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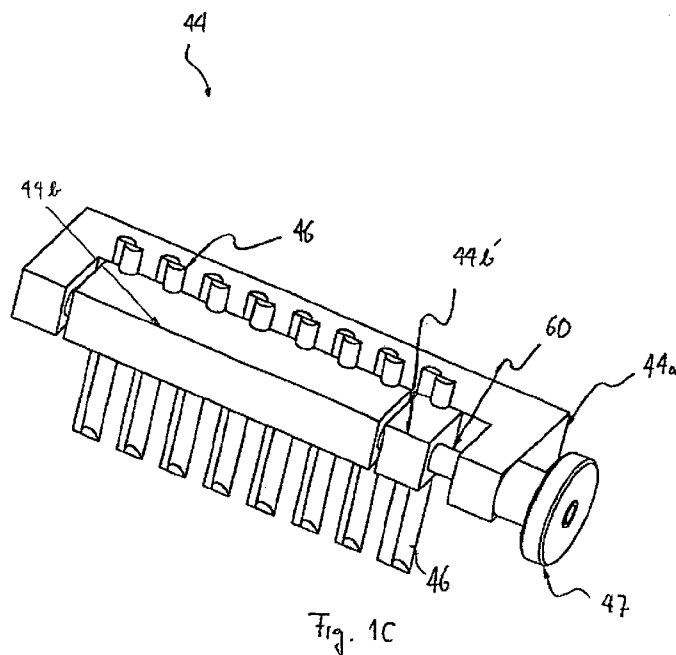
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(54) Title: CUTTING TOOL FOR SOFT TISSUE SURGERY



(57) Abstract: The present invention relates to a cutting tool (44, 52) for soft tissue surgery, a system employing such cutting tool and a method of cutting soft tissue. The cutting tool comprises a set of elongate members (46) suitable for simultaneously inserted into a soft tissue body. When inserted into the soft tissue body part, the cutting tool (44, 52) is suitable for defining a cutting plane with respect to said soft tissue body part, denaturizing, and in particular coagulating" and/or cauterizing the tissue in the vicinity of each elongate member (46) and/or between elongate members (46) and cutting tissue between at least some adjacent ones of said elongate members (46).



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## **Cutting Tool for Soft Tissue Surgery**

### **FIELD OF THE INVENTION**

The present invention relates to a cutting tool for soft tissue surgery and a method of cutting soft tissue. The invention also relates to a system and a method for computer assisted surgery in soft tissue.

### **BACKGROUND OF THE INVENTION**

In soft tissue surgery, usually a scalpel is used for cutting the soft tissue body part along a predetermined section plane. In the simplest case, the “predetermined section plane” is simply the plane of the cut which the surgeon has in mind, based on his experience and clinical information. For example, if the surgeon intends to excise a tumor, the surgeon may have studied x-ray or nuclear magnetic resonance (NMR) images of the soft tissue body part from which the surgeon can discern the location of the tumor. Under surgery, the surgeon can then mentally register the true soft tissue body part with the medical image and cut along what he or she believes is the suitable section plane.

Alternatively, the predetermined section plane could be obtained using computer based surgical planning which gives the surgeon all the necessary information for choosing the best section plane for the individual patient. For example, research scientists at the German Cancer Research Center have developed a surgical planning software for liver surgery which extracts all the data from routinely acquired preoperative medical images and delivers optimized models to lay open the details of the visceral anatomy, which highly differs from patient to patient. Also, computer based surgical planning allows for obtaining quantitative information from a preoperative medical image such as the volume of organs or tumors or volumes of a portion of the liver to be transplanted and of the portion remaining with the donor. Another quantitative information that can be derived from medical images by modern planning software is the vascular supply for given areas of the organ under treatment.

While all this information is useful in predefining the section plane along with the organs to be cut during the actual surgery, there still remains the problem to actually perform the cut along the predetermined section plane.

A severe problem in this regard is that once the surgeon starts cutting the soft tissue body part, its topology will change as compared to the medical image on which the planning of the section plane is based, be it computer assisted planning or purely mental planning of the surgeon based on the medical image. Due to the topology change of the soft tissue body part, orientation becomes difficult, and there is a risk that the surgeon will deviate from the predetermined section plane.

If the surgery involves the excision of tumors, deviating from the planned section plane has the further risk that a tumor could be accidentally cut which would lead to a tumor seeding.

A further problem encountered when cutting soft tissue with an ordinary scalpel is bleeding, which is not only harmful for the patient but also makes the surgery more complicated and difficult.

From US,6887,204 B1, electrosurgical forceps are known which utilise both mechanical clamping action and electrical energy to effect haemostasis by heating tissue and blood vessels to cause coagulation and/or cauterization.

US 2007/0078459 A1 discloses an endoscopic forceps for vessel sealing comprising a pair of jaw members moveable such as to grasp tissue therebetween, where each of the jaw members is adapted to connect to an electrosurgical energy source such that the pair of jaw members are capable of conducting energy through the tissue held therebetween to effect tissue seal.

While such forceps type instruments are suitable to cut tissue or vessels grasped in between the jaws while preventing bleeding due to coagulation or cauterisation, this technology is not applicable for cases where a soft tissue body part is to be cut along a predetermined two-dimensional plane and proves to be too thick for a forceps type instrument.

## SUMMARY OF THE INVENTION

What is needed is a means and a method to facilitate cutting along a predetermined section plane in soft tissue in view of the above mentioned problems.

According to one aspect of the invention, a cutting tool for soft tissue surgery is provided which comprises a set of elongate members suitable for being simultaneously inserted into a soft tissue body part. When the cutting tool is inserted into the soft tissue body part, it is suitable for defining a cutting plane with respect to the soft tissue body part and for denaturizing, and in particular coagulating and/or cauterizing the tissue in the vicinity of each elongate member and/or between adjacent elongate members and for cutting tissue between at least some adjacent ones of said elongate members.

According to this embodiment of the invention, the cutting tool can be inserted into the soft tissue body part such as to define a cutting plane with respect thereto. For example, the cutting plane could be defined by the envelope of the set of elongate members. In other words, a two-dimensional plane can be defined directly within the body part upon a single step of inserting the instrument only. What is more, defining the section plane within the body part can be performed in a stage where the body part has not yet been cut, i.e. where its topology has not changed yet. Accordingly, at this stage registering the body part with a preoperative medical image is much easier than in a state when the body part has already been cut. Note in this regard that the “registering” could again be a mental registering by the surgeon who only mentally compares a preoperative medical image with the actual body part, as well as different types of computer assisted registering and tracking described in more detail below. In both cases, the possibility to insert the cutting tool into the body part before the cutting greatly facilitates to transfer the predetermined section plane to the soft tissue body part.

After the cutting tool has been inserted into the soft tissue body part, the tissue in the vicinity of each elongate member and/or between adjacent elongate members can be denaturized, in particular coagulated and/or cauterized. Accordingly, bleeding of the tissue caused upon inserting the elongate members into the soft tissue body part can be stopped practically immediately. Herein, any type of denaturizing could be employed that changes the tissue in a way to stop bleeding, and such denaturization could be achieved thermally, chemically, by means of electric currents or electromagnetic fields or combinations thereof. Also, the denaturizing can be carried out during insertion of the instrument. What is more, if the cutting tool should acci-

mentally be inserted incorrectly and hurt a tumor, tumor seeding can be prevented by said denaturization, in particular coagulation or cauterization in a similar way as known for example from tumor ablation using RF Fields. Herein, the term denaturization shall however encompass any way of changing the tissue such as to stop bleeding or tumor seeding, and can comprise the application of heat or coldness, chemicals, electrical currents and RF-Voltages or Fields.

Finally, after the denaturization step, the tissue can be cut between at least some adjacent ones of the elongate members while still inserted into the soft tissue body part. In other words, the tissue can be cut precisely along the two-dimensional section plane as defined upon insertion of the cutting tool. Since the tissue has been denaturated, e.g. coagulated or cauterized prior to this cutting step, there will be a clean cut without bleeding of the tissue.

While the elongate members are preferably parallel such as to not compress or stretch the tissue upon insertion, they need not be straight. Instead, the elongate members could be curved and therefore define a curved section plane. According to the invention, a set of cutting tools of different shapes, sizes and with different distances between adjacent elongate members could be provided corresponding to the desired sizes and shapes of predetermined cutting planes.

In summary, the cutting tool of the invention greatly facilitates cutting of soft tissue along a predetermined cutting plane, as it allows to define a two-dimensional plane within the body part upon insertion of the cutting tool only, at a stage where the body part has not been hurt and its topology has not yet been changed. At the same time, the cutting tool of the invention allows to prevent bleeding and possible tumor seeding by its denaturization, in particular coagulation and/or cauterization capability.

Preferably, the instrument comprises one or more members in addition to the aforementioned elongate members adapted for cutting the tissue between said elongate members after insertion into the soft tissue body part. In this embodiment, the elongate members may be fixed with respect to the tissue during cutting while the additional blade member or members are moved.

In one embodiment, the cutting tool may comprise a first and a second member, each of said first and second members comprising a set of substantially parallel blade-like elements, said

first and second members being moveable to a first position, in which the blade-like elements of the first member are substantially congruent with corresponding blade-like elements of the second member, said corresponding blade-like elements in the congruent state forming said elongate members, and a second position, in which – when viewed from a direction perpendicular to the direction of relative motion of the first and second members – blade-like elements of the first member are located substantially between adjacent blade-like elements of said second member. Such embodiment is very easy in construction and at the same time highly efficient.

When the first and second members are in the first position, the instrument can be inserted into the soft tissue body part, since the blade-like elements of the first and second members are substantially congruent with each other, which means that the insertion is similar to a situation where a set of single members were inserted. After insertion, the section plane is physically defined by the blade-like elements being inserted into the tissue. During or immediately after insertion of the instrument with the first and second members in the first position, the tissue surrounding the instrument may be denaturized, e.g. cauterised or coagulated to stop bleeding. Then, by moving the first and second members into the second relative position, the tissue is cut along the section plane as defined upon insertion of the instrument, which in turn coincides with the planned section plane.

Note that in this embodiment, the aforementioned elongate members are formed by the blade-like elements themselves, which are congruent with each other upon insertion but which will be moved relative to each other upon cutting.

Instead of providing two sets of elongate members, in an alternative embodiment the first member could comprise a set of substantially parallel blade-like elements, while the second element could comprise a single blade-like element only. In this embodiment, the first and second members could be movable relative to each other to a first position, in which the single blade-like element of the second member is substantially congruent with one of the blade-like elements of the first member, and the second member could be moved relative to first member such that the single blade-like element of the second member moves along the plane defined by said set of blade-like elements of the first member such as to cut the tissue between at least some of the blade like elements of the first member. In this embodiment, the set of blade-like elements of the first member would correspond to the aforementioned elongate members to be inserted into the soft tissue body part.

