Training systems for endoscopic soft-tissue surgery

Review report – GR/L80577/01

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Abbreviations

A/D:	Analogue to Digital
CASMS:	Computer-Assisted Surgical Monitoring System
CASTS:	Computer-Assisted Surgical Training System
GUI:	Graphical User Interface
IRED:	Infra-Red Emitter Diode
MIMLab:	Mechatronics in Medicine Laboratory, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine
NURBS:	Non-Uniform Rational B-Splines
OR:	Operating Room
PC:	Personal Computer
TURP:	TransUrethral Resection of the Prostate
VR:	Virtual Reality

1. *Project objectives*

The original objectives, as presented in the grant proposal, are:

a) To identify generic criteria for *in vitro* and *in vivo* computer-based endoscopic surgery training aids.
b) To provide a camera-based tracking system with fixed model prostate phantom as a computer-based *in vitro* prostatectomy training aid.
c) To provide a tracking system and ultrasound measurement facility as a computer-based *in vivo* prostatectomy training aid.

2. *Background/ context*

TURP has been described as the most difficult operation to learn and to teach. Training is passive initially as the trainee observes the trainer perform the operation. After a certain period of observation, the trainee is allowed to perform the operation under close supervision, without any transition between observation and practice. The trainers themselves may be sometimes unaware of some of the difficulties the trainee can encounter.

There are a few courses available to the trainee where more theoretical knowledge can be gained. These courses also utilise practical skills stations where the trainee performs a TURP under supervision on a resectable prostate model.

In addition, the Calman training scheme for higher surgical training, introduced in the United Kingdom since 1993, has reduced the training period significantly. The possibility of a European directive, which may further reduce training hours, is becoming realistic and may compound this factor. All these facts highlight the need for a simple, realistic teaching aid for this operation that will provide active feedback.

3. *Methodological approach and achievements against objectives*

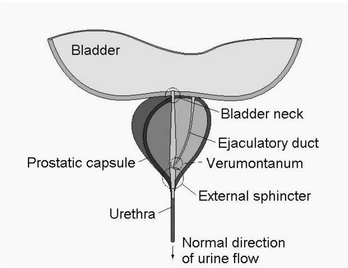
Objective 1 was addressed in lengthy discussions between the researchers at Imperial College and the clinical collaborators. Different scenarios were presented in the meetings, drawing on existing research on surgical training, surgical simulation and computer-assisted surgical systems, on observations of surgical procedures, as well as on previous research work at MIMLab.

Objective 2 was realised in the development of CASTS, by instrumenting surgical tools for optical tracking and providing global positional information of the tools in relation to a prostate phantom inserted in a mock-up abdomen. CASTS was fully tried by the surgical collaborators and the findings were used as an input to CASMS.

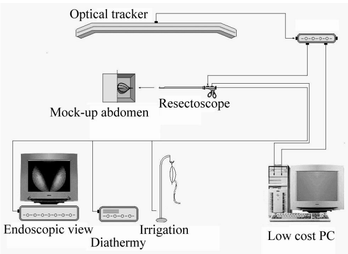
Objective 3 was attained by designing a second generation of tools, fully sterilisable, and by developing a method for building the patient's prostate model from transrectal ultrasound scans. Ethics Committee approval was obtained for the operating room trials. Components of CASMS were successfully tested in the OR and the test of the integrated system is underway (see section 6 for justification).

4. *Project's summary*

The prostate gland is a male organ and surrounds the urethra at the bladder outlet (below, left). With age, a benign enlargement of the tissue can develop, leading to obstruction of the bladder outlet and urine retention. Transurethral Resection of the Prostate (TURP) aims to alleviate the urinary constriction by debulking the enlarged tissue from within the urethra.

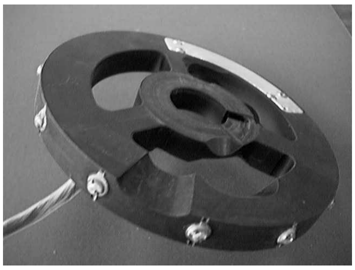


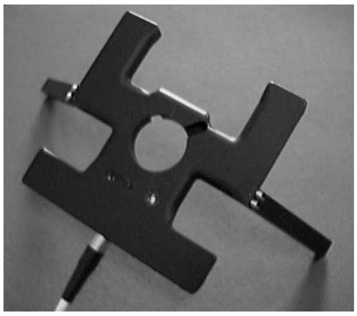
The urologist carries out a TURP using a resectoscope inserted through the shaft of the penis, under endoscopic guidance (right).



