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ROBOTIC SURGERY AND LASER TECHNOLOGY: AN OPPORTUNITY TO DISCOVER

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Summary.- *The use of laser technology in the field of urologic surgery has experienced great advances over the past 20 years. Since the beginning of this century robotic technology has landed in a determined manner in our specialty and every day will be more and more indications on what is going to have a final deployment. The current combination of laser and surgical robots, can be focused on two distinct areas, but possibly complementary, the use of lasers to guide the surgical procedure, what we might call "landmarks and structures recognition" or "positioning" and laser use because of its ablative ability minimizing blood loss and increasing the resection accuracy. This paper reviews most recent articles and contributions on the combination of these two technologies.*

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Resumen.- *El uso de la tecnología láser en el campo de la cirugía urológica ha vivido grandes avances en los últimos 20 años. Desde los comienzos de este siglo la tecnología robótica ha desembarcado de una manera decidida en nuestra especialidad y día tras día van siendo más y más las indicaciones en las cuáles está teniendo una implantación definitiva. Las actuales combinaciones del láser quirúrgico y los dispositivos robóticos, se pueden centrar en dos áreas claramente diferenciadas, pero posiblemente complementarias; la utilización del láser para guiar el procedimiento quirúrgico, lo que podríamos llamar "reconocimiento de estructuras" o "posicionamiento" y el uso de láser por su capacidad ablativa minimizando la pérdida sanguínea y aumentando la precisión de la resección. En este trabajo se revisan los artículos y aportaciones más recientes en la combinación de estas dos tecnologías.*

Palabras clave: *Robot. Da Vinci®. Nuevas tecnologías. Láser.*

INTRODUCTION

The use of laser technology in the field of urological surgery has experienced great advances over the past 20 years. Its use has expanded to become the "standard reference" on some techniques and procedures. Also since the beginning of this century techno robotics technology has landed in a determined manner in our specialty and day after day will be more and more indications on what is going to have a permanent implantation.

The merger of the da Vinci robotic platform with laser technology in whatever form, is something being born, but it certainly will not die and I dare say that this is "just the beginning" of a great story.

FIGURE 1. CO_2 laser fiber through rigid endoscope (By courtesy of Omni Guide® Inc, USA).

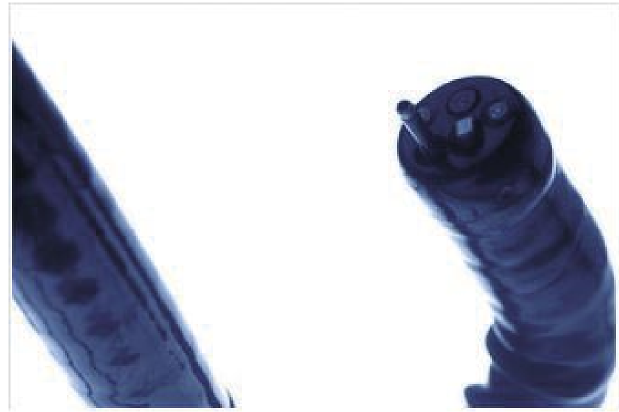

FIGURE 2. CO_2 laser fiber through flexible endoscope (By courtesy of Omni Guide® Inc, USA).

Lasers with more current implementation are the Holmium: YAG laser, the Neodymium-YAG and CO_2. Recently, several groups are communicating interesting experiences with the Tulium laser (1) and Erbium: YAG (2).

One of the technical developments which has allowed to extend its application in Urology and more specifically in Endourology (including robotic and laparoscopic techniques) has been the chance to drive the laser energy through flexible fibers that can be introduced through the work channel of endoscopic instrumentation (Figures 1 and 2).

These fibers manufactured in silica let you transmit the laser energy from the generator to the point of application. They are bio-compatible and flexible, relatively economic, reasonably durable, if used to moderate power moderate, and can be reused.

The distal end of the fiber can deliver the energy directly (parallel to the fiber), laterally (with certain angle with regard to the fiber) or "in dispersion" (with multiperforated end) (Figure 3).

The advantages that robotic surgery offers nowadays, can be specify in:

• Improved display of anatomical structures, due to magnification and three-dimensional vision.

FIGURE 3. CO_2 laser fiber distal end detail (By courtesy of OmniGuide® Inc, USA).

• Improved surgical skill y for the surgeon, simplifying technology, filtering tremor and escalating their natural movements with greater degrees of freedom than in conventional laparoscopic surgery.

