserquelle (2) in Bezug auf das Gewebe (8); und
 eine Positioniervorrichtung (3), die eingerichtet ist, um die Laserquelle (2) in Bezug auf das Gewebe (8) zu bewegen;
dadurch gekennzeichnet, dass sie ferner umfasst:
 eine Anpassungsstruktur (41, 47), die zum Anpassen einer Intensität des Laserstrahls (21) eingerichtet ist; und
 eine Steuereinheit (4), die eingerichtet ist
 zum Definieren einer Photoablationszone (2112, 2122) des Laserstrahls (21), wobei die Photoablationszone (2112, 2122) in einer Schneidstirnseite (2113, 2123) endet, die sich in Ausbreitungsrichtung (213) des Laserstrahls (21) nach der Strahltaile (2111, 2121) befindet,
 zum Anpassen einer Intensität des Laserstrahls (21) an der Schneidstirnseite (2113, 2123) der Photoablationszone (2112, 2122) mithilfe der Anpassungsstruktur (41, 47) und
 zum Bewegen des Laserstrahls (21) mithilfe der Positioniereinrichtung (3) in Richtung des Gewebes (8), wobei die durch den Positionsdetektor (6)
 erkannte Position der Laserquelle (2) ausgewertet wird.
2. Photoablationsvorrichtung (1) nach Anspruch 1, wobei die Anpassungsstruktur (41, 47) eine Stromanpassungseinrichtung zum Anpassen von Strom und/oder Spannung, der bzw. die der den Laserstrahl (21) ausbreitenden Laserquelle (2) bereitgestellt wird, und/oder eine Pulsanpassungseinrichtung zum Anpassen einer Länge eines Pulses des Laserstrahls (21), umfasst.
3. Photoablationsvorrichtung (1) nach Anspruch 1 oder 2, umfassend einen akustischen Sensor (7), der eingerichtet ist, um eine durch den auf das Gewebe (8) treffenden Laserstrahl (21) erzeugte akustische Welle zu erfassen und ein entsprechendes Signal