The blade-like elements could have any shape or cross section suitable for cutting the tissue. In a preferred embodiment, some or all of the blade-like elements have a cross-sectional shape defined by a straight edge and a curved edge meeting at an acute angle of 50° or less, preferably 30° or less.

In an alternative embodiment, the cutting tool could further comprise one or more blade members configured to be inserted in a space between adjacent elongate members in a direction parallel to the insertion direction of the cutting tool. For example, if the cutting tool is inserted into the soft tissue body part from above, the one or more blade members would be also inserted from above into a space between adjacent elongate members in a guillotine-like manner.

In one embodiment, the cutting tool is a preferably navigated laparoscopic instrument, a preferred embodiment of which being shown in the description below.

In a preferred embodiment, the cutting tool comprises means for denaturizing, and in particular coagulating and/or cauterizing the tissue, said means employing one or more of heat, coldness, chemical agents, electrical currents and electromagnetic fields.

In one embodiment, the cutting tool comprises means for applying monopolar RF-Voltages to at least some of said elongate members and/or means for applying bipolar RF-Voltages between adjacent elongate members. By suitable control of the monopolar and/or bipolar voltages, the size and shape of the denaturized area of the tissue can be controlled, as can be the character of the denaturization. For example, by applying monopolar voltages to elongate members, annular denaturized tissue regions can be formed surrounding the respective elongate members. By applying bipolar voltages across adjacent elongate members, the tissue inbetween said elongate members can be denaturized. Also, depending on the frequency and applied power, different types of denaturation can be caused, for example agglutinating collagen, fibrin or elastin contained in the tissue in a way known per se from the instrument "Ligasure" from Valleylab, Inc. By applying bipolar voltages between adjacent elongate members, the tissue therebetween can be denaturized in a spatially controlled way. Also, in one embodiment the cutting tool may be adapted for cutting the tissue between adjacent elongate members by electro surgery. In a preferred embodiment, a combination of mechanical and

electrosurgical cutting is provided, where monopolar voltages suitable for cutting tissue around blade members are applied, which allows to facilitate the mechanical cutting.

In a preferred embodiment, the cutting tool is a navigated instrument. For example, the cutting tool could comprise markers that are locatable by a tracking system. Using a navigated cutting tool, the proper insertion of the cutting tool can be further facilitated by appropriate computer assisted cutting tool guiding means. However, it is emphasized that appropriate computer assisted guiding means could also be devised for non-navigated cutting tools, examples of which will be given below.

If a navigated cutting tool is used, it may preferably comprise markers suitable for tracking by a tracking system. Alternatively, the cutting tool could be adapted to be manipulated by a robot. Accordingly, with suitable programming the robot could insert the cutting tool into the soft tissue body part such that the section plane defined by the inserted cutting tool coincides with at least a portion of a planned section plane.

According to a further aspect, the present invention comprises a system for computer assisted surgery in soft tissue comprising a cutting tool as defined in one of the above embodiments and a computer assisted cutting tool guiding means to assist or enable guiding the cutting tool upon insertion into the body part such that the section plane defined by said inserted cutting tool coincides with at least a portion of a planned section plane.

Herein, the assisted instrument guiding means may comprise positioning assisting means for assisting a user to position the cutting tool at the soft tissue body part prior to insertion, wherein said positioning assisting means is adapted to generate and display an image allowing a user to assess how the leading edge of the cutting tool has to be moved in order to approach the intersection line of the surface of the body part and the planned section plane. Such positioning assisting means greatly facilitates positioning the cutting tool prior to insertion, such that the section plane defined by said instrument upon insertion will coincide with the planned section plane.

Preferably, the image generated by the positioning assisting means represents a relative position between said intersection line and a projection of said leading edge of the cutting tool onto the surface of said body part. Herein, the projection may for example be a projection

along a vector defining a predetermined insertion direction. Note that the projection of the leading edge of the cutting tool onto the surface of the body part resembles two-dimensional information only. However, this is exactly the two-dimensional information that is crucial for correctly positioning the cutting tool prior to insertion. By reducing the displayed information to the information that is actually needed in the positioning step, the respective image becomes very easy to understand and intuitive to interpret, as will be especially clear from an exemplary embodiment shown below.

It is noted that a similar assisted instrument guiding means is described in US patent application US 61/075,467 coined by some of the inventors for use with targeting of a target with an elongate instrument, which is included herein in its entirety by reference.

Preferably, the assisted instrument guiding means further comprises assisted instrument directing means for generating and displaying an image allowing a user to assess to which extent a plane defined by said instrument is aligned with the planned section plane. If the instrument (cutting tool) defines a flat plane, for example by a number of straight parallel elongate members, alignment of the plane defined by said cutting tool with a planned section plane means that the respective two planes coincide. In this case, the image generated by said assisted instrument directing means can for example be a two-dimensional image displaying a projection of a portion remote from and parallel to said leading edge of the cutting tool onto a plane perpendicular to a vector defining a predetermined insertion direction.

In a preferred embodiment, the assisted instrument guiding means is further adapted to generate an image corresponding to a view of a virtual camera placed at the leading edge of the cutting tool. Preferably, the assisted instrument guiding means is further adapted to display medical images of predetermined objects, in particular, but not limited to, blood vessels, tumors, bony structures and organs. Accordingly, upon insertion of the cutting tool, the user can confirm that such objects are reliably avoided.

In an alternative embodiment, the computer assisted instrument guiding means may comprise means for projecting light signals onto the soft tissue body part indicating where the cutting tool is to be positioned and/or how it is to be directed for proper insertion. In this example, the cutting tool need not be a navigated instrument.

In a further alternative embodiment the computer assisted instrument guiding means may comprise a robot suitable for manipulating the cutting tool for proper insertion.

In yet another embodiment, the computer assisted instrument guiding means may be based on augmented reality. In augmented reality, real world and computer-generated image data are combined, such that computer graphics objects may be blended into real images. For example, real world video images can be digitally processed to be augmented by the addition of computer-generated graphics. In one embodiment, images of the real soft tissue body part may be augmented with graphics indicating how the cutting tool is to be positioned and/or how it is to be directed for proper insertion. In an alternative embodiment, a surgeon may wear augmented reality glasses in which the real world field of view as seen through the glasses may be augmented with graphics indicating how the instrument is to be directed for proper insertion. In this embodiment too, the cutting tool need not be a navigated cutting tool.

In a preferred embodiment, the system further comprises means for tracking said cutting tool such as to continuously locate the position and orientation thereof in a tracking coordinate system. Herein, the tracking means may be configured for tracking said cutting tool based on signals received from optical and/or electro-magnetic and/or ultra sound means. However, other types of tracking means are conceivable, such as mechanical tracking or fiber-optics tracking. Further, the system is preferably adapted to register said tracking coordinate system with a coordinate system of an intraoperative medical image of said body part. Also, the system preferably comprises means for registering a planning medical image containing the planned section plane with the intraoperative image. In a preferred embodiment, there will thus be two registering steps, namely a first registering step of registering the planning medical image with the intraoperative image and second step of registering the intraoperative image with the tracking coordinate system. However, the first and second registering steps may be combined in a single registering step. Due to this two-step registering, the location of the planned section plane in the tracking coordinate system can be obtained.

With regard to the first registering step, in some cases it cannot be expected that the planning medical image and the intraoperative medical image reflect the same motion state of the organ under surgery, since the organ has been exposed in between the acquisition of the two images. Accordingly, registering the planning medical image with the intraoperative medical image will take some deformation between the images into account.

As regards the second registering step, in one embodiment, registering the intraoperative image with the tracking coordinate system is achieved by locating the medical imaging apparatus within the tracking coordinate system and using information about the spatial relationship between the medical imaging apparatus and the medical image. For this purpose, markers could be attached to the medical imaging apparatus that can be located by the tracking system. However, this registration is only valid as long as the patient and in particular the organ under surgery does not move after taking the intraoperative medical image. Subsequent movement of the body part under surgery could be detected and accounted for by using navigation aids, such as fiducials, to be provided on or inserted into the body part.

While the coordinate system of the intraoperative medical image can be registered with the tracking coordinate system, due to soft tissue motion, in some cases the motion state of the intraoperative medical image of the soft tissue body part need not coincide with the actual motion state thereof upon insertion of the instrument. According to one embodiment of the invention, such soft tissue motion can be accounted for during an initial registering step and optionally also during consecutive registering steps for real-time compensation of soft tissue motion. In one embodiment, the navigation aids are inserted prior to taking the intraoperative medical images. During surgery the navigation aid may then be tracked during a time interval in which the navigation aids may move along with the body part due to soft tissue motion. A motion state during this interval may be determined in which the positions of the navigation aids coincide best with their positions in the intraoperative medical image. Then, the registration of the intraoperative image with the tracking coordinate system may be performed based on the tracked position of the navigation aids in said determined motion state. The rationale behind this embodiment is that a deviation of the motion state of the body part from the motion state in which the intraoperative medical image was taken is reflected in a deviation of the tracked positions of the navigation aids from their positions in the intraoperative medical image. Determining the motion state in which the positions of the navigation aids coincide best with their positions in the intraoperative medical image thus allows to identify a motion state that is very close to the motion state of the body part upon taking the intraoperative medical image.

If navigation aids are applied prior to taking the intraoperative medical image, the system may be configured for repeatedly determining and displaying a value indicating how well the cur-

rent positions of the navigation aids in the tracking coordinate system correspond with their positions in the intraoperative medical image. An example of such a value, called fiducial registration error (FRE) is described in more detail in the co-pending patent application US 61/075,467 and the references cited therein. If the current motion state of the body part leads to a small FRE, this indicates that the motion state is similar to the one in which the registration of the intraoperative image with the tracking coordinate system has been performed, which means that in this instant, the problems due to soft tissue motion are less pronounced. In other words, the FRE can serve as a confidence value that the registration of the intraoperative image and tracking coordinate system currently is valid.

Additionally or alternatively, the system may comprise means for compensating the motion of the soft tissue, said means being configured to calculate the current position of the planned section plane based on information of the motion state of the body part. Herein, the information of the motion state of the body part may be represented by the positions of navigation aids attached to and/or inserted to the body part, and the calculation may be based on a deformation model of the body part.

Note that navigation aids are just one possible means of observing the motion state of the body part. In an alternative embodiment conceived by the inventors, a tracked 3D ultrasound imaging apparatus could be used to continuously acquire medical images of characteristic land marks of the organ under surgery, such as its vessel tree, which could then be matched in real time with the corresponding landmarks planning medical image. With this real time approach, all soft tissue motion during the intervention can be accounted for in a very powerful manner.

## **BRIEF DESCRIPTION OF THE FIGURES**

The accompanying drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of embodiments of the invention.

