Robotics, Telesurgery and Telementoring - their position in modern urological laparoscopy.

JENS RASSWEILER¹ and THOMAS FREDE².

Department of Urology Klinikum Heilbronn¹ and Medical School of Mannheim², University of Heidelberg, Germany.

Summary.- OBJECTIVES: Laparoscopic surgery in general is handicapped by the reduction of the range of motion from six to four degrees of freedom. This has a major impact on technically difficult procedures such as laparoscopic radical prostatectomy. Solutions for this problems include the understanding of the geometry of laparoscopy with sophisticated training programs, but lie also in newly developed surgical robots, computer-simulators and telementoring. This article evaluates the value of these alternatives based on own experiences and an analysis of the current literature.

METHODS: Own experiences with robot-assisted surgery include 406 laparoscopic radical prostatectomies using a voice-controlled camera-arm (AESOP) as well as 6 telesurgical interventions with the Da Vinci-system. Additionally, substantial experimental studies have been performed focussing on the geometry of laparoscopy and new training concepts such as perfused pelvitrainers and computersimulation. Moreover, the current literature of the last 10 years on telesurgery and telementoring has been reviewed.

RESULTS: The geometry of laparoscopy includes the angles between the instruments which have to be in a range of 25° to 45°; the angles between the instrument and the working plane that should not exceed 55°; and the angle between the shaft of the needle holder and the needle which has to be adapted according to the anatomical situation in range of 90 to 110°. 3-D-systems did not yet proved to be effective due to handling problems such as shutter glasses, video-helmets or reduced brightness. At the moment, there are only two robotic surgical systems (ZEUS, Da Vinci) in clinical use for telesurgery, of which only the Da Vinci provides stereovision and all six degrees of freedom (DOF). In the meantime, more than 200 laparoscopic radical prostatectomies have been performed with this system. Until now, however, there was no evidence of any advantages over the conventional laparoscopic approach. The ZEUS in combination with the telecommunication system SOKRATES is the only device enabling to realize telemanipulation and telementoring over long distances (i.e. transatlantic).

CONCLUSION: Robotic surgery represents a turning point of surgical research. However, broad use of robotic systems is limited mainly because of the high investment and running costs. Whereas there will be a clear role of audio-visual telementoring in future training concepts, the need of telemanipulation/telesurgery has not yet been clarified. New technological concepts promote the development of hand-held mechanical manipulators (i.e. 6-DOF-needle-holder) used in combination with mono-tasking computerized robots (i.e. AESOP) resulting in a significant cost reduction.

Keywords: Laparoscopy. Radical Prostatectomy. Telesurgery. Robotics. Telementoring.
**Resumen.** OBJETIVO: En general, la cirugía laparoscópica está limitada por la reducción del rango de movimiento de seis a cuatro grados de libertad. Este hecho tiene un gran impacto en procedimientos técnicamente difíciles como la prostatectomía radical laparoscópica. Las soluciones para estos problemas incluyen el entendimiento de la geometría de la laparoscopia mediante sofisticados programas de entrenamiento, y también en el desarrollo reciente de robots quirúrgicos, simuladores computadorizados y de la supervisión a distancia. El objetivo de este artículo es evaluar, a través de nuestra experiencia personal y del análisis de la literatura actual, el valor de estas alternativas.

MÉTODOS: Nuestra experiencia personal en cirugía asistida por robots incluye 406 prostatectomías radicales utilizando un brazo robótico controlado por la voz para la cámara (AESOP) así como 6 intervenciones telequirúrgicas con el sistema Da Vinci. Además, se han desarrollado importantes estudios experimentales enfocados en la geometría de la cirugía laparoscópica y en nuevos conceptos como "pelvitrainers" con perfusión y simulación por ordenador. Por otra parte, se ha revisado la literatura de los últimos 10 años sobre telecirugía y supervisión a distancia.

RESULTADOS: La geometría de la laparoscopia incluye los ángulos entre los instrumentos, que tienen que estar en un rango entre 25° y 45°; el ángulo entre los instrumentos y el campo de trabajo, que no debe superar los 55°; y el ángulo entre el porta y la aguja que se tiene que adaptar de acuerdo con la situación anatómica en un rango entre 90° y 110°. Los sistemas de 3-D todavía no han demostrado ser eficaces debido a problemas de manejo como la gafas obturadoras, video-cascos o disminución de la luminosidad. Por el momento, solamente hay dos sistemas de robot quirúrgico (ZEUS, Da Vinci) en uso clínico para telecirugía, de ellos sólo el Da Vinci ofrece visión en estereoscópica y los 6 grados de libertad. Mientras tanto, se han realizado más de 200 prostatectomías radicales laparoscópicas con este sistema, sin embargo, hasta ahora no hay evidencia de ninguna ventaja sobre el abordaje convencional laparoscópico. El ZEUS en comunicación con el sistema de telecomunicación SOKRATES es el único aparato que permite la realización de telemanipulación y telesupervisión a larga distancia (por ejemplo, transatlántica).