These two pillars have led to lower the learning curve for urological routine proceeding performing, allowing procedure standardization and make it accessible to many more surgeons (which means many patients) in a more homogeneous and ethical way.

Although these advantages have undoubtedly supposed a huge advance, we cannot fail to mention the potential benefits of the electronic device that is contained within the surgical console.

The current da Vinci S HD system allows to project within the surgeon's visual field images, in real time or delayed of any type (angiographies, 3D images or reconstructions of CT or high resolution MRI, real-time echocardiography).

All this will allow in a very short time, the clinical development of guided by image surgery, by means of "magnified reality ", "image-fusion", "virtual reality" and "tissues recognition in real time" techniques.

What has been a dream for decades can become a reality and certainly the current da Vinci system and others that are to come, suppose for the time being the ideal platform.

The current combination of surgical laser and robotic devices can focus on two distinct but possibly complementary areas:

• the use of laser to guide the surgical procedure what we might call "structures recognition" or "positioning".

• The use of laser for its ablative ability minimizing blood loss and increasing the accuracy of the resection.

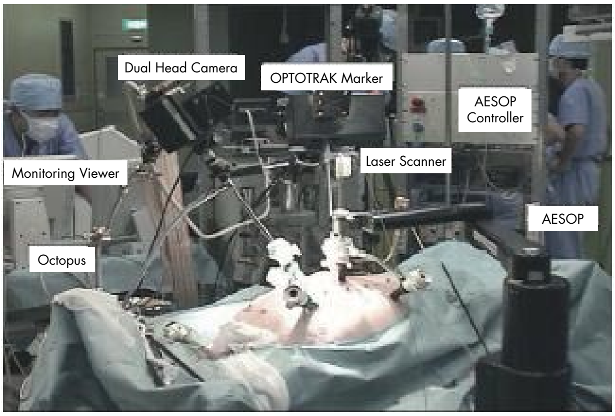

FIGURE 4. Complete system during "live" experiment (By courtesy of Prof. Hayashibe. Tokyo University, Japan).

LASER AS A SYSTEM OF RECOGNITION AND POSITIONING DURING ROBOTIC SURGERY

To have a system guiding their eyes and hands, with a millimeter accuracy, to the site of lesion to be removed, recognizing and avoiding damage to the anatomical structures that are nearby, it has been and remains the desire of any surgeon.

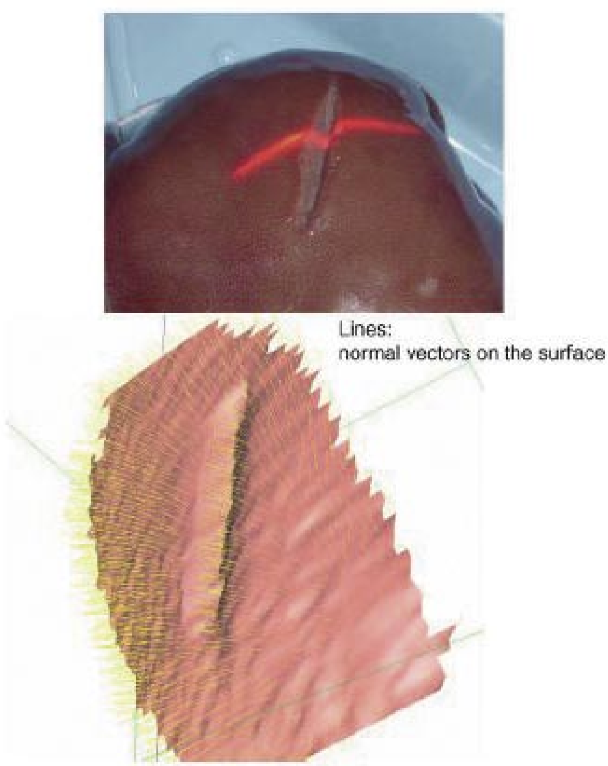

FIGURE 5. 3D reconstruction of pig hepatic surface calculated by "live" measurements (By courtesy of Prof. Hayashibe.Tokyo University, Japan).

Reviewing recent literature in the field of bioengineering and the medical imaging, there are several references and research groups actively working on the issue.

The strategies that allow to perform guided surgery in real time, may come from the hands of two approaches, which may even complement; one possible option is to use the current radiological system (High resolution CT or MRI) (3), that, once connected to robotic system, make cuts in real time and thus be able to obtain images that the surgeon could see inside the surgical console and could guide him to the lesion. So far, and due to its great technical complexity, it has only been performed in experimental environment. It would follow the same example that currently uses the systems of skull or body radio surgery.