Fig. 1A shows a number of schematic views of a cutting tool according to an embodiment of the present invention,

- Fig. 1B shows two schematic side views of a laparoscopic cutting tool according to an embodiment of the invention,
- Fig. 1C shows a perspective view of a cutting tool according to an embodiment of the invention,
- Fig. 1D shows the cross section of two blade like elements of the embodiment of Fig. 1C,
- Fig. 2 is a schematic diagram illustrating the steps performed in planning a section plane and inserting the cutting tool of the invention such as to define at least a portion of a section plane coinciding with said planned section plane,
- Fig. 3 is a schematic perspective view illustrating the function of the positioning assisting means according to one embodiment of the present invention,
- Fig. 4 is a screenshot of an image generated and displayed by positioning assisting means according to an embodiment of the invention,
- Fig. 5 is a schematic perspective diagram illustrating the function of an assisted instrument directing means according to an embodiment of the present invention,
- Fig. 6 is a screenshot of an image generated and displayed by an assisted instrument directing means according to an embodiment of the present invention,
- Fig. 7 is a schematic perspective image illustrating the function of the assisted instrument insertion-guiding means,
- Fig. 8 is a screenshot of a virtual image generated and displayed by the assisted instrument insertion-guiding means of Fig. 7,

## **DESCRIPTION OF THE PREFERRED EMBODIMENT**

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the preferred embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, such alterations and further modifications in the illustrated device and method and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur now or in the future to one skilled in the art to which the invention relates.

With reference to Fig. 1A and 1B examples of cutting tools of the present invention are shown. In Fig. 1A, side and top views of a cutting tool 44 in an open state (left column) and a closed state (right column) are shown. When inserted into a body part, the cutting tool defines at least a portion of a section plane and while inserted may cut the tissue along the section plane.

The cutting tool 44 is comprised of first and second members 44a and 44b which are shown separately in Fig. 1A (e). Each of said first and second members 44a, 44b has a comb-like structure with a set of substantially parallel blade like elements 46 spaced at equal intervals. In the assembled state the first and second members 44a, 44b can be moved with respect to each other between a first or open position shown in panels (a) and (c) and a second or closed position, shown in panels (b) and (d) of Fig. 1A. In the first or open position, the blade-like elements 46 of the first member 44a are congruent with the blade-like elements 46 of the second element 44b, leaving free spaces 48 in between when viewed from a direction perpendicular to the direction of relative motion of the first and second members 44a, 44b. Hence, this position is called the “open position”. Herein, each pair of congruent blade-like elements 46 can be regarded as an “elongate member” as mentioned above.

In the second or closed position, blade-like elements 46 of the first member 44a are located between adjacent blade-like elements 46 of the second member 44b, when viewed in a direction perpendicular to the direction of relative motion as is seen in Fig. 1A (b). For obvious reasons, the second position is also called the closed position.

Finally, in the embodiment of Fig. 1A, the blade-like elements 46 of the first member 44a are connected with conductors 50 which in turn are connected with an electro-surgical generator

(not shown) such that an appropriate voltage, frequency or waveform can be applied to the blade-like elements 46.

Next, the operation of the cutting tool 44 will be explained:

The cutting tool 44 in the open position can be inserted into a living object's body part such that the plane defined by the envelope of the blade-like elements 46 coincides with a planned section plane. For proper insertion, computer assisted instrument guiding means as described below could be used. However, the cutting tool 44 could also be inserted solely based on the surgeon's judgment. During or after the cutting tool 44 is inserted to define a section plane corresponding to a planned section plane, the blade-like elements 46 of the first member 44a of the instrument 44 are powered by the electro-surgical generator (not shown) such as to coagulate the tissue surrounding each of the blade-like elements 46 as well as the tissue in the spaces 48 between adjacent blade-like elements 46. For example, the tissue may be coagulated within an area equal or less than 0,5 to 1cm away from one of the blade-like elements 46. By the coagulation, bleeding caused by insertion of the element 44 into the tissue will be stopped. For example, first a monopolar coagulating voltage could be applied to the blade-like elements 46 such as to coagulate the tissue between adjacent blade-like elements 46, and consecutively a bipolar voltage could be applied between adjacent blade-like members such as to coagulate the tissue therebetween.

Next, first and second members 44a, 44b are moved from the open position (see Fig. 1A (a), (c)) to the closed position (see Fig. 1A (b), (d)), thereby cutting the coagulated tissue in the spaces (48) between adjacent elongate blade-like elements 46. Accordingly, the tissue is completely cut along the section plane defined by the cutting tool 44 upon insertion. At the same time, due to the previous coagulation step, no bleeding will occur upon cutting the tissue. Also, if accidentally a tumor should be cut, tumor seeding can reliably be prevented due to the coagulation step. The cutting tool 44 shown in Fig. 1A thus allows for a safe and fast cutting of tissue. Moreover, it is very easy to use and prevents bleeding and tumor seeding.

In a preferred embodiment, a monopolar voltage suitable for cutting tissue is applied to each blade-like element during cutting such as to facilitate the mechanical cutting.

While the cutting tool 44 shown in Fig. 1A is designed for use in open surgery, the same principle can be applied in a laparoscopic instrument as well, as is shown at reference sign 52 in Fig. 1B. The instrument 52 has a front portion 54 which is similar to the cutting tool 44 shown in Fig. 9 and is hingedly connected to an elongate instrument body 56 by a hinge 58. The distal end of instrument body 56 is connected with a handle for guiding the instrument (not shown) and an electro-surgical generator (not shown)

Fig. 1C shows a perspective view of a more detailed embodiment of a cutting tool 44 as shown in Fig. 1A. As seen in Fig. 1C, the cutting tool 44 comprises a first member 44a having a first set of blade-like elements 46. Further, the cutting tool 44 comprises two second members 44b, 44b' slideably supported on a shaft 60. In the configuration shown in Fig. 1C, the second members 44b, 44b' are connected to be moved jointly slidingly along shaft 60, such as to effectively form a configuration as seen in Fig. 1A. However, by opening a thumb screw 47, the shaft 60 can be removed which in turn allows to remove second member 44b and to reassemble the cutting tool 44 with only the second member 44b', which carries only a single blade-like element 46. Accordingly, the cutting tool 44 can be operated also in a configuration where the second member 44b' is carrying only a single blade-like member 46 as the only second member which can be moved along the full length of shaft 60. Both configurations have been found to operate well. In the embodiment shown, the second members 44b, 44b' are moved manually. In an alternative embodiment, the second members 44b, 44b' are spring loaded and are moved upon release of the spring.

In the embodiment shown in Fig. 1C, eight blade-like elements 46 are provided on the first member 44a and either eight (in the first configuration) or only a single blade-like element 46 (in the second configuration) are provided on the second members 44b, 44b'. As mentioned before, in a state where the blade-like elements 46 of the first and second members 44a, 44b, 44b' are congruent with each other, each pair of congruent blade-like elements in combination form an elongate member to be inserted into the soft tissue body part. In this embodiment, the cutting tool has a comb-like structure with a number of parallel elongate members, where the elongate members are arranged either in a flat or a curved plane, depending on the shape of the resection plain envisaged.

The number of elongate members is not limited to eight. Preferably, the number of elongate members is three or more, more preferably four or more and most preferably five or more. Preferably, the distance between adjacent elongate members is between 0,8 and 15 mm.

Fig. 1D shows an enlarged cross section of two opposite blade-like elements 46. As can be seen in Fig. 1D, the cross section of each blade-like element is defined by a straight edge 46a and a curved edge 46b, meeting at an acute angle  $\alpha$ .

In Fig. 2, for illustration purposes the workflow of computer assisted liver surgery is schematically summarized, in which the cutting tool of the invention can be employed. In this exemplary embodiment, the cutting tool is a navigated instrument for assisting proper insertion thereof. By way of example only, the intervention is considered to be the excision of a tumor in a human body's liver. However, it is to be understood that the cutting tool, system and method of the invention is by no means limited to this application and can be employed for any type of surgery in soft tissue.

In a first step, schematically shown in panel (a) of Fig. 2, a medical image for planning the surgery is acquired. In the present example, the medical image is a CT image, but other types of medical images, such as NMR-images could also be used. This planning medical image could be acquired a few days or even weeks prior to the actual surgery, depending on the type of surgery to be performed.

The medical image data acquired in step (a) can then be used in a planning software for calculating a resection proposal, as indicated in panel (b) of Fig. 2. For example, the planning software may construct a three-dimensional model of the patient's anatomy from the medical image data acquired in step (a). From this model, an appropriate resection plane proposal can be calculated, taking account of for example the volume of the target organ, the position of the tumor, the position of risk structures such as large vessels that have to be avoided, the blood supply and drainage, the volume of the part of the liver remaining with the patient etc. Also, the appropriate section plane 10 will be such that it can ensure that the whole tumor will be resected, while as much healthy tissue as possible remains with the patient. The function of such surgery planning software is described in Fischer L, Hoffmann K, Neumann JO, Schöbinger M, Grenacher L, Raeloff B, Friess H, Meinzer HP, Büchler MW, Schmidt J,

Schemmer P; "The Impact of Virtual Operation Planning on Liver Surgery"; Imaging Decisions 2007;1:39-44, which is incorporated herein by reference.

In step (c) the actual liver surgery starts with exposure of the liver. In step (d) of Fig. 2 an intraoperative CT image of the patient's body part (i. e. the abdomen) containing the liver is taken. As above, note that in the general framework of the invention different types of medical imaging could be used, such as NMR imaging and ultrasound imaging.

In step (e) the coordinate system of the planning CT acquired in step (a) and the coordinate system of the intraoperative CT acquired in step (d) are registered with each other. Accordingly, the planned section plane 10 determined in step (b) can be defined in the intraoperative image coordinate system.

Registering the intraoperative image and the planning image is a first registering step performed in the exemplary work flow of Fig. 2. This registration of the two images amounts to a matching of the images with each other. Note that this registering will generally not involve a rigid coordinate transformation only, since in the present example after the patient has been opened, the shape or motion state of the liver will be different from the shape when taking the planning medical image. Instead, this first registering step will need some type of coordinate transformation accounting for deformation of the body part. After this first registering step, the planned section plane can be transferred from the planning image to the intraoperative image. The first registering step could for example be based on a registering of the respective vessel trees of the respective images.

Next, in step (f), the navigated cutting tool, such as cutting tool 44 shown in Fig. 1A, is inserted into the liver such as to define at least a portion of a section plane therein. To allow for navigation of the navigated cutting tool, a tracking system 12 is provided which allows tracking of the navigated cutting tool in a tracking coordinate system. Also, in order to guide the navigated instrument such as to find the planned section plane, the intraoperative medical image needs to be registered with the tracking coordinate system. This is the second registration step used in the work flow of Fig. 2.