CONCLUSIONES: La cirugía robótica supone un punto de inflexión en la investigación quirúrgica. Sin embargo, la utilización amplia de los sistemas robótizados está limitada principalmente por la gran inversión y el costo de su utilización. Mientras que existirá un claro papel de la enseñanza/supervisión audiovisual a distancia entre los conceptos de enseñanza futuros, la necesidad de la telemanipulación/telecirugía no está clara todavía. Los nuevos conceptos tecnológicos promueven el desarrollo de instrumentos de manipulación mecánica manuales (por ejemplo, portas con 6 grados de libertad) utilizados en combinación con robots computadorizados monotarea (por ejemplo AESOP) dando como resultado una reducción significativa del coste.

**Palabras clave:** Laparoscopia. Prostatectomía radical. Telecirugía. Robótica. Supervisión a distancia.

**INTRODUCTION**

The use of robots has significantly changed and improved the production of cars, i.e. near Heilbronn 80% of the new Audi A2 is currently manufactured by robots alone. The medical application of robots includes various fields, starting with machines for automatic laboratory examinations, aids for handicapped patients up to devices for different surgical procedures (1, Table I). Recently some of the industrial robots have been modified to create exact shaft cavities for hip-joint replacement (2, Fig. 1). Robotic systems navigating the surgeon during the procedure has been utilized already extensively in neurosurgery (3) and otorhinolaryngology (4).

During the end of the last millennium, in urology there has been an increasing use of computerised technology, too, starting with the introduction of

<table>
<thead>
<tr>
<th>Criteria</th>
<th>N</th>
<th>with 3D</th>
</tr>
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<tbody>
<tr>
<td>w/o AESOP</td>
<td>43</td>
<td>-</td>
</tr>
<tr>
<td>with AESOP</td>
<td>406</td>
<td>41</td>
</tr>
<tr>
<td>with Da Vinci</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>455</td>
<td>47</td>
</tr>
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</table>
extracorporeal shock wave lithotripsy of urinary calculi in the early eighties (5, 6), followed by microwave therapy for benign prostate hyperplasia (7, 8) and high-energy focussed ultrasound for treatment of prostate and renal cancer (9, 10). However, experience with direct application of manipulating robots in urologic surgery is still very limited: Only few centers have tried to realize a robotic transurethral resection (11, 12; Fig. 2), and recently the successful application of master-slave systems for telesurgical laparoscopic radical prostatectomy has been realized (13-18). Based on our own experience in the field of advanced laparoscopic procedures with and without robots (Table I), we want to focus on the description of such systems and further perspectives, such as telementoring. However, also the actual role of robotics is critically assessed.

THE PRINCIPLES OF TELEPRESENCE SURGERY

The use of master-slave systems principally means the application of telepresence surgery as defined by Satava in the early nineties (19; Table II). Originally such systems have been developed to perform open trauma surgery in the battlefield with the surgeon controlling the manipulators from a distant and safe location (20). In the meantime, such devices have been improved and modified for telepresence laparoscopic surgery, in order to overcome some of the principal drawbacks of laparoscopy (21-24).

<table>
<thead>
<tr>
<th>Classification of Telematics (modified from Satava)</th>
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<tbody>
<tr>
<td>Teleoperation</td>
</tr>
<tr>
<td>Telerobotics</td>
</tr>
<tr>
<td>Telepresence</td>
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<tr>
<td>Telementoring</td>
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LIMITATIONS OF LAPAROSCOPY

Laparoscopic surgery in general is handicapped by the reduction of the range of motion because of fixed trocar position determining the angle of the respective instrument to the working field (25-27; Table III). The incision point acts like a spherical joint that limits the degrees of freedom (DOF) of the instrument from six to only four (Fig. 3): jaw, pitch, rotation, insertion plus the actuation of instrument. This applies also to the endoscope making it impossible to observe anatomic structures from different sides while keeping the viewpoint in focus.

Another problem is the two-dimensional view of the video-camera (27-29). The absence of shadows, stereovision and movement parallax in particular, make it difficult for a surgeon to accurately determine spatial distance and movements and impairing his eye-hand coordination (25). The latter may be compensated by surgeon’s experience if the working field is small and the camera can be put close to the object (i.e. during laparoscopic adrenalectomy), however particularly in case of reconstructive surgery (pyeloplasty, urethro-vesical anastomosis) it becomes a crucial handicap (28).

STEREOVISION

In the laparoscopic literature, a number of aids have been described to improve the surgeon’s depth perception (25). Shadows can be introduced by using illumination cannulae. Stereovision can be introduced by using a stereo-endoscopic system (27). Earlier systems (i.e. Opticon) used two 5 mm-lenses in one telescope creating a double-image on the video-monitor which was unified to a three-dimensional picture.
by use of shutter glasses (Fig. 4a). The main problem beside the difficulties with the glasses represented the fact that only the surgeon had a normal endoscopic picture whereas the assisting nurses and the anesthesist had to view on the double-image on the screen (Fig. 4b).

Recently, we had the opportunity to test a new 3-D-system (Karl Storz, Tuttlingen, Germany) taking two images with one telescope from different angles. The image is digitally reconstructed. If the surgeon wears polarised glasses quite similar to sunglasses he gets a three-dimensional image, whereas without glasses the picture on the screen is normal (Fig. 5). We were able to perform a variety of laparoscopic procedures with this system including radical prostatectomy (Table I). The handling was much more convenient for the assisting surgeon and nurse, however, actually the system has been only realised for 0°-lenses. Moreover, the picture loses brightness comparing to the dedicated three-chip-CCD-camera (Endocam, Karl Storz) which is even more pronounced when using the polarised glasses.