Other approaches are related to the introduction into the abdominal or thoracic cavity of devices that can identify and rebuild the anatomical structures that are displayed. In this sense the group at the University of Tokyo(4) recently announced the use of a laser system as "surface scanner " associated with an endoscope and a robotic arm controlled by voice type AESOP (5) (Scar-laser endoscope) (Figure 4).

This is a complex system and, "a priori", something bulky that through multiple devices allows having image data as well as texture, size, density, location, etc.., of the different intra-abdominal structures through scanning its surface with a laser fiber (Figure 5).

The possibility of geometrically reconstruct the geometrical shape of certain areas, it may be useful to three-dimensionally calculate distances and spatial relationships between structures and thus avoid the collision of instruments or inadvertent lesion of adjacent organs or that are in the same trajectory. The system allows warning the surgeon in advance, before the collision occurs, to prevent it. In this way, the procedure safety is increased exponentially (Figures such 6 and 7).

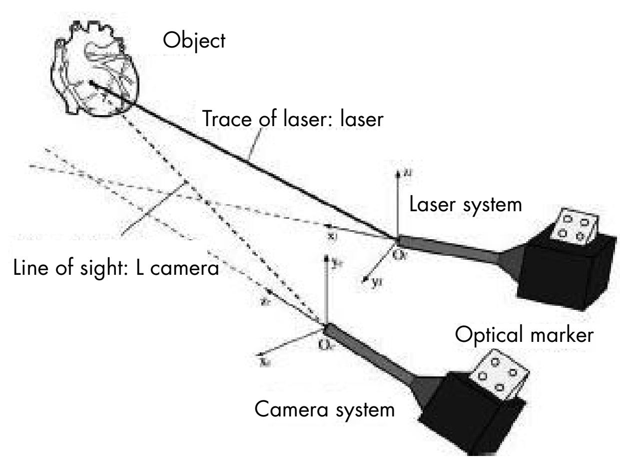

FIGURE 6. Laser-camera coordinated system scheme (By courtesy of Prof. Hayashibe.Tokyo University, Japan).

In addition to these virtues, the system is capable of generating a three dimensional image of objects captured on the surface and its texture (Figure 5). This technology allows handling the system via satellite or merely web-based for tele-surgery and tele-diagnosis performing. In the same manner, the texture patterns whether or not associated with the administration of ultraviolet light can be useful in terms of diagnosis.

This may allow, something like a system "internalize and integrate" the reality of an image. Subsequently it would allow to correlate this pattern or model with a preview image (CT or MRI, etc.), and superimpose both images so they can guide the surgeon ("Image-fusion" Technology).

To recreate the three-dimensional reality it uses the same principle as da Vinci robotic surgery combining the use of two cameras arranged in parallel to generate a 3D image. The laser fiber (100mW) is introduced into the abdomen coupled to a high-speed digital camera. The laser and camera are coordinated through a system named OPTOTRAK (Northern Digital Inc.)(4) (Figure 7).

A clear limitation of this system lies in that up to now, is only able to capture information of the organ or tissue surface, but not of all its three-dimensional volume.

It has been published in the literature some laparoscopic image analysis approaches to improve the segmentation, location and tracking of laparoscopic instruments (5, 6). The self-positioning of laparoscopic instruments through the use of a laser pointer and a monocular endoscope was described in 2003 by Krupa et al (7). This system allows the surgeon to manipulate instruments that are outside his vision field.

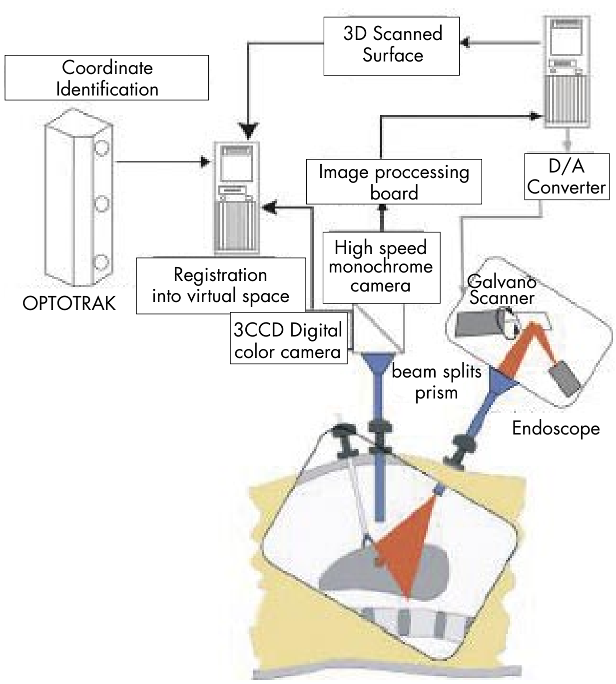

FIGURE 7. Scan Laser endoscope: System configuration (By courtesy of Prof. Hayashibe. Tokyo University, Japan).