There are different strategies conceivable to register the intraoperative image coordinate system with the tracking coordinate system, three of which shall be briefly discussed for illustrative purposes only:

A first variant would be based on a tracked medical imaging apparatus. Namely, if the medical imaging apparatus used in step (d) of Fig. 2 itself is tracked in the tracking coordinate system, the location of the intraoperative medical image acquired thereby can also be determined in the tracking coordinate system or in other words, be registered with the tracking coordinate system. This variant has the advantage that it is comparatively easy and fast to employ. However, this variant of course only works if it can be ensured that after taking the intraoperative medical image, the patient is not moved with respect to the tracking coordinate system or only moved in a way that can be accounted for.

In a second variant, markers such as fiducial needles could be attached to or inserted into the liver prior to taking the intraoperative medical image, i.e. between steps (c) and (d) of Fig. 1. In a preferred embodiment fiducial needles (not shown) are inserted into the liver, such that their tips will lie within the liver and in the vicinity of the tumor to be excised. The fiducial needles preferably have a needle-shaped body with a rotationally symmetric elongate portion serving as a marking portion for tracking. Suitable embodiments of such fiducial needles are described in EP 1632194A1. Custom-designed silicon patches may be used to affix the fiducial needles to the skin of the patient and to prevent them from slipping out. Alternatively, the fiducial needles are fixed in the liver. As has been demonstrated in the article "Soft Tissue Navigation Using Needle-Shaped Markers: Evaluation of Navigation Aid Tracking Accuracy and CT Registration", in proceedings of SPIE Medical Imaging 2007: Visualization, Image-Guided Procedures and Display, K. R. Cleary and M. I. Miga, editors 65026 (12 pages), February 2007, L. Maier-Hein, D. Maleike, J. Neuhaus, A. Franz, I. Wolf and H.-P. Meinzer, such fiducial needles can be constructed precisely to obtain sub-millimeter tracking accuracy.

Since the fiducial needles can be tracked by the tracking system 12 and are also visible in the intraoperative medical image, the latter can be registered with the tracking coordinate system in a way known per se from prior art. Note that such fiducial needles or other types of markers have the additional advantage that they allow to notice and to a certain extent correct for deformation or other types of motion of the body part after the intraoperative medical image

has been taken, in a way explained in more detail in the co-pending application US 61/075,467.

A third and very elegant exemplary method of registration conceived by the inventors is a method in which the first and second registration steps are continuously or repeatedly performed in real time. For example, instead of taking a single intraoperative image as indicated in panel (d) it is suggested to repeatedly or continuously take intraoperative images in real time, for example using a tracked 3D ultrasound imaging apparatus. Using appropriate software, certain landmarks or structures of the liver such as the vessel system could be identified and registered with the planning medical image. This way, the motion or deformation state of the organ during surgery can be fully and elegantly accounted for. Note that this third variant can be regarded as an extension of the first variant, in which the first and second registering are repeatedly performed.

With further reference to panel (f), the navigated marking tool 14 is inserted to the liver such that the section plane defined thereby coincides with the planned section plane 10 determined in step (b). For this purpose, computer assisted instrument guiding means to assist or enable guiding the instrument 14 upon insertion into the liver are provided. Examples of such computer assisted instrument guiding means are described below. An example of computer assisted guiding means “enabling” guiding the instruments could for example be a robot for inserting the same.

After the navigated cutting tool has been properly inserted in the step of panel (f), the liver tissue may be safely cut along the section plane defined by the elongate members of the cutting tool inserted therein (step (g)). In particular, first the tissue in the vicinity of each elongate member and in between adjacent elongate members is subjected to coagulation or cauterization. For this purpose, a monopolar or bipolar electric field can be applied to the elongate members such that the tissue in the vicinity will be coagulized or cauterized by a current flowing therethrough. Alternatively, the tissue could be coagulized by applying heat or coldness to the elongate members inserted into the liver. The coagulation or cauterization could for example take between three and ten minutes.

After the coagulation/cauterization is finished, the tissue between the elongate members is cut. This cutting of the tissue can be performed with the mechanism as shown in Fig. 1A or

any other suitable mechanism, including electrosurgery. Since the tissue has been coagulated prior to cutting, there will be a clean cut without any bleeding. What is more, if accidentally a tumor should have been hurt upon insertion of the cutting tool, due to the coagulation or cauterization the tumor will become necrotic and tumor seeding can be prevented.

Note that steps (f) and (g) can be carried out repeatedly, where in each step an additional portion of the planned section plane 10 is cut. For example, the navigated cutting tool can be pushed forward in a number of discrete steps, wherein the tissue is coagulized/cauterized and cut for each of the steps. This allows for example to move the cutting tool along a predetermined curved section plane.

Also note that the size and shape of the cutting tool will be matched with the planned section plane. While in Fig. 1A and 1B only a very simple and schematic view is shown, in practice, one would preferably provide a set of cutting tools having different sizes and different shapes, in particular different curvatures allowing to define different cutting planes or portions thereof.

As becomes apparent from the work flow of Fig. 2, according to the invention the transfer of the planned section plane 10 to the patient's soft tissue body part essentially amounts to a single step of inserting the cutting tool to the soft tissue body part such that the section plane defined by the inserted cutting tool coincides with the planned section plane 10. As mentioned above, in some embodiments a sequence of insertion steps may be employed each defining a portion of a section plane, where the cutting tool is pushed forward in a number of consecutive steps. In order to assist guiding the cutting tool upon insertion into the body part, according to an embodiment of the invention computer assisted instrument guiding means are provided, which will be described next with reference to Fig. 3 to 7.

However, while using computer assisted guiding means facilitates the operation of the cutting tool such as cutting tool 44 of Fig. 1A, it is again emphasized that the cutting tool could also be used without such computer assisted guiding means and be guided based on the surgeons discretion and experience only.

Inserting the cutting tool into the soft tissue body part comprises three crucial steps: The first is to position the leading edge of the navigated cutting tool properly on the surface of the soft tissue body part. The second step is to properly direct the cutting tool such that the plane de-

defined by the instrument coincides with the planned section plane 10. In other words, this second or directing step is a step of tilting the cutting tool until the cutting tool is aligned with the planned section plane. In a third step, the cutting tool is inserted into the soft tissue body part up to a predetermined depth. If the planned section plane and the corresponding navigated instrument are curved, the third step also comprises guiding the cutting tool along a curved insertion path. In any case, the cutting tool has to be guided such as to not deviate from the planned section plane.

In a preferred embodiment of the present invention, the computer assisted instrument guiding means generates and displays appropriate images that support the user in carrying out each of the three sub-steps of insertion of the instrument. This computer assisted guiding is similar to the guiding described in the co-pending application US 61/075,467, with regard to targeting of a target such as a tumor with an elongate instrument, such as a biopsy needle. However, the inventors have confirmed that such computer assisted guiding means co-invented by some of the present inventors for use with targeting of a target with an elongate instrument can also be very successfully used with the insertion of the navigated cutting tool according to an embodiment of the present invention.

Fig. 4 shows a screenshot of an image generated and displayed by positioning assisting means according to an embodiment of the present invention. In this image, a projection 22 of a leading edge of a cutting tool 44' onto the surface of the body part is displayed. Herein, the "leading edge" is the line connecting the tips of the elongate members or blade-like members of the navigated cutting tool 44' and the projection is a projection along a vector 24 defining a predetermined insertion direction, as is illustrated by the schematic perspective view of Fig. 3, in which a cutting tool 44' is only schematically indicated for illustrative purposes.

Also in the exemplary screenshot of Fig. 4 a depth indicator 26 is displayed. The depth indicator 26 is a bar diagram representing the distance between the leading edge of the cutting tool 44' and the envisaged insertion depth for defining the planned section plane 10 or a respective portion thereof. If the bar of the depth indicator 26 has reached a center line 28, this means that the leading edge of the cutting tool 44' has reached the surface of the organ under surgery, for example the liver. Also shown in Fig. 4 is a box 30 including the intersection line of the surface of the body part and the planned section plane 10.

Further, in Fig. 4 a signal light 32 and arrows 34 and 36 are displayed, the function of which will be explained below.

The image generated by the positioning assisting means as displayed in Fig. 4 is meant to assist the surgeon in properly positioning the leading edge of the cutting tool 44' on the surface of the organ under surgery, such as the liver. When the surgeon lowers the instrument 44' to the surface of the organ, he only has to make sure that the projection 22 coincides with the box 30. The two-dimensional information displayed in Fig. 4 is the crucial information for properly positioning the cutting tool, while the third dimension can be accessed by the surgeon easily by noticing that the tips of the elongate members have touched the surface of the organ. Also, this third dimension is reflected by the depth indicator 26. This rather abstract way of separately displaying the critical two dimensions has been found to greatly assist the surgeon in properly positioning the instrument. Positioning is further assisted by guiding arrows 34, 36 indicating the surgeon how the instrument has to be moved such as to be positioned properly. Once the cutting tool 44' has been positioned at the surface of the organ with the predetermined precision, this is indicated by the signal 32 and the positioning step is completed.

In the next step, the instrument 44' shall be aligned with the planned section plane. This is assisted by assisted instrument directing means for generating and displaying an image allowing a user to assess to which extent a plane defined by the instrument (i.e. cutting tool) 44' is aligned with the planned section plane 10.

If the planned section plane 10 and the plane defined by the set of elongate elements is a flat plane, this alignment amounts to tilting the cutting tool 44' such that the angle between the two planes becomes zero. If the planes are curved planes, the alignment becomes somewhat more complicated. In that case, the tangential plane at the leading edge of the cutting tool would have to be aligned with the tangential plane to the planned section plane 10 at the intersection with the surface of the organ.

With reference to Fig. 5 and 6, the case of flat planes is discussed. Herein, Fig. 6 shows an image generated and displayed by assisted instrument directing means. The image of Fig. 6 is very similar to the image of Fig. 4. However, this time a projection 38 of a portion 40 remote from and parallel to said leading edge of the cutting tool 44' onto a plane perpendicular to the above mentioned vector 24 defining a predetermined insertion direction is displayed as is il-

illustrated in the schematic perspective view of Fig. 5. While monitoring the image displayed in Fig. 6, the user has to tilt the cutting tool 44' such that the projection 38 coincides with box 30, indicating that the angle between the planned section plane 30 and the plane defined by the elongate elements has become zero. Again, the necessary tilting is facilitated by an arrow 42 indicating how the cutting tool 44' needs to be tilted. If the cutting tool 44' is sufficiently aligned with the planned section plane, this is indicated by signal light 32 also shown in Fig. 6.

Note that the positioning assisting means and the assisted instrument directing means shown with reference to figures 4 and 6 are only exemplary embodiments, which could be modified in various ways. Irrespectively of the specific way the generated images look, it has been found to be helpful to provide two-dimensional abstract images specifically adapted for assisting the user in positioning and/or directing the instrument. In particular, it has been found to be helpful if the two dimensions represented by the image correspond with the two crucial dimensions of the three-dimensional movement to be performed, be it positioning or directing.