In CASTS (left), the trainee resects a prostate phantom, inserted in a mock-up abdomen, using standard real surgical tools, instrumented for optical tracking (right). A GUI displays a model of the phantom, the position of the resectoscope and the tissue resected.

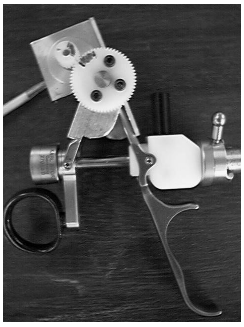
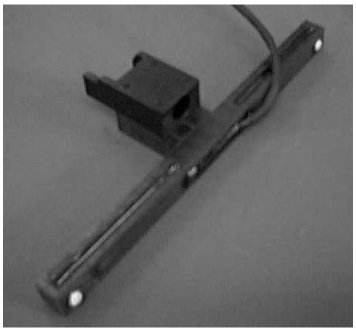
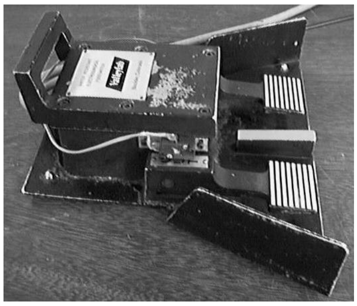
Three aspects of the surgical tools were instrumented. The first relates to the resectoscope's position and orientation. Three generations of IRED tools for optical tracking were developed. The first prototype (below, left) is a 100mm-diameter aluminium ring, with 8 metallic IREDs along its perimeter, at equally spaced intervals. The second (below, centre) is made of a lighter material and has 12 metallic IREDs for improved visibility. The third (below, right) has 14 ceramic IREDs in a non-coplanar arrangement for improved accuracy, and it can be sterilised. It has been especially designed for CASMS (OR).



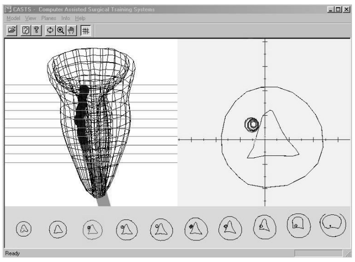
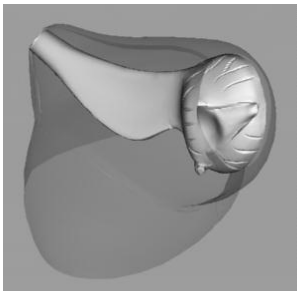


The position of the cutting loop in relation to the resectoscope's sheath is also known. For CASTS, a potentiometer arrangement was attached to the resectoscope (below, left). For CASMS, an alternative sterilisable IRED probe was designed (below, centre).

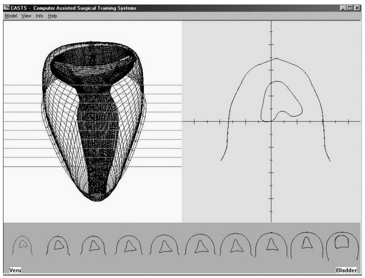
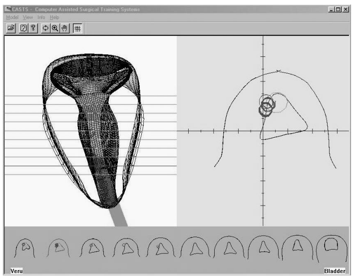
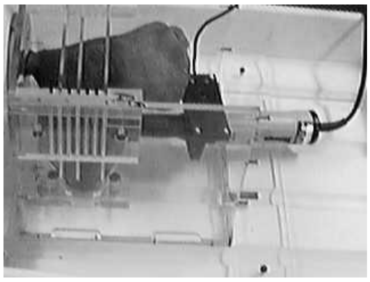
Finally, the system needs to know when the surgeon is cutting or coagulating. Two switches have been connected to the diathermy pedals and to an A/D board in the PC (below, right). The pedal is placed in a sealed plastic bag in the OR.