- bereitzustellen.
4. Photoablationsvorrichtung (1) nach Anspruch 3, wobei die Steuereinheit (4) eingerichtet ist, um das durch den akustischen Sensor (7) bereitgestellte Signal auszuwerten, um eine Photoablation des Gewebes (8) zu erkennen.
 5. Photoablationsvorrichtung (1) nach Anspruch 4, wobei die Steuereinheit (4) eingerichtet ist, um die Intensität des Laserstrahls (21) kontinuierlich zu erhöhen, bis die Photoablation des Gewebes (8) erkannt wird, indem das durch den akustischen Sensor (7) bereitgestellte Signal ausgewertet wird.
 6. Photoablationsvorrichtung (1) nach einem der Ansprüche 3 bis 5, wobei die Steuereinheit (4) eingerichtet ist, um ein Frequenzspektrum der akustischen Welle zu überwachen, indem das durch den akustischen Sensor (7) bereitgestellte Signal ausgewertet wird.
 7. Photoablationsvorrichtung (1) nach einem der Ansprüche 3 bis 6, wobei der akustische Sensor (7) ein Mikrofon und/oder ein piezoelektrischer Druckwandler und/oder ein Lasermikrofon ist.
 8. Verfahren zur tiefenüberwachten Photoablation von menschlichem oder tierischem Gewebe (8), umfassend
Bereitstellen eines fokussierten Laserstrahls (21) mit einer Strahltaile (2111, 2121), wobei ein Radius des Laserstrahls (21) von der Strahltaile (2111, 2121) aus in einer Ausbreitungsrichtung (213) des Laserstrahls (21) zunimmt;
Definieren einer Photoablationszone (2112, 2122) des Laserstrahls (21), wobei die Photoablationszone (2112, 2122) in einer Schneidstirnseite (2113, 2123) endet, die sich in Ausbreitungsrichtung (213) des Laserstrahls (21) nach der Strahltaile (2111, 2121) befindet;
Anpassen des Laserstrahls (21), sodass eine Intensität an der Schneidstirnseite (2113, 2123) der Photoablationszone (2112, 2122) zu niedrig ist, um das Gewebe (8) mittels Photoablation abzutragen;
Bewegen der Laserquelle (2) in Bezug auf das Gewebe (8), sodass die Schneidstirnseite (2113, 2123) der Photoablationszone (2112, 2122) an einer Oberfläche des Gewebes (8) angeordnet ist;
kontinuierliches Erhöhen der Intensität des Laserstrahls (21), bis die Intensität an der Schneidstirnseite (2113, 2123) der Photoablationszone (2112, 2122) ausreichend hoch ist, um das Gewebe (8) mittels Photoablation abzutragen; und
Bewegen der Laserquelle (2) in Richtung des Gewebes (8), wobei das menschliche oder tierische Gewebe (8) in vitro mittels Photoablation abgetragen wird.
 9. Verfahren nach Anspruch 8, bei dem die Photoablationszone (2112, 2122) des Laserstrahls (21) einer Raleigh-Zone des Laserstrahls (21) entspricht.
 10. Verfahren nach Anspruch 8 oder 9, wobei die Intensität des Laserstrahls (21) durch Anpassen von Strom und/oder Spannung, der bzw. die einer den Laserstrahl (21) ausbreitenden Laserquelle (2) bereitgestellt wird, und/oder Anpassen einer Länge eines Pulses des Laserstrahls (21) angepasst wird.
 11. Verfahren nach einem der Ansprüche 8 bis 10, wobei kontinuierlich erfasst wird, ob das Gewebe (8) mittels Photoablation abgetragen wird, und die Zunahme der Intensität des Laserstrahls (21) gestoppt wird, wenn erfasst wird, dass die Photoablation des Gewebes (8) beginnt.
 12. Verfahren nach Anspruch 11, wobei akustisch erfasst wird, ob das Gewebe (8) mittels Photoablation abgetragen wird, wobei vorzugsweise ein Frequenzspektrum einer akustisch erfassten Welle überwacht wird.
 13. Verfahren nach einem der Ansprüche 8 bis 12, wobei durch Anwenden einer optischen Kohärenztomographie optisch erfasst wird, ob das Gewebe (8) mittels Photoablation abgetragen wird.
 14. Verfahren nach einem der Ansprüche 8 bis 13, umfassend das Verringern der Intensität des Laserstrahls (21), sodass die Intensität an der Schneidstirnseite (2113, 2123) der Photoablationszone (2112, 2122) zu niedrig ist, um das Gewebe (8) mittels Photoablation abzutragen, und das erneute kontinuierliche Erhöhen der Intensität des Laserstrahls (21), bis die Intensität an der Schneidstirnseite (2113, 2123) der Photoablationszone (2112, 2122) ausreichend hoch ist, um das Gewebe (8) mittels Photoablation abzutragen.
 15. Verfahren nach einem der Ansprüche 8 bis 14, wobei Eigenschaften des Gewebes (8) ermittelt werden, bevor die Intensität des Laserstrahls (21) kontinuierlich erhöht wird, wobei die Eigenschaften berücksichtigt werden, wenn das Gewebe (8) mittels Photoablation abgetragen wird.
- Revendications**
1. Dispositif de photo-ablation (1) pour la photo-ablation d'un tissu humain ou animal (8), comprenant une source laser (2) agencée pour propager un faisceau laser (21) focalisé avec une taille minimale de faisceau (2111, 2121), dans laquelle un rayon du faisceau laser (21) augmente depuis la taille minimale de faisceau (2111, 2121) dans une direction