In the third step, the properly positioned and directed cutting tool 44' is inserted into the soft tissue body part along the planned section plane 10. This insertion is facilitated by an assisted instrument insertion guiding means adapted to generate an image corresponding to a view of a virtual camera 43 placed at the leading edge of the cutting tool 44'. The concept of the virtual camera 43 is schematically illustrated in Fig. 7, while a view provided by such virtual camera 43 is schematically shown in Fig. 8. As is seen in Fig. 8, the cutting plane 10 is also inserted into the virtual camera image. By providing the virtual camera image, the surgeon can be sure not to accidentally hurt any risk structures like large blood vessels or tumors upon insertion. Also in Fig. 8, the depth indicator 26 is displayed indicating how far the instrument 14 has to be inserted into the soft tissue body part.

As has become apparent from the description of Fig. 3 to 8, the computer assisted guiding means greatly facilitate insertion of the navigated cutting tool 44' such that the section plane defined by the inserted instrument 44' coincides with the planned section plane 10.

Note that the computer assisted guiding of the navigated instrument relies on the registration of the preoperative medical image with the intraoperative medical image and the registration

of the intraoperative medical image with the tracking coordinate system. As is described in more detail in the co-pending application US 61/075,467 and the references cited therein, registration errors may occur due to soft tissue motion. However, these errors can be kept small and/or compensated for by means also described in more detail in the co-pending application US 61/075,467 such that the details are not repeated herein. Besides instrument manipulation and movement of the patient, in many cases a main source of soft tissue motion is breathing. If fiducials are applied prior to taking the intraoperative image, the system may be configured to repeatedly determine and display a value indicating how well the current positions of the navigation aids correspond with their positions in the intraoperative medical image. An example for such a value is the so-called fiducial registration error, which is described in more detail in the co-pending application US 61/075,467 and the references cited therein. If this value indicates that the current positions of the navigation aids are similar to those in the intraoperative medical image, it can be assumed that the current motion state is very similar to the motion state in the intraoperative image which in turn means that the registration of the intraoperative image and the tracking coordinate system is presumably very precise. Accordingly, the surgeon may observe this value and perform the insertion in a time period or consecutive time periods in which the registration is assumed to be very precise.

In addition, the system can be refined by providing means not only for detecting but actually for compensating the motion of the soft tissue, said means being configured to calculate the current position of the planned section plane based on information of the motion state of the body part, which may be represented by the position of the navigation aids, where the calculation may for example be based on a deformation model of the body part.

While the above preferred exemplary embodiments have been described with reference to navigated cutting tools, alternative computer assisted instrument guiding means may be employed for which the cutting tool itself need not be navigated. For example, means could be provided for projecting light signals onto the soft tissue body part indicating how the non-navigated cutting tool is to be positioned and/or directed. A further example comprising computer assisted instrument guiding means which would not necessarily employ a navigated instrument is the guiding means based on augmented reality mentioned above.

Although preferred exemplary embodiments are shown and specified in detail in the drawings and the previous specification, these should be viewed as purely exemplary and not as limit-

ing the invention. It is noted in this regard that only the preferred exemplary embodiments are shown and specified, and all variations and modifications should be protected that presently or in the future fall within the scope of protection of the invention.

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# LIST OF REFERENCE SIGNS

- 10 planned section plane,
- 12 tracking system,
- 22 projection of leading edge of cutting tool 44',
- 24 vector defining insertion direction,
- 26 depth indicator,
- 28 center line of depth indicator,
- 30 box including section of planned section plane with surface of body part under treatment,
- 32 signal light
- 34, 36 arrows,
- 38 projection of remote portion 40 of cutting tool 44',
- 40 remote portion of cutting tool 44',
- 42 arrow,
- 43 virtual camera,
- 44 navigated cutting tool,
- 44a first member of navigated cutting tool 44,
- 44b second member of navigated cutting tool 44,
- 46 blade-like element,
- 47 thumb screw
- 48 space between adjacent blade-like elements 46,
- 50 conductor,
- 52 laparoscopic navigated cutting tool,
- 54 front portion of laparoscopic cutting tool 52,
- 56 instrument body,
- 58 hinge
- 60 shaft

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**Claims**

1. A cutting tool (44, 52) for soft tissue surgery,  
said cutting tool comprising a set of elongate members (46) suitable for being simultaneously inserted into a soft tissue body part,  
said cutting tool when inserted into said soft tissue body part being suitable for
  - defining a cutting plane with respect to said soft tissue body part,
  - denaturizing, and in particular coagulating and/or cauterising the tissue in the vicinity of each elongate member (46) and/or between adjacent elongate members (46) and
  - cutting tissue between at least some adjacent ones of said elongate members (46) when inserted into the soft tissue body part.
2. The cutting tool of claim 1, wherein said instrument (44, 52) comprises one or more blade members (46) adapted for cutting the tissue between said elongate members (46) after insertion into the soft tissue body part.
3. The cutting tool of claim 1 or 2, wherein the number of elongate members (46) is three or more, preferably four or more and most preferably five or more.
4. The cutting tool (44, 52) of claim 1, wherein the distance between adjacent elongate member (46) is between 0,8 and 15 mm.
5. The cutting tool of one of the preceding claims, wherein said instrument (44, 52) comprises first and second members (44a, 44b),  
each of said first and second members (44a, 44b) comprising a set of substantially parallel blade-like elements (46),  
said first and second members (44a, 44b) being moveable relative to each other to a first position, in which the blade-like elements (46) of the first member (44a) are substantially congruent with corresponding blade-like elements (46) of the second member (44b), said corresponding blade-like elements in said congruent state forming said elongate members, and

- a second position, in which, when viewed from a direction perpendicular to the direction of relative motion, blade-like elements (46) of the first member (44a) are located substantially between adjacent blade-like elements of said second member (44b).
6. The cutting tool of one of the preceding claims, wherein said instrument comprises first and second members,  
said first member comprising a set of substantial parallel blade-like elements and said second element comprising a single blade-like element,  
said first and second members being movable relative to each other to a first position, in which the single blade-like element of the second member is substantially congruent with one of the blade-like elements of the first member,  
and wherein the second member can be moved relative to the first member such that the single blade-like element of the second member moves along the plane defined by said set of blade-like elements of the first member such as to cut tissue between at least some of the blade-like elements of the first member.
  7. The cutting tool of claim 5 or 6, wherein some or all of the blade-like elements 46 have a cross-sectional shape defined by a straight edge 46a and a curved edge 46b meeting at an acute angle of 50° or less, preferably 30° or less.
  8. The cutting tool of claim 2 to 5, further comprising one or more blade members configured to be inserted in a space between adjacent elongate members in a direction parallel to the insertion direction of said cutting tool.
  9. The cutting tool (44, 52) of one of the preceding claims, wherein said cutting tool (52) is a laparoscopic instrument.
  10. The cutting tool (44, 52) of one of the preceding claims, comprising means for denaturing, and in particular coagulating and/or cauterizing the tissue, said means employing one or more of heat, coldness, chemical agent, electrical currents and electromagnetic fields.

11. The cutting tool (44, 52) of one of the preceding claims, wherein means is provided for applying monopolar RF-voltages to at least some of said elongate members and/or means for applying bipolar RF-voltages between adjacent elongate members.
12. The cutting tool (44, 52) of one of the preceding claims, wherein said cutting tool is adapted for cutting the tissue between adjacent elongate members by electrosurgery.
13. The cutting tool (44, 52) of one of the preceding claims, wherein said cutting tool (44, 52) is a navigated instrument.
14. The cutting tool (44, 52) of claim 13, said cutting tool (44, 52) comprising markers suitable for tracking by a tracking system.
15. The cutting tool (44, 52) of one of the preceding claims, said cutting tool being adapted to be manipulated by a telemanipulator or a robot.
16. A system for computer assisted surgery in soft tissue, comprising:  
a cutting tool (44, 52) as defined in one of claims 1 to 15, and  
a computer assisted cutting tool guiding means to assist or enable guiding the cutting tool (44, 52) upon insertion into the body part such that the section plane defined by said cutting tool (44, 52) coincides with at least a portion of a planned section plane (10).
17. The system of claim 12, wherein said assisted cutting tool guiding means comprises positioning assisting means for assisting a user to position the cutting tool (44, 52) at the soft tissue body part prior to insertion,  
said positioning assisting means being adapted to generate and display an image specifically for allowing a user to assess how the leading edge of the cutting tool (44, 52) has to be moved in order to approach the intersection line of the surface of the body part and the planned section plane (10).
18. The system of claim 16 or 17, wherein the image generated by said positioning assisting means represents a relative position between said intersection line and a projection

- (22) of said leading edge of said cutting tool (44, 52) onto the surface of said body part.
19. The system of claim 18, wherein said projection is a projection along a vector (24) defining a predetermined insertion direction.
  20. The system of one of claims 16 to 19, wherein said assisted cutting tool guiding means comprises assisted cutting tool directing means for generating and displaying an image specifically for allowing a user to assess to which extent a plane defined by said cutting tool (44, 52) is aligned with the planned section plane (10).
  21. The system of claim 20, wherein the plane defined by the said cutting tool (44, 52) is a flat plane and the image generated by said assisted cutting tool directing means is a two-dimensional image displaying a projection (38) of a portion remote from and parallel to said leading edge of the cutting tool (44, 52) onto a plane perpendicular to a vector (24) defining a predetermined insertion direction.
  22. The system of one of claims 16 to 21, wherein said assisted cutting tool guiding means is adapted to generate an image corresponding to a view of a virtual camera (43) placed at the leading edge of the cutting tool (44, 52).
  23. The system of claim 22, wherein said assisted cutting tool guiding means is further adapted to display medical images of predetermined objects, in particular, but not limited to, blood vessels, tumors, bony structures and organs.
  24. The system of one of claims 16 to 23, further comprising tracking means (12) for tracking said navigated cutting tool such as to continuously locate the position and orientation of said cutting tool (44, 52) in a tracking coordinate system.
  25. The system of claim 24, wherein said tracking means (12) are configured for tracking said cutting tool based on signals received from optical and/or electromagnetic and/or ultra sound means.