Additionally, comparisons between mono- and stereo-endoscopes have demonstrated that, with current technology, three-dimensional systems show no advantages for the experienced surgeon (28, 30, 31). This indicates that the loss of stereovision can be well compensated by the magnification, brightness and sharpness of the new three-chip-cameras together with the experience of the laparoscopic surgeon.

GEOMETRY OF LAPAROSCOPY

With increasing training and analysis of the important geometrical factors, laparoscopic surgeons were able to deal with these problems, even in case of endoscopic suturing (28, 29):
- the angle between the instruments
- the angle between instruments and working plane
- the distance from surgeon to the working plane
- the angle between the needle and the shaft of the needle-holder

Fig. 4a) 
Fig. 4b) 
Fig. 4c)

*Fig. 4: Stereovision - 3 D-system with shutter glasses (Opticon)*

a) + b) Telescope consisting of two 5 mm-lenses  
c) Shutter glasses for surgeon
With respect to the angle between the instruments it is of importance whether the operative step represents dissection or reconstruction. In case of dissection (i.e. ablative surgery) the angle between the instruments can be in the range of 15 to 25° (i.e. the two left ports during radical prostatectomy; Fig. 5). In contrast to this, the angle should be between 25 and 45° for endoscopic suturing (Fig. 6). This means, that the surgeon has to use a different port for his right hand during radical prostatectomy, if endoscopic suturing is required (i.e. control of dorsal vein complex). Only these angles allow well co-ordinated movements with both instruments, such as endoscopic knotting techniques or free-hand suturing.

Important too, is the angle between the instruments and the horizontal line of the working plane. During open procedures, the surgeon chooses a flat angle if possible (i.e. during construction of an ileal neobladder). The same applies to microsurgery where the surgeon works with support of the forearms. In case of laparoscopy, the angle should be at least less than 55°. If the anatomical situation does not allow an adequate placement of the trocars, turning the patient towards the surgeon (i.e. using a steeper Trendelenburg position during radical prostatectomy; Fig. 6b) can reduce the angle in relationship to the horizontal line.

Even if both geometrical criteria are properly considered, laparoscopic suturing may become very cumbersome due to an inadequate working height of the surgeon. Usually, the distance to the trocars is too small, which has to be compensated by lifting of the surgeon's shoulders. An ergonomically relaxed working situation requires that the surgeon's hands touch the abdominal wall with orthogonal deflected elbows. For this purpose, the operating table has to be lowered maximally and – according to its size – the surgeon may need an additional stand (platform).

Frequently, the laparoscopic anastomosis cannot be performed with adequate exposure of the tissue (i.e. urethral stump). Therefore, the angle between the needle and the shaft of the needle-holder is important. In case of an easy suture (i.e. reconstruction of the bladder neck), the stitch is orthogonal to the tissue thus requiring a 90°-angle between shaft and needle (Fig. 7a) similar to the open technique. For difficult sutures with oblique direction of the stitch (i.e. control of the

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**Table IV: Telemanipulators – Experimental and Clinical devices**

<table>
<thead>
<tr>
<th>Device</th>
<th>Imaging</th>
<th>Control of Camera</th>
<th>DOF</th>
<th>Tactile feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARTEMIS</td>
<td>2-D</td>
<td>voice, finger-ring joystick</td>
<td>6</td>
<td>force-feedback</td>
</tr>
<tr>
<td>ZEUS</td>
<td>2-D</td>
<td>voice</td>
<td>4</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>(3-D-option)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Da Vinci</td>
<td>3-D</td>
<td>master-handle foot-pedal</td>
<td>6</td>
<td>none</td>
</tr>
<tr>
<td>Laprotek</td>
<td>2-D</td>
<td>Electronic glooves</td>
<td>6</td>
<td>none</td>
</tr>
</tbody>
</table>
a) The angle between the instruments should be 25°-45° to enable optimal endoscopic suturing and knotting. Therefore the right medial port is used for introduction of the needle-holder.

b) The angle between the horizontal plane and the working field should be less than 55°. This can be accomplished by turning the table towards the surgeon.

dorsal vein complex, urethrovesical anastomosis) the position of the needle has to be adapted according to the anatomical situation (Fig. 7b). It has to be achieved that the needle passes the tissue only by rotation of the instrument with minimal traumatisation. Usually, the angle is more than 90° (in the range of 100 and 120°).

However, the experienced laparoscopic surgeon applying these geometrical aspects is still limited in his movements compared to open surgery. This becomes most evident when performing a complex procedure such as laparoscopic radical prostatectomy.

TELEMANIPULATORS

Experimental systems

A more conceptional approach to these problems represents the development of computer enhanced
telemanipulators (Tab. IV). Various authors (1, 19, 20) have described the concept of intelligent steerable surgical instrument system. A first functional master-slave manipulator for surgery was introduced by Green et al. (20) in 1991. This manipulator was not designed for endoscopic use and had only four DOF in its first release. But it formed the basis for the industry to develop a marketable product providing six (seven) DOF: the Da Vinci-System. (21).

In Germany, the group around Buess and Schurr (32, 33) developed the ARTEMIS-System and presented first experimental results in 1994 when successfully performing a telesurgical laparoscopic cholecystectomy on swine (Fig. 8). ARTEMIS also consists of two parts, the user station (master) and the instruments station (slave). While this device is still an experimental device, other groups entered the area of clinical use of robotic manipulators.