Lasers have also been applied to perform instruments triangulation on a fixed and predefined target (8).

Another application focused on improving the maneuverability capability of laparoscopy instruments is the "what-you-draw-is-what-you-cut" (9,10). This device was designed to improve the ablation precision of CO_2 laser in endometriosis lesions in gynecological surgery.

It consists of a digital board as a graphic palette in which the surgeon draws or paints the contour, shape or trajectory of the area in which the laser, in this case Sharples® 1030 1.5W (CO_2 laser) type will conduct an action, allowing to make an application of laser effect in a much more precise and accurate way.

In another completely different field as it is neurosurgery, it has also been useful the positioning approach by laser (11). In skull base surgery, robotic technology allows great precision in the surgical movements. The system known as ROBIN equipped with laser sensors takes measures or geometric references with respect to fixed anatomical landmarks (usually bone) and compare them with previously established references through CT preoperative simulation (11).The authors report that the system offers accuracy in measure of spatial resolution of 0.02 mm in each dimension. Therefore, it allows performing a guided-laser robotic microsurgery.

APPLICATION OF LASER TECHNOLOGY AS ABLATIVE TECHNOLOGY DURING ROBOTIC SURGERY

Most of the classic applications of different laser types (Holmium-YAG, Nd-YAG, $C0_2$, KTP, etc.), in the field of urological surgery has been due to its ablative, fragmented or exeretic capability.

The most relevant precedents of laser application as an ablative component in procedures for robotic surgery took place at the end of the nineties in the field of minimally invasive cardiac surgery (12-14).

Hughes et al., first demonstrated in an animal model (12) and subsequently in humans (13) the feasibility and efficacy of myocardial revascularization by conducting multiple (up 25) transmural channels with Holmium-Yag laser fiber in the myocardial thickness of the left ventricle (Figure 8). It is a procedure indicated in patients with very bad situation basal no candidates for other endovascular treatment.

Through a thoracoscopic approach and the use of da Vinci system the laser fiber is introduced, without needing a bypass or cardioplegy, it is possible to make these tunnels to improve myocardial vascularization (14, 15).

A few months ago a new device from the da Vinci system with the FDA (Food and Drug Administration) approval and known as "In Endowrist® introducer 5Fr (16) has been described. It consists of a cannula which allows the passage through its light of a laser fiber. Originally approved for Lasercope Aura® XP (17) and Lisa Laser Revolix®(18). In the first case it is a KTP laser and the second, a Tulium laser.

The work element of allows movement with the same freedom degrees that the ®Endo-wrist system but the effect or element of the same is not a clam or a pair of scissors but the laser fiber and its issuance.

This will add to the precision and maneuverability of classical robotics instruments the ablative power of the different types of laser energy.

Recently the group of Mayo Clinic (1) has filed a pioneering experience in an animal model (pig), performing partial nephrectomy without vascular clamp with a Tulium laser fiber coupled to a Laser fiber Introducer® system (16). The authors reported excellent results in terms of minimizing blood loss, safety and precision in the cut-off line (1).

The Tulium laser fiber has some specific peculiarities. It not only allows transmitting the energy that is produced in the generator (as conventional silica fibers) but also fiber, alone, is capable of producing laser energy. It has the power to adjust the wave length from 1800 to 2100 nm. Therefore it can be used for the same applications as the Holmium laser: YAG (lithotripsy, incision of stenosis, prostate enucleation and vaporization, etc.).The generator is smaller and easier to use than other laser types, since it does not need cooling system using water (2).

We will have to wait for the clinical experience, but is probably a new way to explore, since the results seem very promising.

Since its beginnings the main purpose of the da Vinci robot surgery was endocavitary, i.e. that one that is performed under pneumoperitoneum and using laparoscopic techniques. However, in certain specialties such as surgery for head and neck another possible application was explored. The concept is based on using the da Vinci system as a surgical working tool that provides precision, magnified and stable vision and filtering of surgeon trembling. Therefore, it would be something like a technical support to classical microsurgery.