26. The system of claim 24 or 25, further adapted to register said tracking coordinate system with a coordinate system of an intraoperative medical image of said body part.
27. The system of claim 26, further adapted to register said intraoperative medical image with a preoperative medical image containing the planned section plane (10).
28. The system of one of claims 16 to 27, further comprising navigation aids, such as fiducials, to be provided on or inserted to the body part.
29. The system of claim 28, wherein said navigation aids comprise a needle-shaped body having an elongate portion serving as a marker.
30. The system of claim 29, further configured to track said navigation aids during a time interval during which the navigation aids are allowed to move along with the body part due to soft tissue motion, and to determine a motion state of the body part in which the positions of the navigation aids coincide best with their positions in the intraoperative medical image.
31. The system of one of claims 28 to 30, further configured to repeatedly determine and display a value indicating how well the current positions of the navigation aids correspond with their positions in said intraoperative medical image.
32. The system of one of claims 16 to 31, further comprising means for compensating the motion of the soft tissue, said means being configured to calculate a current position of the planned section plane based on information of the motion state of the body part.
33. The system of claim 32, wherein said information of the motion state of the body part is represented by the positions of navigation aids attached to and/or inserted to the body part, and the calculation is based on a deformation model of the body part.
34. The system of one of claims 16 to 33, wherein the computer assisted cutting tool guiding means comprise means for projecting light signals onto the soft tissue body part indicating how the cutting tool (44, 52) is to be positioned and/or directed.

35. The system of one of claims 16 to 34, wherein the computer assisted cutting tool guiding means comprise a telemanipulator or a robot for manipulating the navigated cutting tool (44, 52).
36. The system of one of claims 16 to 35, wherein the computer assisted instrument guiding means comprise means for augmenting video images of the operational site or a view through glasses worn by a surgeon by the addition of computer-generated graphic indicating how the instrument is to be positioning and/or directed.
37. A method of cutting soft tissue, comprising the steps of inserting a set of elongate members (46) of a cutting tool (44, 52) simultaneously into a soft tissue body part, said set of elongate members (46) defining at least a portion of a cutting plane within said soft tissue body part,  
denaturizing, in particular coagulating and/or cauterizing the tissue in the vicinity of each elongate member (46) and/or between adjacent elongate members during or after insertion of the cutting tool (44, 52), and cutting tissue between at least some adjacent ones of said elongate members (46) while the cutting tool (44, 52) is inserted into said soft tissue body part.
38. The method of claim 37, wherein said step of inserting the cutting tool (44, 52) into the body part is carried out using computer assisted instrument guiding means and such that the section plane defined by said inserted instrument (44, 52) coincides with a planned section plane (10).
39. The method of claim 37 or 38, further comprising a step of preoperatively acquiring a preoperative medical planning image and a step of determining a planned section plane (10) based on said preoperative planning image.

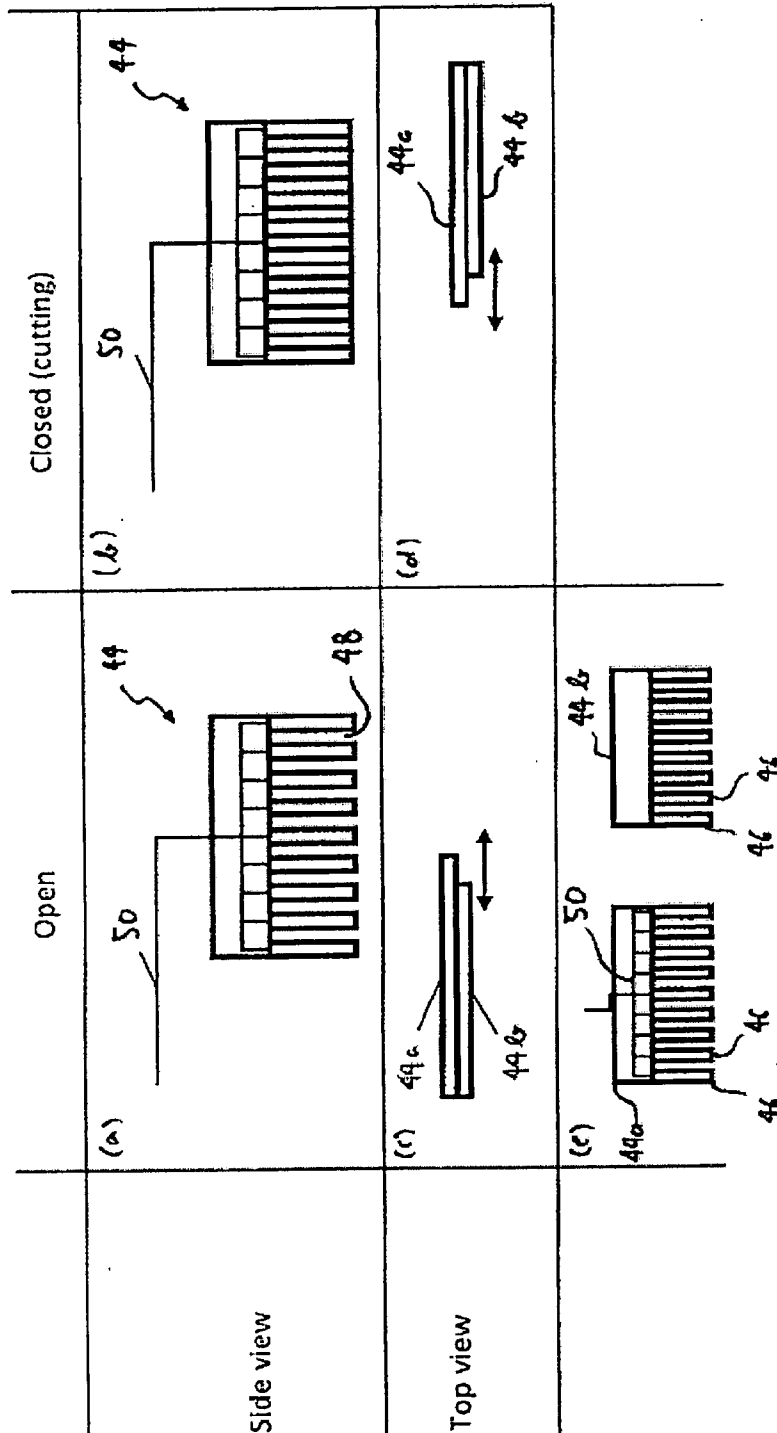


Fig. 1A

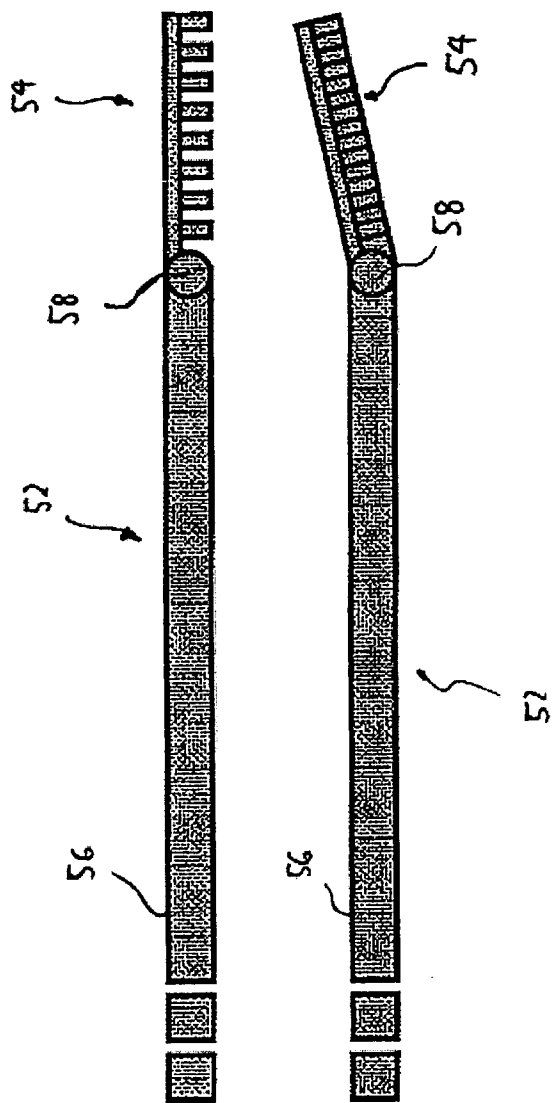
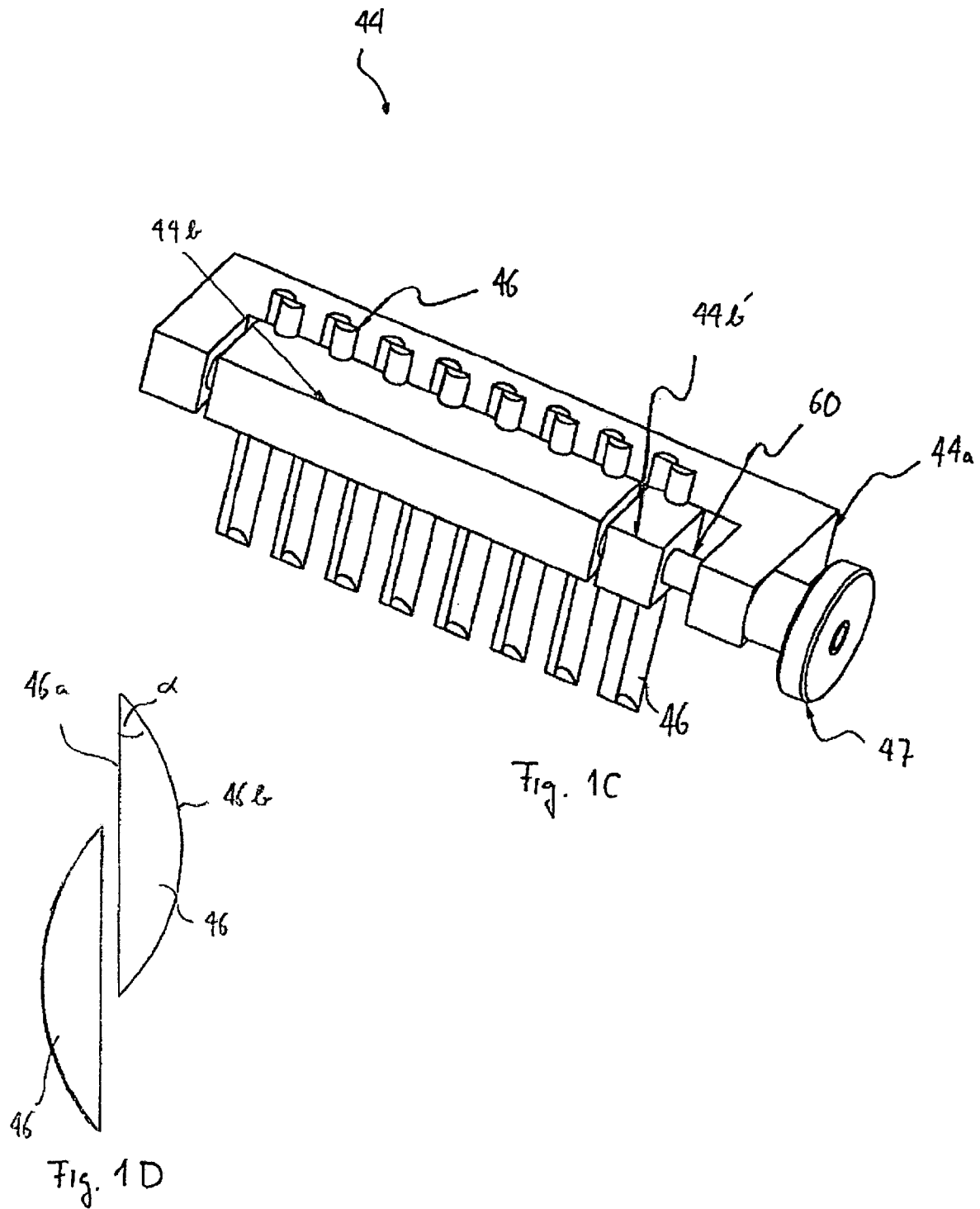