- de propagation (213) du faisceau laser (21) ; un détecteur de position (6) pour détecter une position de la source laser (2) par rapport au tissu (8) ; et un dispositif de positionnement (3) agencé pour déplacer la source laser (2) par rapport au tissu (8) ; **caractérisé en ce qu'il** comprend en outre une structure de réglage (41, 47) agencée pour régler une intensité du faisceau laser (21) ; et une unité de commande (4) agencée pour
- définir une zone de photo-ablation (2112, 2122) du faisceau laser (21), dans laquelle la zone de photo-ablation (2112, 2122) se termine en une face de coupe (2113, 2123) qui est décalée par rapport à la taille minimale de faisceau (2111, 2121) dans la direction de propagation (213) du faisceau laser (21), régler une intensité au niveau de la face de coupe (2113, 2123) de la zone de photo-ablation (2112, 2122) du faisceau laser (21) au moyen de la structure de réglage (41, 47), et déplacer le faisceau laser (21) vers le tissu (8) au moyen du dispositif de positionnement (3), la position de la source laser (2) détectée par le détecteur de position (6) étant évaluée.
2. Dispositif de photo-ablation (1) selon la revendication 1, dans lequel la structure de réglage (41, 47) comprend un dispositif de réglage de courant pour régler le courant et/ou la tension fournie à la source laser (2) par propagation du faisceau laser (21) et/ou un dispositif de réglage d'impulsion pour régler une longueur d'une impulsion du faisceau laser (21).
 3. Dispositif de photo-ablation (1) selon la revendication 1 ou 2, comprenant un capteur acoustique (7) agencé pour capter une onde acoustique générée par le faisceau laser (21) frappant le tissu (8) et fournir un signal correspondant.
 4. Dispositif de photo-ablation (1) selon la revendication 3, dans lequel l'unité de commande (4) est agencée pour évaluer le signal fourni par le capteur acoustique (7) afin de détecter la photo-ablation du tissu (8).
 5. Dispositif de photo-ablation (1) selon la revendication 4, dans lequel l'unité de commande (4) est agencée pour augmenter de manière continue l'intensité du faisceau laser (21) jusqu'à ce que la photo-ablation du tissu (8) soit détectée par évaluation du signal fourni par le capteur acoustique (7).
 6. Dispositif de photo-ablation (1) selon l'une quelconque des revendications 3 à 5, dans lequel l'unité de commande (4) est agencée pour surveiller un spectre de fréquence de l'onde acoustique par évaluation du signal fourni par le capteur acoustique (7).
 7. Dispositif de photo-ablation (1) selon l'une quelconque des revendications 3 à 6, dans lequel le capteur acoustique (7) est un microphone et/ou un transducteur de pression piézoélectrique et/ou un microphone laser.
 8. Procédé de photo-ablation contrôlée en profondeur d'un tissu humain ou animal (8), comprenant la fourniture d'un faisceau laser (21) focalisé avec une taille minimale de faisceau (2111, 2121), dans laquelle un rayon du faisceau laser (21) augmente depuis la taille minimale de faisceau (2111, 2121) dans une direction de propagation (213) du faisceau laser (21) ; la définition d'une zone de photo-ablation (2112, 2122) du faisceau laser, dans laquelle la zone de photo-ablation (2112, 2122) se termine en une face de coupe (2113, 2123) décalée par rapport à la taille minimale de faisceau (2111, 2121) dans la direction de propagation (213) du faisceau laser (21) ; le réglage du faisceau laser (21) de telle sorte qu'une intensité au niveau de la face de coupe (2113, 2123) de la zone de photo-ablation (2112, 2122) est trop faible pour pouvoir faire la photo-ablation du tissu (8) ; le déplacement de la source laser (2) par rapport au tissu (8) de sorte que la face de coupe (2113, 2123) de la zone de photo-ablation (2112, 2122) est agencée au niveau d'une surface du tissu (8) ; l'augmentation de manière continue de l'intensité du faisceau laser (21) jusqu'à ce que l'intensité au niveau de la face de coupe (2113, 2123) de la zone de photo-ablation (2112, 2122) soit suffisamment élevée pour faire la photo-ablation du tissu (8) ; et le déplacement de la source laser (2) vers le tissu (8) dans lequel la photo-ablation du tissu humain ou animal (8) se fait in vitro.
 9. Procédé selon la revendication 8, dans lequel la zone de photo-ablation (2112, 2122) du faisceau laser (21) correspond à une zone Raleigh du faisceau laser (21).
 10. Procédé selon la revendication 8 ou 9, dans lequel l'intensité du faisceau laser (21) est réglée par réglage du courant et/ou de la tension fournie à une source laser (2) qui propage le faisceau laser (21) et/ou par réglage d'une longueur d'une impulsion du faisceau laser (21).
 11. Procédé selon l'une quelconque des revendications 8 à 10, dans lequel on détecte de manière continue si la photo-ablation du tissu (8) est réalisée et l'augmentation de l'intensité du faisceau laser (21) cesse lors de la détection du démarrage de la photo-ablation du tissu (8).
 12. Procédé selon la revendication 11, dans lequel la