Recently, another experimental telesurgery-system (Laprotek, Brock-Rogers, Boston, USA) has been introduced by Birkett (34). The instruments provide all six degrees of freedom and – similar to the da Vinci-system they are moved mechanically by metal cables. However, they are moved by mini-motors mounted on both sides of the operating table. The control of the end-effectors is realised by use of electronic data-gloves transmitting the movements of the finger and ankle-movements (Table IV). Actually, the significant advantage of this system represents the considerable lower purchase costs (about 300,000 Euro).

**The ZEUS-System**

The basis of the ZEUS-system represents the voiced controlled camera-arm AESOP (35-37) enabling the surgeon to move the telescope by pre-programmed and individually recorded demands (i.e. "AESOP, move left!"). Every surgeon has his own voice-disk that allows him to use any AESOP worldwide. The device alone enables solo-surgery in case of retroperitoneoscopic procedures (i.e. simple nephrectomy) or in case of radical prostatectomy the operation can be performed by only two surgeons (Fig. 5). We are successfully using the AESOP since the beginning of 2000, particularly for laparoscopic radical prostatectomy (38, 39; Table I). AESOP is the first robotic device that was used for transatlantic telementoring (40).

The ZEUS-system (ComputerMotion Inc., Goleta, CA, USA) has been developed and already used for cardiac surgery and gynaecological procedures (41-43). The ZEUS-System (Fig. 9) is also based on the combination of a control unit and a telemanipulator. The manipulator consists of three separate robot arms, which are transported on small carts. The arms are
mounted by hand on the rails of the operating table. They can be moved freely in the operating field holding the trocar in position, using the so-called "free-pivot" technology. Two arms control the 4-mm reusable instruments; the third arm consists of an AESOP camera manipulator. The surgeon is seated in a high-backed chair with armrests, handling the instrument controllers. The camera is positioned by voice control. A 2-D video endoscopic camera routinely provides operating field visualisation. For 3D-vision the ZEUS-system can be combined with a head mounted system (i.e. as provided by VISTA technologies).

In urology, the ZEUS-system has been studied experimentally for ablative and reconstructive procedures on kidney and adrenals (44). Clinically experience has been gained by Guillonneau et al. using the device for laparoscopic pelvic lymph node dissection, nephrectomy and pyeloplasty (45,46). We had the opportunity to test the ZEUS-system in the pelvi-trainer at Singapore University. As mentioned above, this system provides only two-dimensional vision using a standard three-chip-camera and the instruments have only four degrees of freedom. In conclusion, surgery has become even more difficult reflecting in longer OR-times (i.e. 73.5 vs.27.5 min. for laparoscopic nephrectomy) or to perform a coronary anastomosis (46 vs. 12 min.) in an experimental setting (41, 44).

The Da Vinci-system

The Da Vinci-System (Intuitive Surgical, Mountain View, CA, USA) is the first surgical system that addresses most of these problems more sufficiently, such as the problem of depth perception, eye-hand co-ordination, and limited range of motion (i.e. DOF). For this purpose a computerised robotic system has been designed with stereo-endoscopic system, a computer controlled mechanical wrist providing six DOF (plus actuation of the instrument), used from a console with handles that can be utilised at the console always in an ergonomic working position (Fig. 10).

The surgeon performs the procedure seated at the console holding specially designed instruments (Fig. 10a). Highly specialised computer software and mechanics transfer the surgeon's hand movements exactly to the microsurgical movements of the manipulators at the operative site. The video image gathered from inside the abdomen provided by two parallely arranged 3-chip-cameras is projected so it coincides with the workspace of the master manipulators. This overlap creates the visual illusion for the surgeon that his hands are holding onto tool tips inside the body (Surgical Immersion® Technology).

As a result, the surgeon manipulates the tools as though he was holding on to the instruments directly. Every motion of the handles is sensed by high-resolution motion-sensors, processed and transferred to the two surgical manipulators (Fig. 10b). These slave manipulators (surgical arms) provide three degrees of freedom (pitch, jaw, insertion). The last

Fig. 8: The ARTEMIS-System. The Surgeon’s console with three video screens and two master manipulators.

Fig. 9: The ZEUS-System. Three slave-manipulators, one voice-controlled camera-arm and two master-controlled surgical arms. The surgeon's console with 2D-video-monitor and two master manipulators. The surgeon wears a head-microphone to control the telescope.
element are the surgical instruments or end-effectors (Fig. 10c): At the tip of the instruments, a cable driven mechanical wrist (Endo-wrist®-technology) adds three more DOF (including rotation) and one motion for tool actuation. The grip torque of the end-effector (i.e. needle-holder, DeBakey forceps) was programmed to 1.0 Newton. Monopolar electrocautery can be applied to one of the end-effectors by using one of the three foot switches at the console, if the respective instrument has been introduced (i.e. electrocautery hook). In order to enhance precision the system allows for scaling of the master-slave motion relation. Accordingly, a motion scale of 3:1 will move the tool 1-mm inside the abdomen for every 3-mm of motion at the master console. In this study, a motion scaling of 2:1 was used. In addition unintended movements caused by human tremor are filtered by applying a 6 Hz motion filter. Finally, it is possible to temporarily disconnect the end-effectors from the master handles within its working space, while the position of the instruments remains unchanged (clutch-function controlled by foot-pedal). This allows always an ergonomically optimal working position of the surgeon.