Fig. 1B

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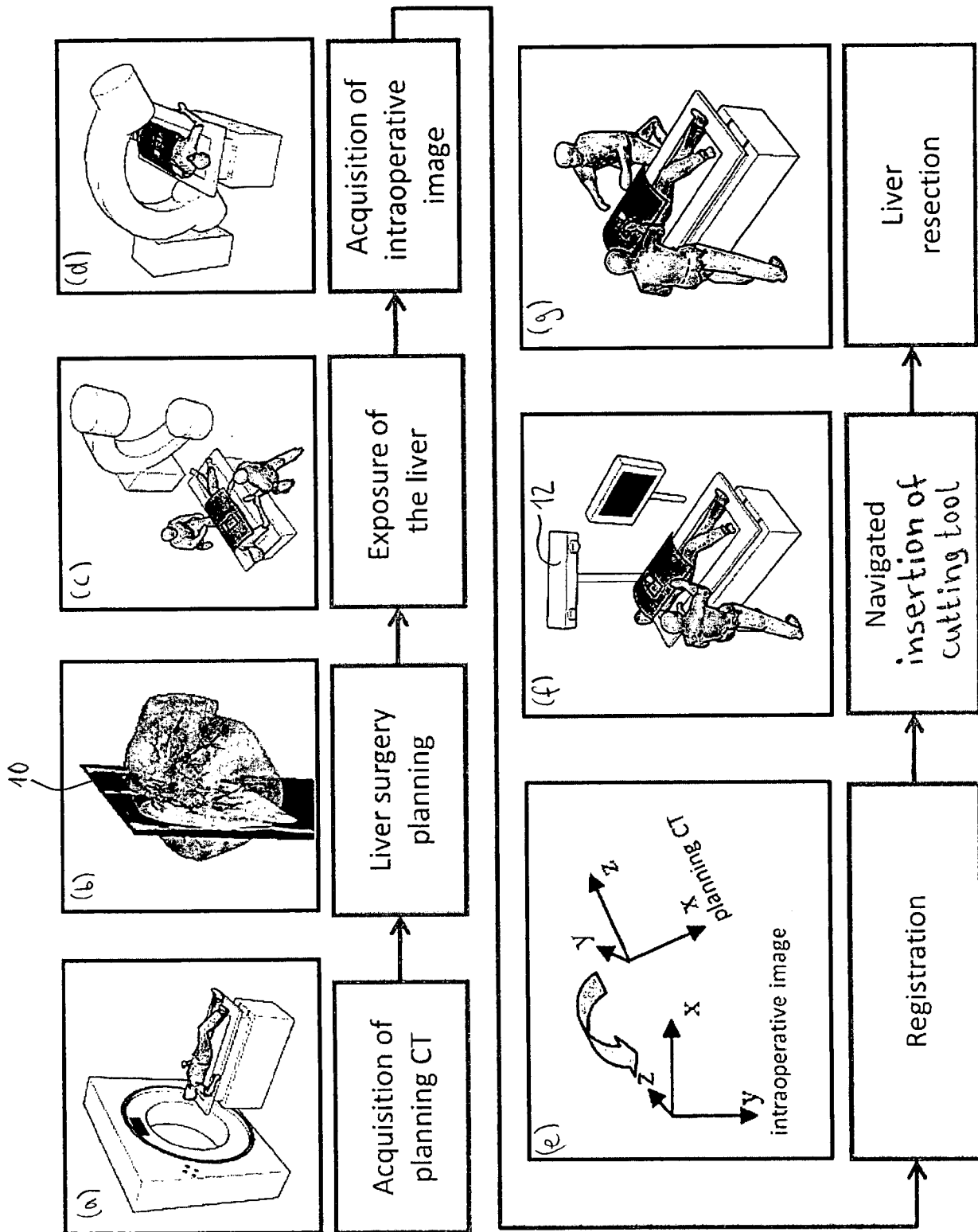


Fig. 2

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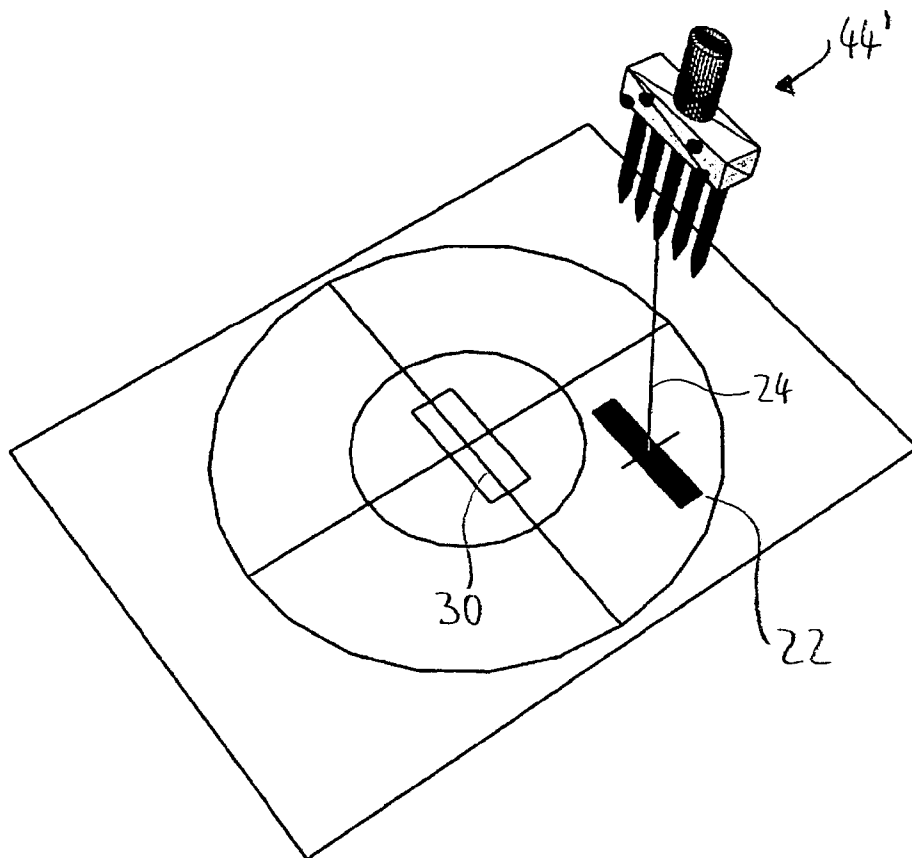