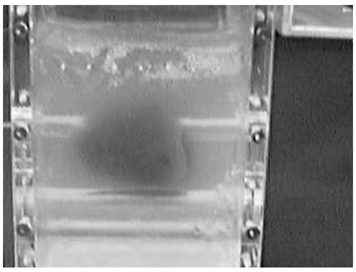
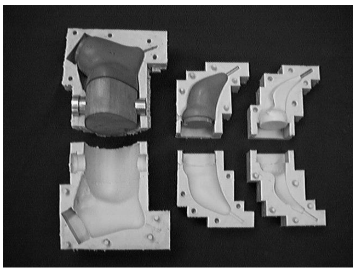
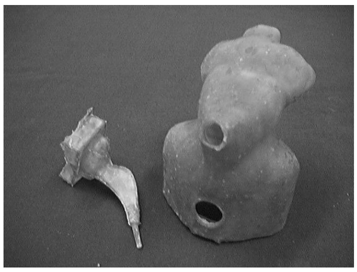
The GUI (below, left) has been kept simple and the different views (3D, 2D, thumbnails) can be turned on/ off as required by the surgeon. The graphical computer model (below, centre) was obtained by measuring hard casts of the Limbs & Things phantom used for conventional urological surgery training (below, right), and using software to build NURBS surfaces from the measured points.


It was found that the Limbs & Things phantom moved and deformed whilst being resected, due to forces exerted by the resectoscope, release of internal forces and to absorption of irrigant. This was taken into account by: a) pre-calculating deformations and selecting appropriate control points for the NURBS surfaces (below, left and centre), b) partially constraining the motion with a set of Perspex profiles (below, right), and c) using ultrasound for tracking motion, with an optically tracked ultrasound probe (below, right).

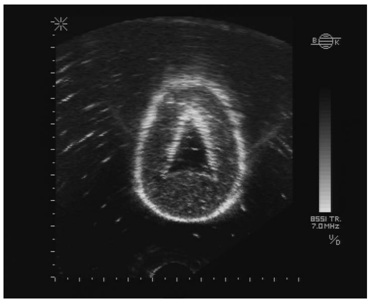




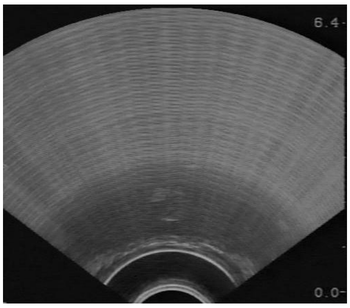
Since the Limbs & Things phantom is opaque to ultrasound, alternative phantoms, made of gelatine and an ultrasound scatterer, were developed. The first prototype (below, left) was based on a resection shape from anatomical diagrams. The second prototype (formers and moulds below, centre and right), based on the Limbs & Things phantom, includes anatomical features, thus allowing a laboratory-based assessment of the *in vivo* system, more closely mimicking the actual operation.

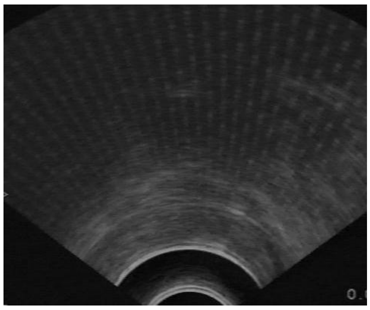




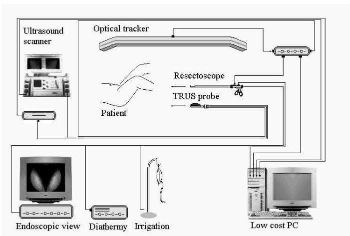
The gelatine phantoms were used to form ultrasound images with clearly visible capsule and urethra (right). Automatic segmentation of this quality image is feasible.

Transrectal ultrasound images of a patient's prostate are much more difficult to analyse automatically, as they depict artefacts due to the shadow created by the resectoscope (below, left), and by the diathermy current when cutting (below, centre) and coagulating (below, right).

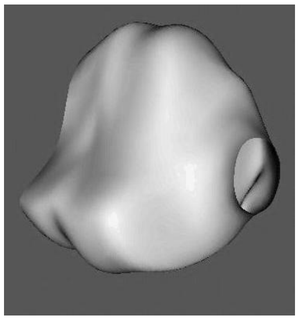






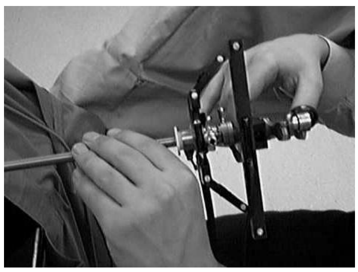


In CASMS (left), the surgeon acquires a set of 2D pre-operative transrectal ultrasound scans of the patient's prostate, using an optically tracked ultrasound probe. The scans are then manually segmented by the urologist who delineates the areas to be resected. A 3D model is automatically built and rendered in a computer display (right).