photo-ablation du tissu (8) est détectée de manière acoustique, dans lequel, de préférence, un spectre de fréquence d'une onde détectée de manière acoustique est surveillé.

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13. Procédé selon l'une quelconque des revendications 8 à 12, dans lequel la photo-ablation du tissu (8) est détectée de manière optique par application d'une tomographie par cohérence optique.

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14. Procédé selon l'une quelconque des revendications 8 à 13, comprenant la diminution de l'intensité du faisceau laser (21) de sorte que l'intensité au niveau de la face de coupe (2113, 2123) de la zone de photo-ablation (2112, 2122) est trop faible pour faire la photo-ablation du tissu (8) et l'augmentation de manière continue de l'intensité du faisceau laser (21) de nouveau jusqu'à ce que l'intensité au niveau de la face de coupe (2113, 2123) de la zone de photo-ablation (2112, 2122) soit suffisamment élevée pour faire la photo-ablation du tissu (8).

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15. Procédé selon l'une quelconque des revendications 8 à 14, dans lequel les propriétés du tissu (8) sont déterminées avant d'augmenter de manière continue l'intensité du faisceau laser (21), dans lequel les propriétés sont prises en compte lors de la photo-ablation du tissu (8).

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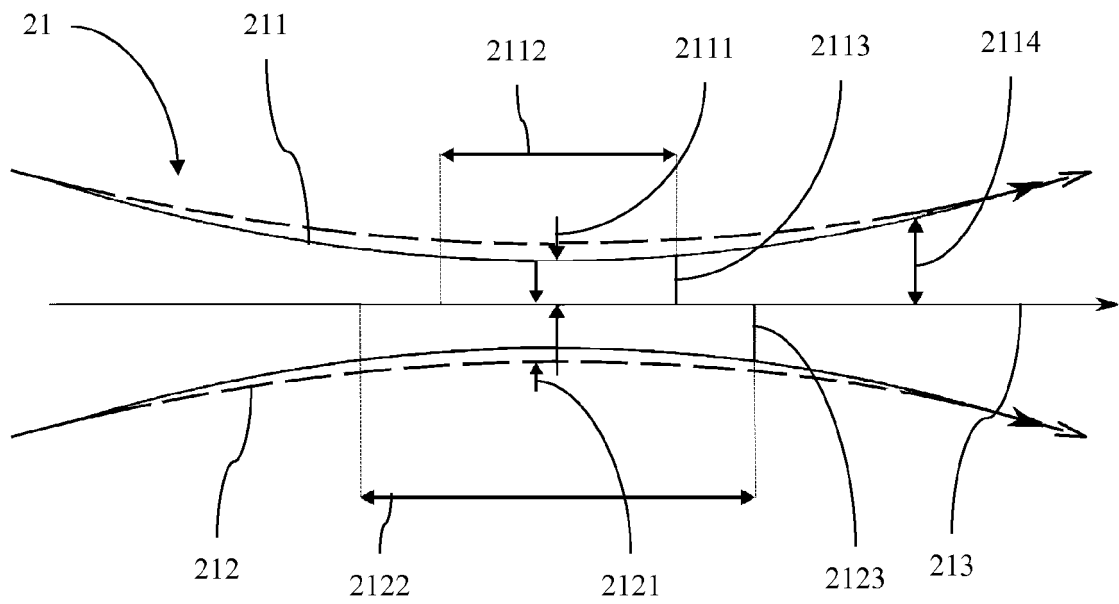