Fig. 3

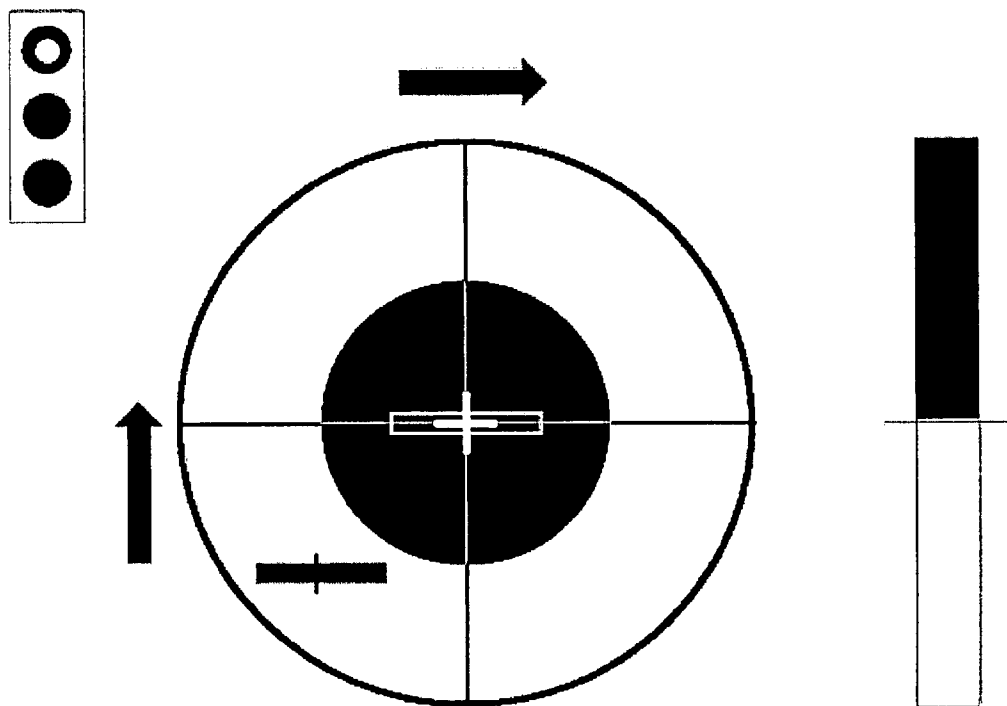


Fig. 4

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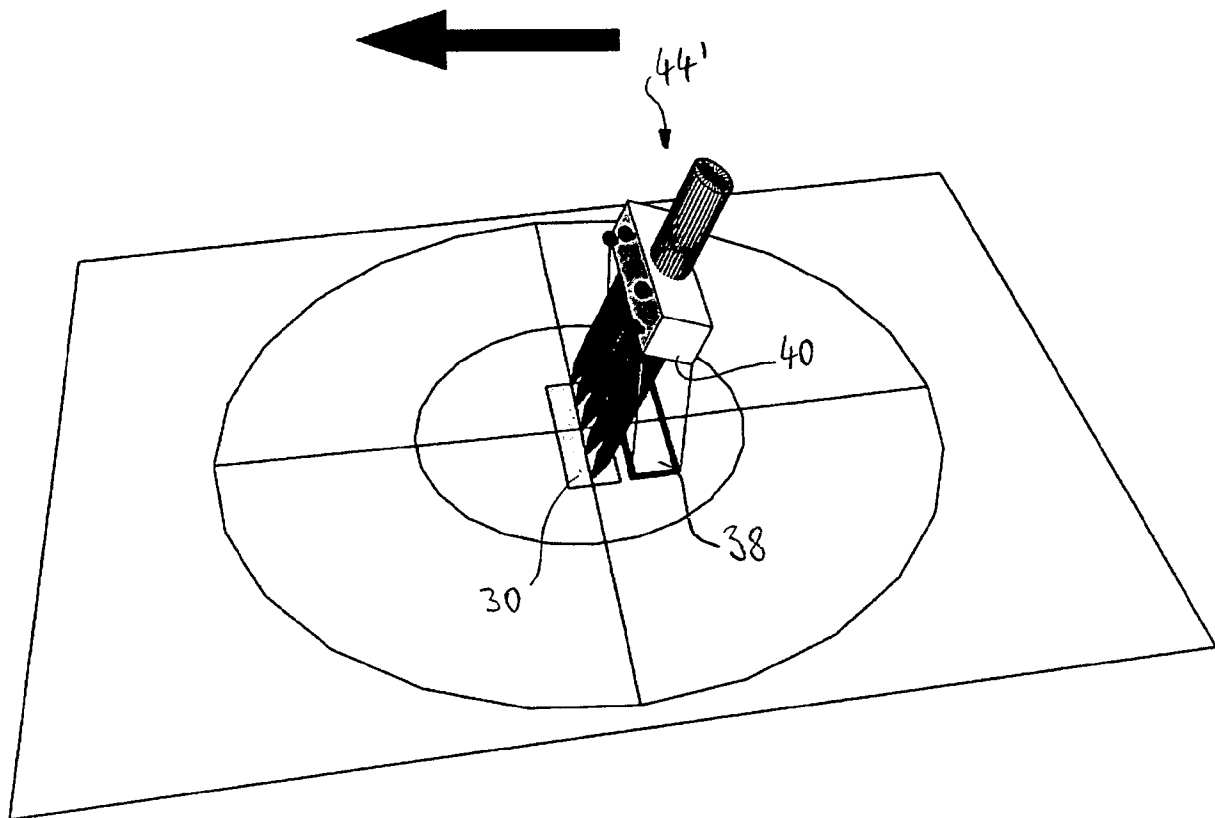


Fig. 5

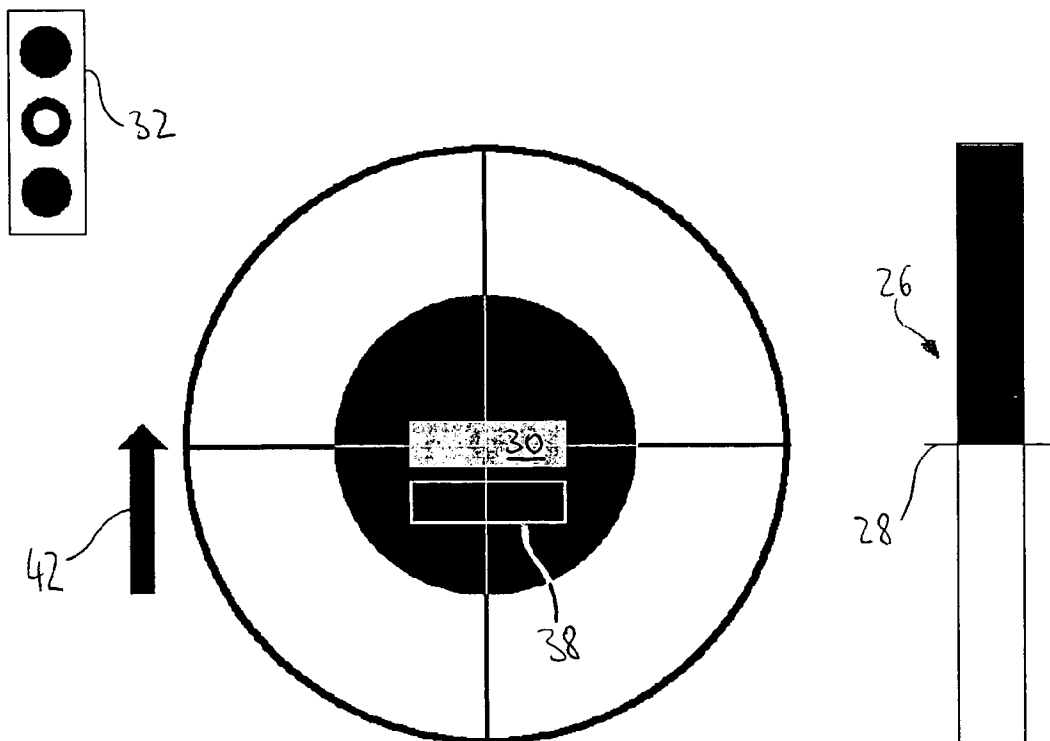


Fig. 6

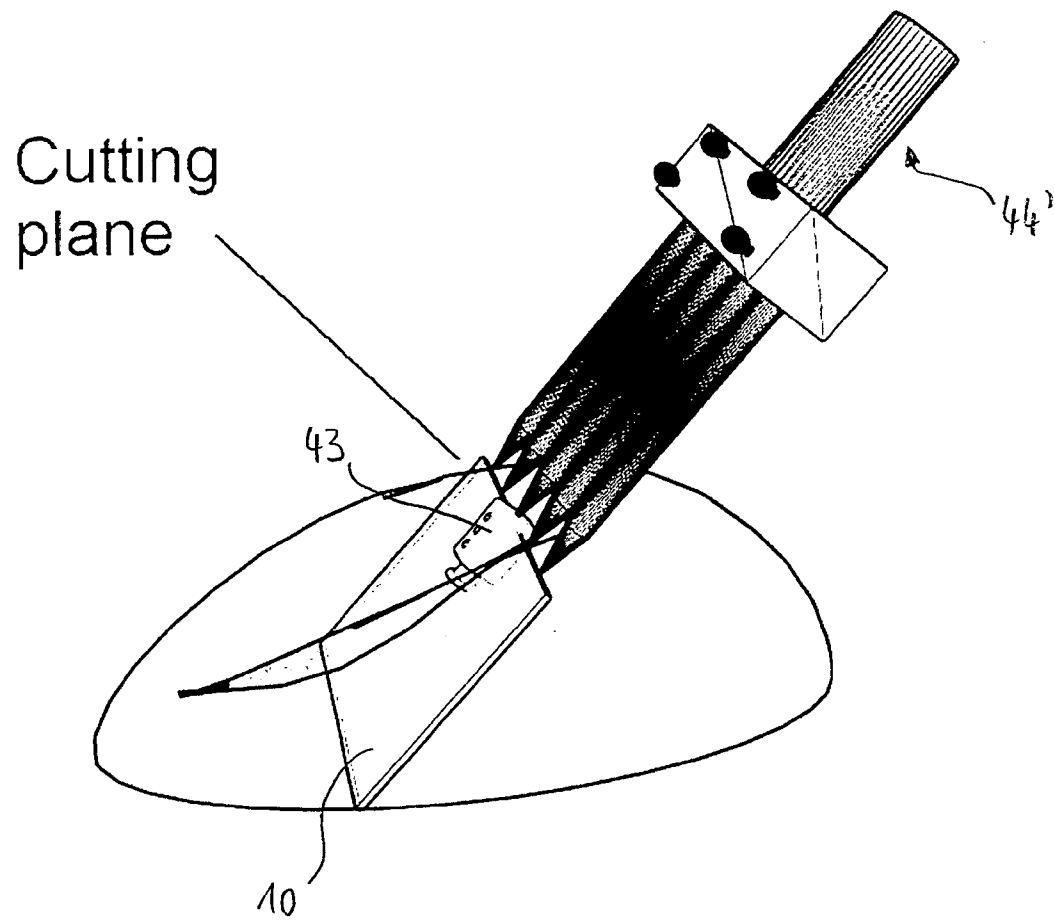


Fig. 7

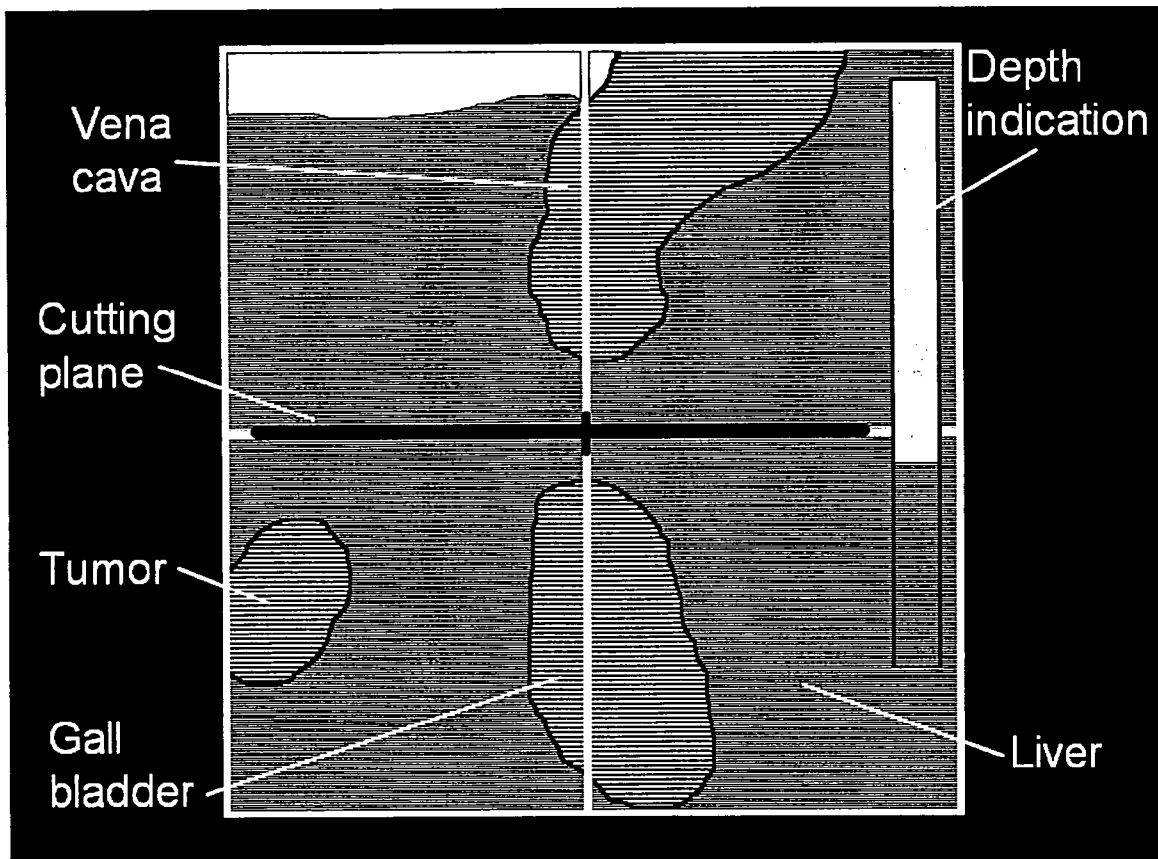


Fig. 8