The high-resolution 3-D endoscope consists of two – three-chip charge coupled device cameras (InSite®) with two high-intensity illuminators to ensure a bright image of the operative field. 0° as well as 30° lenses can be used, the 30° lenses can be additional mounted either down or upside looking. The video image enables a five to ten fold magnification according the distance of the endoscope to the operative field. The surgeon moves the endoscope - once inserted -: Camera control is performed by pressing the footswitch that locks the slave-tool manipulators in place and gives the operator control of the camera through the master manipulators. The endoscope is then manipulated according to the movement of the handles at the console. The same foot pedal can be also used for re-focussing the image.

Fig. 10: The DaVinci System.

10-a) The master console with control panel, 3D-imaging of the working field, two master handles and three footswitches for camera control, disconnection of end-effectors (clutch) and activation of coagulation.

10-b) Surgical manipulator consisting of two lateral surgical arms with three degrees of freedom (outer pitch, outer yaw and insertion) and one camera arm holding an stereo-optical system of two 3-chip cameras.

10-c) Endoscopic view of end-effectors (i.e. needle-holder during 6 o clock stitch of urethrovesical anastomosis).
Adequate interaction between the surgeon and the assistants at the OR-table is guaranteed by a continuous communication. In some theatres (i.e. cardiac surgery; 47), the surgeon’s console stands in a separate room connected with an audioline (microphone, loudspeaker) to the OR-room. In other instances, the console is mounted in the same room: The surgeon gives the distinct commands (i.e. use of bipolar coagulation, succion/irrigation, retraction) to the assistants based on the 3D-image provided at the console.

**Table V: Main components of the telesurgical daVinci-system.**

**Surgeon’s Console:**
- 3-D-videoscreen (one monitor for each eye)
- Control panel of the machine
  - emergency button
  - activation / desactivation of the system
  - adjustment of camera-angle (0° vs. 30°)
  - adjustment of motion scale (2:1, 3:1, 5:1)

**Surgical handles (master)**
- Footswitches
  - movement of camera
  - activation of electrocautery
  - disconnection of end-effectors (clutch-function)

**Surgical Arm Unit:**
- Two robotic arms for manipulation of instruments
  - with three electronically controlled joints
  - specially designed instruments with six DOF (variable set of instruments)
  - adapted to 8 mm metal trocars
- One robot arm for the stereo-endoscopic camera system
  - two integrated 3 chip-CCD-cameras with two light sources (0°, 30°)
- adapted to a 10 mm trocar

### TELESURGERY IN UROLOGY

There are long-term experiences with the Da Vinci-system in several dedicated cardio-surgery centers (21-23). First experiences in urology have been gained by Binder et al. (13) in the year 2000 when performing a telesurgical laparoscopic radical prostatectomy. In the same year other European groups have used DaVinci for the same procedure (14-17). In the last year this device has been increasingly used by some urological centers in the United States (i.e. Denver, Cleveland).

**Surgical Training**

To get acquainted with system, we have carried out a previously standardized training program of endoscopic suturing at the pelvi-trainer. Additionally, various trocar positions for the two instrument arms have been tested to ensure optimal coordination between the surgeon and the assistants and to exclude collision of the instrument arms with the camera arm during the procedure. Finally the interpretation of the anatomical structures using the 3 D-system with up to 10 fold magnification as well as the optimal choice and application of the instruments has been simulated at two cadavers.

**Preliminary results of telesurgical laparoscopic radical prostatectomy**

Beside the lateral placement of the working trocars for the robot, the same position of the ports and patient was used. World wide about 100 patients have been successfully treated with the daVinci system. The main data of 43 patients who underwent radical prostatectomy and have been published yet are summarized on Table VI.

The time for mounting the system averaged 50 minutes. The OR-time differed considerably among the three groups. In Paris, no lymph node dissection has been performed resulting in a mean time of 220 minutes, in Heilbronn the mean operating time was 351 minutes including pelvic lymph node dissection in all cases. In Frankfurt, where the group has had no experience with laparoscopic radical prostatectomy at all, the OR-time including lymphadenectomy has been considerably longer averaging 555 minutes. The experienced groups encountered difficulties with the use of the system only during the first two cases, which were mainly due to the different endoscopic 3D-view.
the high scale magnification and the lack of tactile feedback. After that the time for the control of the dorsal vein complex averaged 5 min. with a suturing and knotting time of 60 seconds per suture. Overall, the pathological staging revealed 11 pT2a, 17 pT2b, 10 pT3a, and 2pT3b tumors. There had been 9 positive margins (20.1%). The mean catheter time was 6.7 days (Table VIb).

Advantages and Disadvantages of Telesurgery

In urology, laparoscopic radical prostatectomy has gained significant interest after the initial reports of Guillonneau and Vallancien (38). However, as mentioned already, this is a very complex surgical procedure. In this situation, the use of a robotic telesurgical system might be attractive to reduce the technical difficulties, particularly for those surgeons who are not experienced in urological laparoscopy. Indeed, at the University of Frankfurt/Main urologists with limited laparoscopic expertise and no experience in laparoscopic prostatectomy have successfully performed the first laparoscopic radical prostatectomies using the Da Vinci, but the operating time was still in the range of 9 hours (Table VI).

