SMARTsurg

SMart we**A**rable **R**obotic **T**eleoperated **surg**ery

D2.1: End user requirements, use cases and application scenarios

Due date: M7

Abstract: The present document is a deliverable of the SMARTsurg project (732515), funded by the European Commission's Directorate-General for Research and Innovation (DG RTD), under its Horizon 2020 Research and innovation programme (H2020). The document consists of information on the use cases workflows (Orthopaedics – 2, Urology-3, and Cardiac surgery – 2). Based on surgeon's interviews, we further specified user requirements analysis and elicitation methodology. The results are presented based on the mandatory user requirements and mapping with the System Blocks components. Based on the elicited user requirements, possible application scenarios are elicited and specified for a paradigmatic use case of each specialty.

Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
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Prepared by	POLIMI
Contributors	IEO, UWE, TheMIS, UoB, NBT, cybernetix
Checked by	Elena De Momi, Giancarlo Ferrigno, Ioannis Mariolis, Sanja Dogramadzi
Approved by	Giancarlo Ferrigno
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Contact Points

Coordinator		
University of the West of England, UWE Bristol	University of the West of England/ Bristol Robotics Laboratory T Building, Frenchay Campus BS16 1QY Bristol, UK	Tel: +44 117 32 81301 E-mail: Sanja.Dogramadzi@brl.ac.uk Website:www.brl.ac.uk/research/researchthemes/medicalrobotics.aspx

Partners		
iti Information Technologies Institute	Centre for Research and Technology Hellas / Information Technologies Institute Building A - Office 1.1A 6th km Charilaou - Thermi, 57001 Thessaloniki, Greece	Tel.: +30 2311 257777 Fax: +30 2310 474128 E-mail: tzovaras@iti.gr Website: www.iti.gr
POLITECNICO MILANO 1863	Politecnico di Milano Department of Electronics, Information and Bioengineering Building 32.2 Via G.Ponzio 34/5 Milan, Italy	Tel.: +39 022 399 3371 E-mail: giancarlo.ferrigno@polimi.it Website: www.nearlab.polimi.it
Bristol Urological Institute	North Bristol National Health Service Trust/ Bristol Urological Institute Brunel Building, Southmead Hospital BS10 5NB Bristol, UK	Tel.: +44 117 4140898 E-mail: anthony.koupparis@nbt.nhs.uk Website: www.nbt.nhs.uk/bristol-urological-institute
University of BRISTOL	University of Bristol Translational Biomedical Research Centre Senate House, Tyndall Avenue BS8 1TH Bristol, UK	Tel.: +44 117 3423286 E-mail: r.ascione@bristol.ac.uk Website:www.bristol.ac.uk/health-sciences/research/tbrc
IEO Istituto Europeo di Oncologia	European Institute of Oncology Division of Urology Via Ripamonti, 435 20141 Milan, Italy	Tel.: +39 0257489516 E-mail: ottavio.decobelli@ieo.it Website: www.ieo.it
TheMIS Thessaloniki Minimally Invasive Surgery Orthopaedic Center	TheMIS Orthopaedic Center 6 Adrianoupoleos St. 55133 Thessaloniki, Greece	Tel.: +30 2310 223 113 E-mail: papacostas@the-mis.gr Website: www.the-mis.gr

	Cybernetix 306 Rue Albert Einstein 13882 Marseille, France	Tel.: +33 491 210 484 E-mail: jvandenbosch@cybernetix.fr Website: www.cybernetix.fr
	Optinvent R&D Department Avenue des Buttes de Coesmes 80 35700 Rennes, France	Tel.: +33 299871066 E-mail: khaled.sarayeddine@optinvent.com Website: www.optinvent.com
	HIT Hypertech Innovations 10 Polytechneiou Str. 3083, Límassol, Cyprus	E-mail: contact@hit-innovations.com Website: www.hit-innovations.com

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1. Introduction

1.1 Objective and Scope

The purpose of this deliverable (D 2.1 – “End user requirements, use cases and application scenarios”) is to provide a comprehensive and motivated list of the end user requirements for a new surgical system with the capabilities of SMARTsurg on Robot-assisted MIS surgery. The requirements were elicited by the interviews on the use cases, agreed upon at the KOM, of Urology, Cardiology and Orthopaedics procedures as explained in section 2.1. The use cases are tailored to provide ground for the scientific and technical developments on the framework requirements of a new surgical system as envisaged by the consortium.

Particularly this document outlines:

- Surgical use cases.
- User requirements analysis methodology.
- User requirements analysis and elicitation.
- Mapping of end user requirements with system blocks components.
- Application scenarios.