During the TURP, the display shows the current status of the resection by superimposing a rendering of the resectoscope onto the patient's prostate model. The resected cavity is also rendered. Per-operative ultrasound, with a tracked and motorised probe, is used to detect and compensate for the movement of the prostate.

Following Ethics Committee approval, mock-up of the tools were tried in the OR during TURP (below, left). The optical tracker was suspended from the ceiling of the OR, on a counterbalanced arm (below, top right). Tests of visibility of the IRED tools in the OR were successful (below, bottom right).



5. *Main findings/ key advances*

Integration of training in the OR Although there are many systems available for training surgeons in the skills of minimal access surgery, there is still a large gap between such systems and the real surgical procedure. The dual system CASTS/CASMS reduces this gap by providing assistance during both *in vitro* training, and the *in vivo* procedure.

Realism There are several approaches to computer-assisted training systems involving one or a combination of computer graphics and VR, haptic feedback, and finite element modelling. However, even the most advanced haptic systems are seen by some as not giving the same feel as cutting through real human tissue. The use of physical phantoms in CASTS is more realistic and provides a natural progression from traditional training.

Measurable performance CASTS/ CASMS provide objective data to enable the measurement of performance and improvement, such as the amount of tissue resected, perforation or damage to high-risk areas, and the time taken to complete the procedure.

Role of CASTS The system can be used as an extra cue for endoscopic navigation, as a "black box" for logging the session, or as the basis of a VR system.

Role of CASMS The system can be used as an extra cue for endoscopic navigation, as a "black box" for logging the surgical procedure, or as a pre-operative planner.

Streamlined information Whilst operating conventionally, the surgeon views the endoscopic camera display, and uses both hands to operate the resectoscope and ancillary equipment, as well as one foot to activate the diathermy unit. In CASTS/ CASMS, extra intervention or information has therefore been kept simple and to a minimum to avoid changing the procedure.

Changes to procedure As far as possible, the trainer/ monitor does not change the TURP procedure. Real surgical equipment is used. The weight of the instrumentation used to track the resectoscope was kept to a minimum.

Prostate phantoms The hygroscopic behaviour from the Limbs & Things prostate phantom causes great difficulty in the modelling of the procedure. Alternative phantoms were developed which have overcome this problem.

Deformation and movement The prostate phantom (and the prostate) moves and deforms in unexpected modes. This was tackled by introducing partial constraints and precalculated deformations (in CASTS), and by using per-operative ultrasound (in CASMS).

Pre-operative and per-operative ultrasound A transducer, small and powerful enough to fit around the resectoscope's sheath, would avoid the need for transrectal ultrasound and simplify the procedure.

Accuracy and timeliness The information provided has to be accurate and up-to-date. Simple strategies for this were adopted: models that can be rendered quickly, precalculated deformations, partial constraining of motion, multi-threaded code.

Tool tracking A novel IRED probe for tracking the position and orientation of a resectoscope (EndoTracker) has been developed in collaboration with Traxtal Technologies Ltd, Canada. Its average error is less than 0.2mm and the probe is visible over 90% of the time, in spite of ±180° axial rotations.

6. *Project plan review*

The original research proposal stated that "The target [the prostate] would be assumed not to move significantly intra-operatively so that pre-operative 3D models can be used". This was found to be only valid in the previous research context, where all data was in the same coordinate system. The need for tracking motion and deformation of the prostate (and the prostate phantoms) in external (world) coordinates was successfully tackled and accommodated within the project plan.

Two unforeseen factors slowed down the progress of the OR trials. Our main surgical collaborator needed back surgery which forced him to be away from the operating table for several months, impeding the trial of the integrated CASMS, scheduled for January-February 2001. Also, the development of EndoTracker, in collaboration with Traxtal Technologies Ltd, was severely delayed due to a shortage of ceramic IREDs.

7. *Research impact and benefits to society*

Patients, Surgeons, Health Providers, and the NHS benefit from improved training and performance.

Surgeon Training Establishments benefit from improved training, assessment and computer-based certification.

Medical Instrumentation Industry benefits from improved trainers and trackable surgical tools.

The Research Community benefits from computer-assisted training, generic tracking of tools, construction and tracking of ultrasound phantoms, modelling and segmentation of ultrasound images.