In Paris and Heilbronn, the surgeons have tried to transfer our laparoscopic technique that has been applied successfully before in more than 350 respectively 150 cases to the telepresence surgery. Whereas at the pelvi-trainer we felt comfortable with the system after a short time, in the clinical situation, some difficulties have been encountered initially:

- interpretation of magnified anatomy
- lack of tactile feedback
- coordinated interaction between surgeon and assistants
- need of specific instruments for urological procedures
- the cost-benefit relationship.

The first problem for the surgeon was the interpretation of the respective anatomical structures (i.e. the dorsal vein complex, bladder neck, vas deferens) seen under stereoscopic vision with a ten-fold magnification. It proved to be difficult to adjust the new image to the known two-dimensional picture one has been used to over the last decade.

The next difficulty was the lack of haptic sense, which aggravated in this novel situation. There is no doubt, that "standard" laparoscopy does only provide a minimal amount of tactile sensation. However, the effect of training and experience finally enabled the surgeon to have a certain haptic sensation, i.e. to assess the shape of the prostate, the severity of adhesions, the strength of a suture or knot. The Da Vinci-system, actually, does not provide any tactile feedback. To avoid injury to instruments, needles and tissue, the device has a programmable grip torque that differs for the various end-effectors (grasper, fine needle holder, etc.). In this study, we have used a grip torque of 1 N for all our instruments. Moreover, some force feedback is provided, so that tissue contact (i.e. bony resistance), as well as external forces (collision of slaves), are reflected at the master. As currently configured, the slave is capable of detecting forces greater than approximately 2.2 N (40). Finally, the surgeon has to compensate the missing tactile feedback by the improved stereoscopic vision (i.e. observing the deformation of tissue and the increasing tension on the suture). Indeed, with increasing experience, we were able to estimate the applied strength on the suture when performing a knot. It proved to be only difficult, if some tension has to be applied to the suture (i.e. to accomplish the first knot of urethro-vesical anastomosis). Nevertheless, working remotely without tactile feedback requires new surgical skills, solely based on visual inputs.

A further problem lies in the complexity of the operation itself requiring proper assistance and instrumentation. In contrast to a laparoscopic nephrectomy, a laparoscopic radical prostatectomy cannot be performed as solo-surgery. There is a need of retraction of the gland or adjacent structures. Additionally, a coordinated four instrument-based technique proved to be very efficient. This did compensate the lack of some instruments which were not available for the end-effectors (i.e. bipolar coagulation forceps).

It has to be emphasized, that we were able to reproduce our original technique in a reasonable time after only two cases of training, indicating the relatively short learning curve with the device. Particularly during those parts requiring endoscopic suturing, the six degrees of freedom of the end-effectors (i.e. needle-holder) was very helpful. However, there is a need of optimizing the existing instruments for the use of radical prostatectomy (i.e. longer forceps, bipolar coagulation forceps, curved Metzenbaum-type
Table VI: Telesurgical laparoscopic radical prostatectomy – Preliminary results of three European centers

**a) Patients data**

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<thead>
<tr>
<th>Department</th>
<th>N</th>
<th>Age (J)</th>
<th>PSA (ng/ml)</th>
<th>Specimen (g/cc)</th>
<th>Clinical Stage</th>
<th>OR-time (min.)</th>
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<tr>
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<td>20</td>
<td>60.5</td>
<td>6.0</td>
<td>n.b.</td>
<td>1 4 3 7 5</td>
<td>555+</td>
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<tr>
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<td>64.2</td>
<td>8.4</td>
<td>31.3</td>
<td>- 1 3 1 1</td>
<td>351+</td>
</tr>
<tr>
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<td>12.2</td>
<td>37.4</td>
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<td>220</td>
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<td>59</td>
<td>4.5</td>
<td>n.a.</td>
<td>- 1 - -</td>
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<td>60.6</td>
<td>8.0</td>
<td>44.1</td>
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**b) Results**

<table>
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<th>Department</th>
<th>OR-time</th>
<th>Pathological Stage*</th>
<th>Gleason R0 Score</th>
<th>R1</th>
<th>Catheter time (d)</th>
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<td>pT2b</td>
<td>pT3a</td>
<td>pT3b</td>
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<tr>
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<td>10</td>
<td>3 2</td>
<td>6 15 5</td>
<td>n.a.</td>
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<tr>
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<td>1</td>
<td>4 -</td>
<td>6 6 -</td>
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<td>6 4 1</td>
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<tr>
<td>Paris (Creteil)</td>
<td>3</td>
<td>2</td>
<td>3 -</td>
<td>6 8 3</td>
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</tr>
<tr>
<td>London</td>
<td>1</td>
<td>-</td>
<td>- -</td>
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<td>10</td>
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<tr>
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<td>17</td>
<td>10 2</td>
<td>6 27 6 9</td>
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- all pNO M0, except one in Frankfurt  
+ all inclusive pelvic lymph node dissection
scissors). This could speed up the dissection of the gland and thus lead to further reduction of operating time.