1.2 Document Structure

The document consists of use cases workflow diagrams (Section 2), where we outlined the workflow steps of each surgical use case briefly. In Section 3, we specified the user requirements analysis, elicitation methodology, its results and mapping to System Blocks components. Examples on possible application scenarios are explained in Section 4. Appendices summarize detailed descriptions of the use cases, interview documents, audio recordings and transcriptions of interviews, information on System Blocks components, images of graspers and ethical committee approval document.

1.3 Definitions

Ontological class definitions for the video annotations [1]

1. Phase
   Phases are considered as major objectives of the procedure as per standard surgical procedure workflow. The aim of each phase is to reach/target the main surgical site. Each phase includes a major change in the anatomical locations and/or surgical act. Traditionally considered as a “Step” in the surgical community. For example, “tumor exposure” is a phase of a partial nephrectomy procedure, where the surgeon first identifies the site for tumor by cutting Gerota’s fascia, after which surgeon makes the markings on the kidney capsule to expose the tumor area for resection.

2. Step
   Steps are considered as tasks required to accomplish phases of a surgical procedure. Traditionally considered as “Sub-steps” in the surgical community. Each step consists

of a specific action, anatomical location, and instrument. For example, during "tumor exposure" phase, the surgeon makes the "marking" (step) of the "kidney capsule" (anatomical location) by "marking" (action) through the "fenestrated bipolar" (instrument). Sometimes the steps correspond to the same linguistic meaning, where the phases consist of only one step. For example, "Bowel mobilization" phase has only one step - "mobilization".

3. Instrument
   Instrument is annotated based on its usage during a step of the surgery and its appearance in surgical videos. We consider robotic instruments, Left and Right robot arm, for annotating the videos with a few exceptions like "laparoscopic Bulldog", which comprises a lot of frames of the recorded videos. Instruments handled by the assistant surgeons are also annotated.

4. Anatomical Location
   Anatomical location is annotated based on a surgical step and its appearance in the videos.

5. Actions
   Actions are annotated based on a surgical step and actions carried out by specific instruments. For example, "cortical suturing" is a step performed by the "large Needle Driver" to "suture" (action) the "kidney" (anatomical location) during the kidney repair, renorrhaphy, at the end of the procedure.

1.4 Acronyms and Abbreviations

Abbreviation	Definition
2D	Two-dimensional
3D	Three-dimensional
AAA	Abdominal Aortic Aneurysm
ACL	Anterior Cruciate Ligament
BP	Blood Pressure
CABG	Coronary Artery Bypass Grafting
CMRI	Cardiovascular Magnetic Resonance Imaging
CT	Computed Tomography
CV terminals	Cardiovascular terminals
CVD	Cardiovascular Disease
CVP	Central Venous Pressure
CV-UC	Cardiovascular Use Case
CXR	Chest X-Ray
DRE	Digital Rectal Examination
DVC	Dorsal Vein Complex
EAU	European Association of Urology
ECG	Electrocardiogram
LA	Left Atrium
LCA	Left Coronary Artery
LIMA	Left Internal Mammary Artery
LIMA-LAD	Left Internal Mammary Artery/Left Anterior Descending artery
MIS	Minimally Invasive Surgery
MRI	Magnetic Resonance Imaging

mTOR inhibitors	(mechanistic Target Of Rapamycin) Tyrosine kinase inhibitors
MV surgery	Mitral Valve surgery
OPCAB	Conventional CABG surgery without CPB on the beating heart
OUC	Orthopaedic Use Case
PCa	Prostate Cancer
PSA	Prostate Specific Antigen
RA-CABG/PABG	Robot-Assisted Coronary/Vascular surgery
RaLMR	Robot-Assisted Repair of Lateral Meniscus tear
RAMIS	Robot-Assisted Minimally Invasive Surgery
RA-MVR	Robot-Assisted Mitral Valve Repair/Replacement
RaPLM	Robot-Assisted Partial Lateral Meniscectomy
RAPN	Robot-Assisted Partial Nephrectomy
RARC	Robot-Assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder
RARP	Robot-Assisted Radical Prostatectomy
RCA	Right Coronary Artery
SVG	Saphenous Vein Graft
TECABG	Totally Endoscopic CABG
TTE/TOE	Transthoracic and/or Trans-oesophageal Echocardiograms
UUC	Urology Use Case

2. Surgical use cases

As we adopted the user-centred approach for development of SMARTsurg system, we obtained focused end-users requirements on several surgical use cases in different specialities i.e. Orthopaedics, Urology and Cardiology. The surgical use cases are assumed to take advantage of the tele-operated system, or at least the subsystems, during the deployment phase.