8. *Dissemination*

11 papers (all refereed, 3 journal publications) were written and presented to scientific and medical international audiences. A poster was presented at EPSRC's Theme Day in Machine Vision and Image

Processing, on 7th June 2000. Summaries of the papers and other information on the project are available on the web (http://www.me.ic.ac.uk/case/mim/). Links to and from our main surgical collaborators at the Bristol Urological Institute have been established (http://www.bui.ac.uk). Project posters are also displayed in the Mechatronics in Medicine Laboratory of Imperial College and are used to present the project to visitors. A4 copies of the posters have been sent to all collaborators. All collaborators were sent progress reports throughout the project.

9. *Further research*

Industrial collaboration to develop commercial products is under investigation.

The test of the integrated CASMS will be finished when the surgeon is fully recovered.

Results on phantoms and models, soft tissue modelling, and motion tracking with ultrasound have direct relevance to the project at Imperial College on Robotic Systems for a Range of Urological Disorders (EPSRC grant GR/M53394/01), and also to the project on Innovative Haptics for Risk Mediation in VR Arthroscopic Training, jointly with Sheffield and Warwick Universities (EPSRC grant GR/N25459).

A PhD project, carried out by Mr. A.R.W. Barrett, entitled An Investigation into Monitoring Minimally Invasive Surgery has been underway since September 1998.

Know-how in optical tracking is of general importance in the activities of MIMLab, and it has a special synergy with the Acrobot project for Robotic Knee Surgery.

10. *List of publications*

M. P. S. F. Gomes, A. R. W. Barrett, and B. L. Davies, “Computer-assisted soft-tissue surgery training and monitoring”, MICCAI 2001, Utrecht, The Netherlands, Springer, 2001. *Submitted*

M. P. S. F. Gomes, P. V. S. Kumar, A. G. Timoney, and B. L. Davies, “Tool tracking for endoscopic surgery”, *Measurement+Control*, 2001. *To appear.*

P. V. S. Kumar, M. P. S. F. Gomes, B. L. Davies, and A. G. Timoney, “A computer-assisted surgical trainer for transurethral resection of the prostate”, *Journal of Urology*, 2001. *Submitted*

M. P. S. F. Gomes and B. L. Davies, “Computer-assisted surgical training for TURP”, First IFAC Conference on Mechatronic Systems, Darmstadt, Germany, VDI/ VDE - GMA, vol.2, pp. 531-535, 2000.

M. P. S. F. Gomes and B. L. Davies, “Computer-assisted TURP training and monitoring”, MICCAI 2000, Pittsburgh, Pennsylvania, USA, Springer, pp. 669-677, 2000.

P. V. S. Kumar, M. P. S. F. Gomes, B. L. Davies, and A. G. Timoney, “Computer-assisted surgical training system for transurethral resection of the prostate”, American Urology Association 95th Annual Meeting, Atlanta, USA, J. Urol, vol.163:4 Suppl 1476A, pp. 333, 2000.

P. V. S. Kumar, M. P. S. F. Gomes, B. L. Davies, and A. G. Timoney, “Computer-assisted surgical training system for TURP”, British Association of Urological Surgeons (BAUS) Annual Meeting, Birmingham, BJU Intl, vol.85: Suppl 5 63A, pp. 27, 2000.

B. Davies, M. P. S. F. Gomes, A. G. Timoney, and P. V. S. Kumar, “A computer-assisted surgical trainer for transurethral resection of the prostate (TURP)”, International Workshop on Mechatronic Tools for Surgery (MTS), Rome, pp. 24, 1999.

M. P. S. F. Gomes, A. R. W. Barrett, A. G. Timoney, and B. L. Davies, “A computer-assisted training/ monitoring system for TURP - Structure and design”, *IEEE Transactions on Information Technology in Biomedicine*, vol. 3:4, pp. 242-251, 1999.

M. P. S. F. Gomes, P. V. S. Kumar, A. G. Timoney, and B. L. Davies, “A computer-assisted surgical trainer for TURP - Instrumenting the tools”, Second EUREL (European Advanced Robotic Systems Development) Workshop, Pisa, Italy, pp. 124-126, 1999.

P. V. S. Kumar, M. P. S. F. Gomes, B. L. Davies, and A. G. Timoney, “Transurethral resection of the prostate - A computer-assisted training system”, 17th World Congress on Endourology, Rhodes, J. Endourol, vol.13: Suppl 1 BRS5-12, pp. 19A, 1999.