Fig. 2

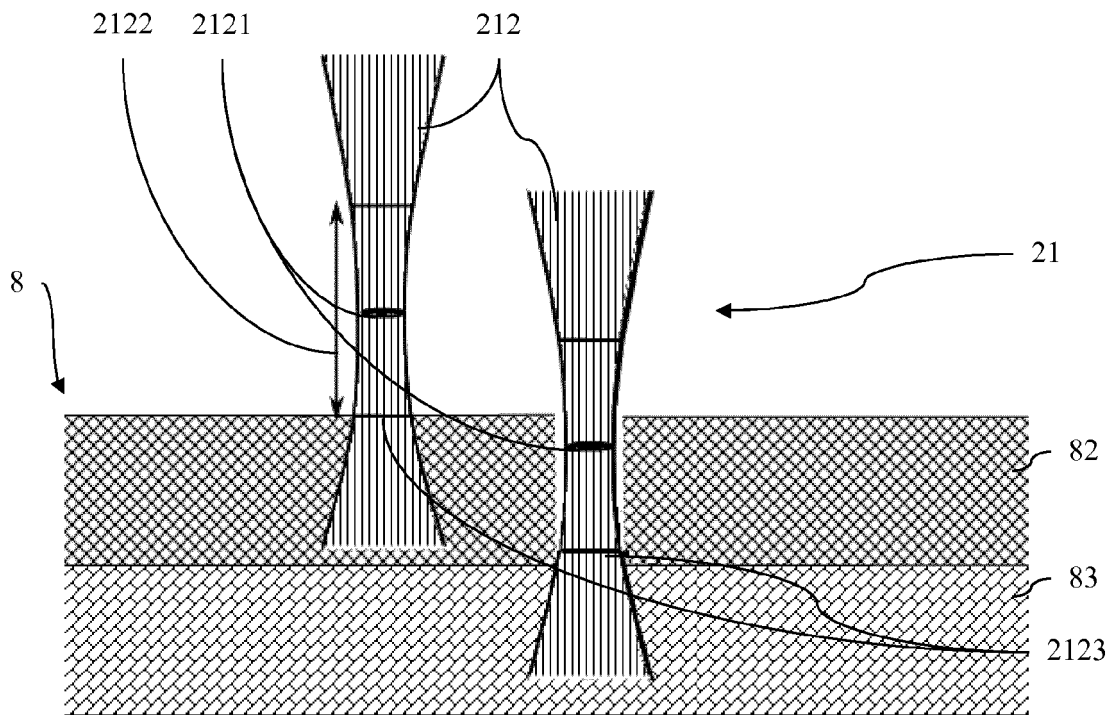


Fig. 3

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2011035792 A1 [0003]

专利名称(译)	深度控制人体或动物组织的光消融		
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[标]申请(专利权)人(译)	先进截骨工具 -AOT股份公司		
申请(专利权)人(译)	高级截骨工具 - AOT AG		
当前申请(专利权)人(译)	高级截骨工具 - AOT AG		
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其他公开文献	EP2938274B1		
外部链接	Espacenet		

摘要(译)

用于人体或动物组织8的光烧蚀的光烧蚀装置1包括：激光源2，其布置成使具有束腰的聚焦激光束21传播，其中激光束21的半径从束腰增加到传播方向。213激光束21；调节结构41,47，用于调节激光束21的强度；位置检测器6，用于检测激光源2相对于组织8的位置；定位装置3设置成使激光源2相对于组织8移动；控制器单元布置成限定激光束21的光烧蚀区域，其中光烧蚀区域在切割面中终止，该切割面位于束腰部或从束腰部偏移到传播方向213。激光束21的调节借助于调节结构41,47在激光束21的光烧蚀区域的切割面处的强度，并且借助于定位装置3将激光束21朝向组织8移动，其中激光的位置评估由位置检测器6检测到的源2。根据本发明的装置允许通过激光束朝向组织的运动方便地控制和确定进入组织的光消融深度。特别地，深度可以对应于激光束朝向组织的运动。此外，可以根据组织精确地调节光消融能量或强度。像这样，可以考虑组织的各个特性并最小化组织的加热，使得例如组织的碳化可以是预防。