In this sense, it began to expand their uses in laryngeal 19-21), oral and maxillofacial surgical interventions (22). The Cleveland Clinic (23) group published last year, their experience in performing robot-assisted supraglottic laryngectomy and using the CO_2 laser. The flexible fiber (OmniGuide, Boston MA) allows its introduction and easy handling with conventional robotic instruments (Figure 9).

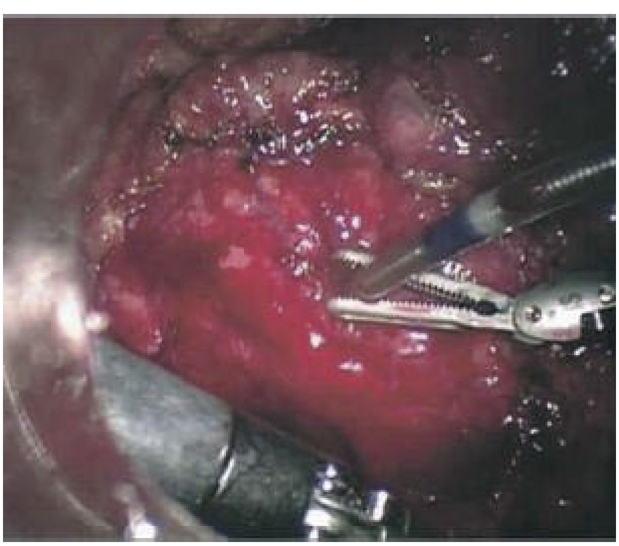

FIGURE 8. Creation by laser of a channel in the lateral wall of left ventricle. Note how the robotic instrument facilitates the movements of the laser fiber (By courtesy of Dr. Brunsting III, The Heart Team, Tennessee, USA).

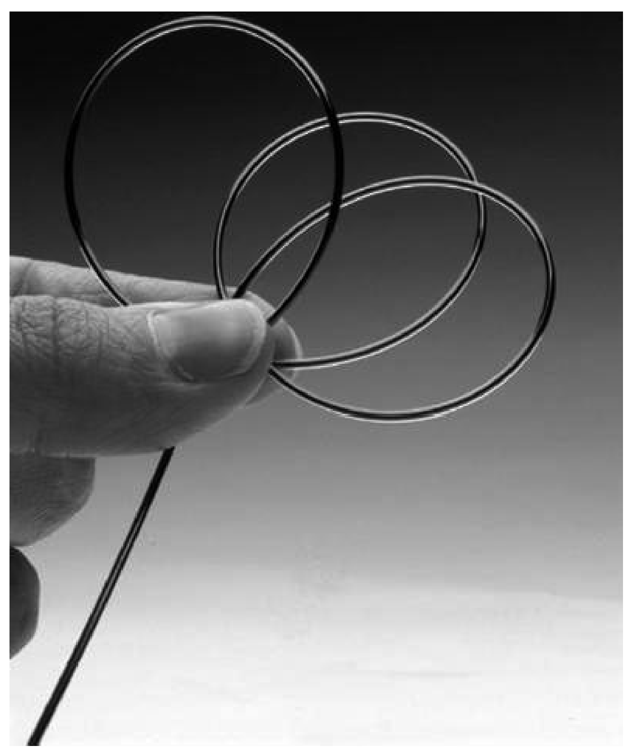

FIGURE 9. Detail of CO_2 laser fiber totally malleable that allows it introduction through flexible working elements (By courtesy of Omni Guide® Inc, USA).

Also the group at the Pennsylvania University, world pioneer in this technique, described its use in the removal of base of tongue tumor through the fusion of these technologies (22).

CONCLUSION

Following the above, we can say that we are seeing a technologies fusion with clear boosting effect.

The advantages of laser technology that can provide solutions to certain technical limitations are accompanied by technical benefits from the current da Vinci platform.

We are sure that in coming years we will live a thrilling emergence of new combinations of these devices that, positively, will improve our performance and therefore the care quality to our patients.