The identified use cases (generally agreed at KOM) are as follows:

1. Orthopaedic surgery:
    a. Robot-assisted Partial Lateral Meniscectomy (RaPLM)
    b. Robot-assisted Repair of Lateral Meniscus tear (RaLMR)
2. Urological surgery:
    a. Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
    b. Robot-assisted radical prostatectomy (RARP)
    c. Robot-assisted partial nephrectomy (RAPN)
3. Cardiac surgery:
    a. Operating/suturing a valve leaflet (OVL)
    b. Suturing a small artery (SSA)

This section represents the surgical workflow of these surgical use cases in a graphical format.

The workflows have been specified using three components of the surgical activity:

(1) Phases and their precedence are specified in the top row of the graph with 'start' and 'end' markings.

(2) The middle row shows a sequence of surgical steps for each phase.

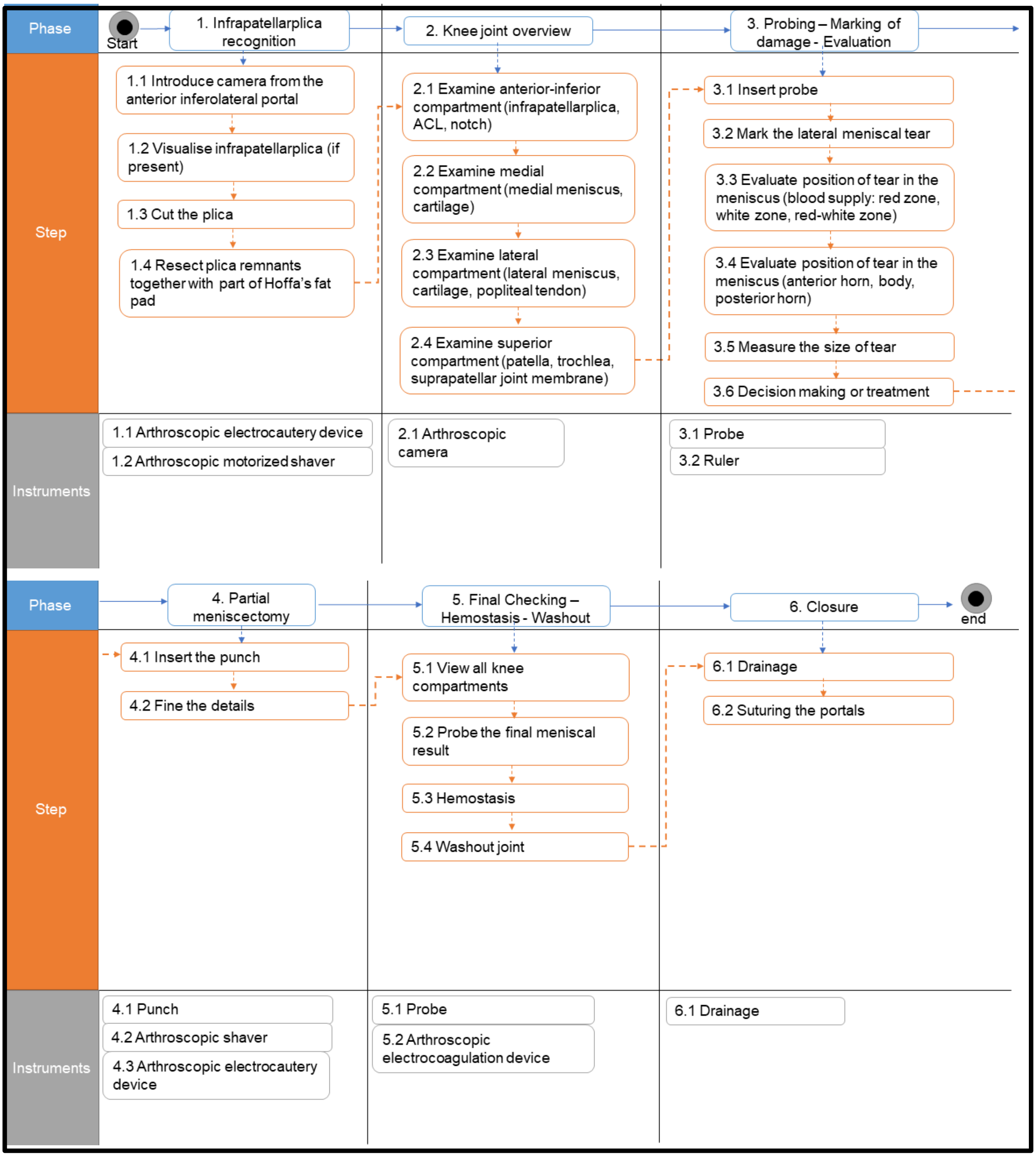
(3) The last row specifies the instruments used in the individual phases of each workflow.