Regarding the practicability of the robot-assisted or telesurgical laparoscopic surgery in urology it has to be mentioned that until now none of the laparoscopy-experienced groups (i.e. Paris-Montsouris, Paris-Creteil, Heilbronn) were able to be quicker with the robot compared to the standard laparoscopic approach using the da Vinci system (14-16,39). Moreover, the ZEUS-system has been applied only for less difficult procedures, such as nephrectomy or pelvic lymph node dissection, also associated with longer OR-times (45,46). This reflects the fact, that despite their significant advantages (i.e. enhanced dexterity, ergonomic working position; Fig. 10) both telesurgical systems still require a significant learning curve at least comparable to standard laparoscopy. Recent experiences from Detroit have reported on a significant decrease of OR-times using the Da Vinci system for radical prostatectomies, which demonstrates that the learning curve can be mastered. However, on the other side, the laparoscopic technique has been more and more standardized resulting in a linear decreasing OR-time (actually 2.5 to 3.5 h including pelvic lymph node dissection) and improvement of the surgical quality (i.e. prolonged catheter time only in 10%). This means that there remains only a small range for further improvement by use of the robot.

Another issue for wide-spread use of the device represent the investment and running costs which amount to actually about 800,000 $ and another 100,000 $ per year. This means, that the cost per case might be increased by 1 500 to 2 000 $. It is evident that with the actual reimbursement situation, there will be only a few urologic centers who could afford this. As mentioned before, all the existing major laparoscopic centers in Europe have long waiting list. This means that – unlike in the United States – the investment in a robotic device will not significantly increase the number of referrals, and therefore any advertising effect is questionable.

On the other hand, particularly in Urology, we have had already considerable experience with the introduction and cost reduction of new computerized devices, such as first, second and third generation lithotriptors or thermotherapy devices (6, 49). Moreover, academic urology should put special emphasis on future development of telerobotics in urologic surgery, mainly because - in contrast to molecular biology – urologists themselves will be actively involved in research as well as in clinical application (49, 50).

Further aspects to use such a systems would be the realization of telementoring as already proposed by Autschbach (51): by coupling two consoles it will be possible for a senior instructor to control a primary surgeon. Both instructor and surgeon will have the same detailed view of the operating field, and the instructor will be able to demonstrate or correct a surgical manipulation from his console. This learning concept which is similar to driver’s training may eventually replace the one-to-one apprenticeship of training that has dominated surgery for the last centuries. In this context the ZEUS-system actually represents the unique system that allows long-distance telesurgery or telementoring by use of the glassfibre-technology based data transmission (Lindbergh-project).

**TRAINING AND TELEMENTORING**

Laparoscopic procedures in Urology are characterized as mostly technical difficult (52). Mainly this concerns radical prostatectomy due to the high number of cases: At our center in Heilbronn we did 175 laparoscopic radical prostatectomies corresponding approximately to the total number of nephrectomies we performed from 1992 to 2000. Undoubtedly, our prognosis from the year 1996 about the role of laparoscopy for complicated pelvic surgery was wrong (53). Laparoscopy may not only minimize the access trauma, but based on an adequate technique and armamentarium due to the magnification of the endoscopic view the dissecting trauma can be also reduced. However, this is only true, if the operating time is reasonable ensuring a minimal associated trauma.

Whereas the standard ESUT-training program (see EAU-guide lines) proved to be sufficient for ablative procedures, such as nephrectomy, it is absolutely insufficient for laparoscopic radical prostatectomy. It has to be emphasized, that Weber et al. have clearly demonstrated that pre-existing laparoscopic experience does not guarantee an uncomplicated introduction of
the procedure (54). On the other hand, laparoscopic radical prostatectomy is not an anecdotal technique. This means, that there is a significant problem of education.

**Laparoscopic training**

The basis for each training program is a good motivation of the trainee with a realistic judgement of his own capabilities. This does not only concern the manual transformation of the laparoscopic techniques, but also includes the formation of an adequate infrastructure (i.e. OR-team, armamentarium, instruments). Quite often, we have seen that laparoscopic surgeons have started with the procedure without taking these factors into consideration (54). It is evident that such an approach has a chance to fail.

In contrast, all components of a standardized step-by-step training program should be utilized, such as:

- Virtual reality simulators
- Standard Pelvi-trainers
- Pelvitainers with pulsatile organ perfusion
- Animal models
- Clinical hospitalization
- Team training
- Clinical fellowship program
- Telementoring

The actual status of *laparoscopic computer simulators* cannot be compared with the high standard of virtual reality trainers in endourology (i.e. Ureteroscopy, Symbionics). The existing devices (Ethicon, Norderstedt, Germany) only simulate basic maneuvers similar to a pelvi-trainer (i.e. grasping, placement of material). There is no anatomical virtual reality like in the endourology simulators. However, in cooperation with InterActive Systems (Marburg, Germany) we have recently started with the construction of a realistic laparoscopy simulator (Fig. 11). Recently, another German Company has introduced a complete hands-on simulator system (Lap-sim One; Select IT Vest Systems; Bremen, Germany). This is based on a project of the Nuclear Research Center in Karlsruhe (KISMET). Until now, VR-simulations for laparoscopic cholecystectomy and hysterectomy have been created (Fig. 11).