REFERENCES AND RECOMENDED READINGS (*of special interest, **of outstanding interest)

**1. TOLLEFSON, M.; GETTMAN, M.; FRANK, I.: "Hemostatic robotic assisted laparoscopic partial nephrectomy in a porcine model using a Thulium Laser". J. Urol., 179: 365, 2008.
*2. PIERRE, S.A.; ALBALA, D.M.: "The future of lasers in urology". World J. Urol., 25: 275, 2007.
**3. HAYASHIBE, M.; SUZUKI, N.; HATTORI, A. y cols.: "Surgical navigation display system using volume rendering of intraoperatively scanned CT images". Comput Aided Surg., 11: 240, 2006.
**4. HAYASHIBE, M.; SUZUKI, N.; NAKAMURA, Y.: "Laser-scan endoscope system for intraoperative geometry acquisition and surgical robot safety management". Med. Image Anal, 10: 509, 2006.
5. WANG, Y.F.; UECKER, D.R.; WANG, Y.: "A new framework for vision-enabled and robotically assisted minimally invasive surgery". Comput. Med. Imaging Graph., 22: 429, 1998.
6. WEI, G.Q.; ARBTER, K.; HIRZINGER, G.: "Real-time visual servoing for laparoscopic surgery. Controlling robot motion with color image segmentation". IEEE Eng. Med. Biol. Mag., 16: 40, 1997.
*7. KRUPA, A.; GANGLOFF, J.; DOIGNON, C. y cols.: "Autonomous 3-D positioning of surgical instruments in robotized laparoscopic surgery using visual servoing". IEEE Transactions on Robotics and Automation, 19: 842, 2003.
8. HANEISHI, H.; YAGIHASHI, Y.; MIYAKE, Y.: "A new method for distortion correction of electronic endoscope images". IEEE Trans. Med. Imaging, 14: 548, 1995.
*9. TANG, H.W.; VAN BRUSSEL, H.; SLOTEN, J.V. y cols.: "Implementation of an intuitive writing interface and a laparoscopic robot for gynaecological laser assisted surgery". Proc. Inst. Mech. Eng., 219: 293, 2005.
*10. TANG, H.W.; VAN BRUSSEL, H.; VANDER SLOTEN, J. y cols.: "Evaluation of an intuitive writing interface in robot-aided laser laparoscopic surgery. Comput". Aided. Surg., 11: 21, 2006.
11. MAASSEN, M.M.; MALTHAN, D.; STALLKAMP, J. y cols.: "Laser-based quality assurance for robot-assisted milling at the base of the skull". Hno., 54: 105, 2006.
12. HUGHES, G.C.; ABDEL-ALEEM, S.; BISWAS, S.S. y cols.: "Transmyocardial laser revascularization: Experimental and clinical results". Can. J. Cardiol., 15: 797, 1999.
13. HUGHES, G.C.; BISWAS, S.S.; YIN, B. y cols.: "A comparison of mechanical and laser transmyocardial revascularization for induction of angiogenesis and arteriogenesis in chronically ischemic myocardium". J. Am. Coll. Cardiol., 39: 1220, 2002.
**14. BRUNSTING, L.A. 3rd.; BINFORD, R.S.; BRALY, K.C. y cols.: "Totally endoscopic robot-assisted transmyocardial laser revascularization". Ann. Thorac. Surg., 82: 744, 2006.
*15. YUH, D.D.; SIMON, B.A.; FERNANDEZ-BUSTAMANTE, A. y cols.: "Totally endoscopic robot-assisted transmyocardial revascularization". J. Thorac. Cardiovasc. Surg., 130: 120, 2005.
**16. www.fda.gov/cdrh/pdf7/K072627.pdf:
17. http://www.laserscope.com/products/aura.html:
18. http://www.lisalaser.de/:
19. HOCKSTEIN, N.G.; NOLAN, J.P.; O'MALLEY B,W. Jr. y cols.: "Robotic microlaryngeal surgery: A technical feasibility study using the daVinci surgical robot and an airway mannequin". Laryngoscope, 115: 780, 2005.
*20. HOCKSTEIN, N.G.; NOLAN, J.P.; O'MALLEY, B.W. Jr. y cols.: "Robot-assisted pharyngeal and laryngeal microsurgery: results of robotic cadaver dissections". Laryngoscope, 115: 1003, 2005.
21. O'MALLEY, B.W. Jr.; WEINSTEIN, G.S.; HOCKSTEIN, N.G.: "Transoral robotic surgery (TORS): Glottic microsurgery in a canine model". J. Voice., 20: 263, 2006.
22. O'MALLEY, B.W. Jr.; WEINSTEIN, G.S.; SNYDER, W. y cols.: "Transoral robotic surgery (TORS) for base of tongue neoplasms". Laryngoscope, 116: 1465, 2006.
*23. SOLARES, C.A.; STROME, M.: "Transoral robot-assisted CO2 laser supraglottic laryngectomy: Experimental and clinical data". Laryngoscope, 117: 817, 2007.