On the other hand, the *standard of pelvi-trainers* could be significantly improved during the last years (55, 56). The simple and sometimes boring exercises of coordination (i.e. grasping peanuts, clipping rubber strings) have been replaced by a specific training at different models. The anatomical basis (including coordination exercises) can best offered by using animal cadavers placed in the pelvi-trainer. This represents an optimal preparation for the work on the animal model which usually is performed on the following day (i.e. ESUT-training course, European Surgical Institute, Norderstedt, Germany). A more elaborated way to train dissection techniques is the use of pulsatile perfused pelvitrainers (57). Such a model allows the simulation of vascular complications and their management. Moreover, complex maneuvers, such as partial nephrectomy or wedge resection, can be trained including clamping of the renal hilum and the application of fibrin-coated collagen vlies (Tachocomb, Nycomed). The principals of endoscopic suturing and knotting techniques are demonstrated at the chicken leg and than transferred to the model of a urethro-vesical anastomosis.

In the animal model, too, the training possibilities have significantly increased during the last years. Whereas in the early days, we were happy, if the trainees were able to perform a varicocelectomy, iliac lymph node dissection, and a nephrectomy during one day, nowadays the majority of participating groups perform additionally a pelvic lymph node dissection, radical prostatectomy, and start with the urethro-vesical
anastomosis. For advanced courses we are able to offer cystectomy, ileal conduit, antireflux plasty, pyleoplasty and the management of vascular complications.

The significant increase of the caseload in the centres of expertise has also improved the quality of clinical hospitation and team courses. For example, at our department we perform two to three laparoscopic procedures daily guaranteeing optimal demonstration of the surgical technique as well as sufficient active participation. However, it has to be emphasised that for successful introduction of laparoscopic radical prostatectomy a long-term clinical fellowship (i.e. 3 – 6 months) is mandatory. The striking argument is that every minute the trainee stays at the centre will be paid back by the amount of time that he does not need to stay in his own theatre thereafter.

Telementoring

It is evident, that actually in Europe there is an enormous demand for laparoscopic training. It is also clear that not every urologist needs to learn or to be taught in laparoscopic surgery. The number of adequate training sites is limited throughout Europe and the United States, however, the number of departments starting with this procedure is steadily increasing. Subsequently, this may result in a kind of snowball-effect creating new training centres. But this can be only realized based on a stringent training program (i.e. coordinated by the ESUT).

Nevertheless, we know from our own experience, that there will be always a situation, when the advice of the tutor – ideally his presence – is desirable. A solution for this problem could be the principle of telementoring (40, 58, 59). For this purpose Compter Motion developed the telecorrespondence system SOKRATES enabling a complex data transmission. In contrast to the Da Vinci-system with data transmission via a maximally 8m long cable, AESOP and ZEUS realised the principle of a real telepresence surgery based on the high speed data transmission via glass fibres (Fig. 13). First experiences focussing only on the movement of the camera via satellite transmission have been initiated by Kavoussi's group (36, 37, 40).

![Fig. 12: Laparoscopic simulator (Lapsim one) for VR-training](image1)

a) The device with two instruments, monitor, and camera. Instruments can be varied (i.e. grasper, scissors, electro-hook, clip-applicator)

b) VR-endoscopic view of the clipping of the bile duct.
A most spectacular event represented the "Lindbergh project" when performing the first telesurgical laparoscopic cholecystectomy with surgeon being in New York and the patient in Strassbourg. The transmission delay was in the range of 150 milliseconds over a distance of more than 15 000 km using a very expensive glass fibre. Until now the same quality (i.e. time-delay) cannot be realized by other types of data transmission (i.e. ISDN-lines = 1 sec. delay), however, this might be achievable in the future via satellites.

The Lindbergh project definitively created the basis for further studies on active telementoring by the tutor far beyond the movement of the camera (AESOP; 36, 37, 40). However, the future will show, how often such active participation will be really necessary. We feel that just an "eye of the experienced surgeon" might be enough in the majority of cases.

On the other hand, it is evident, that the data transmission of the daVinci-system actually cannot be accomplished. Therefore, only a local training setting can be realized, i.e. by combining two consoles (tutor and trainee): The tutor has the possibility to directly control the trained doctor similar to the driver's teaching system in the car (51).

In summary, there is no doubt, that such concepts will have a significant input on the future surgical training replacing the former "see one-do one-teach-one-principle". This concerns not only the rather futuristic ideas about telementoring and telepresence surgery, but primarily the surgical training by use of VR-simulators, organ models and pelvitrainers. The final goal should be, that every surgeon has to fulfil a catalogue of procedures at the different training units before treating the patient. Such a concept will also include telementoring, when starting with the procedure at home.

PERSPECTIVES

The use of robots in operative medicine indeed is on of the most spectacular topics of surgical research. It will definitively change our approach. However, it remains still unclear to what amount robotic systems (i.e. Da Vinci, ZEUS) will become a routine part of our surgical armamentarium. Such systems have to overcome their specific technical drawbacks and as well to demonstrate significant improvements.
compared to the standard laparoscopic/surgical approach justifying the high investment costs.

It is interesting that several groups have started to develop cost-effective mechanical manipulatorsystems moved on-site by the surgeon (i.e. 6DOF-needle-holder; 60). Such devices might be able to overcome some specific drawbacks of the standard instruments without the need of high investment and running costs. Computer-assisted systems may be still required for special functions, i.e. voice-controlled camera-arm or instruments with tactile feedback.

REFERENCES AND RECOMMENDED READING (*of special interest, **of outstanding interest)