The workflow represents the surgical workflow entities e.g. "Phase", "Steps" and "Instruments", as specified in section 1.3, which could be annotated on the recorded surgical videos of each use case. "Actions" and "Anatomical Location" could also be annotated. The annotations refer to the activities observed in the videos. Examples of such activities are the surgical workflow model entities, specified for a specific period, e.g. from t_1 (start time) to t_2 (end time) as the annotations in the videos [1].

A detailed description of each surgical workflow can be found in APPENDIX A.

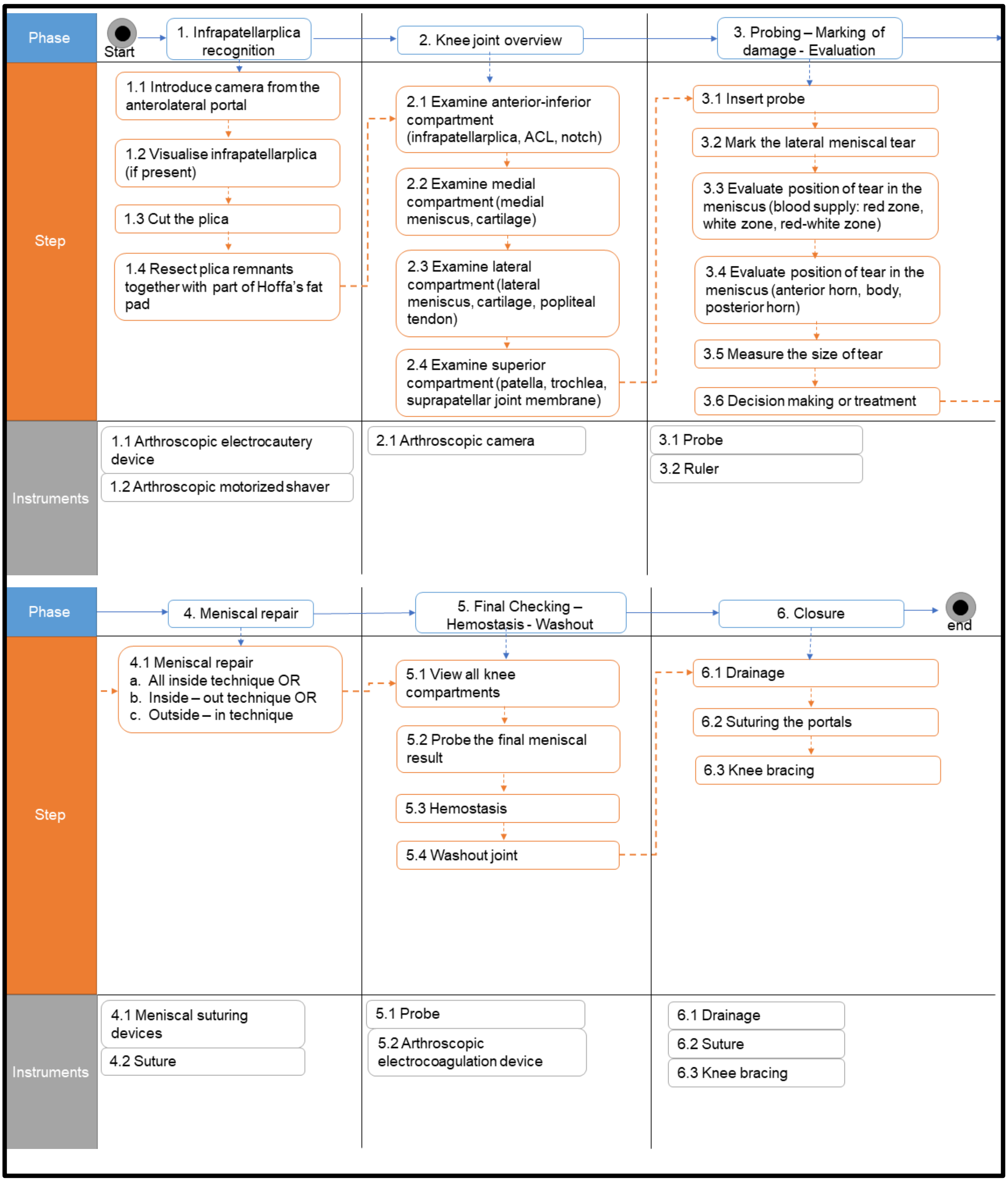
2.1 Orthopaedic use cases

1. Robot-assisted Partial Lateral Meniscectomy (RaPLM)*



* This surgery is not currently robot-assisted so the name refers to the goal of the project demonstrator

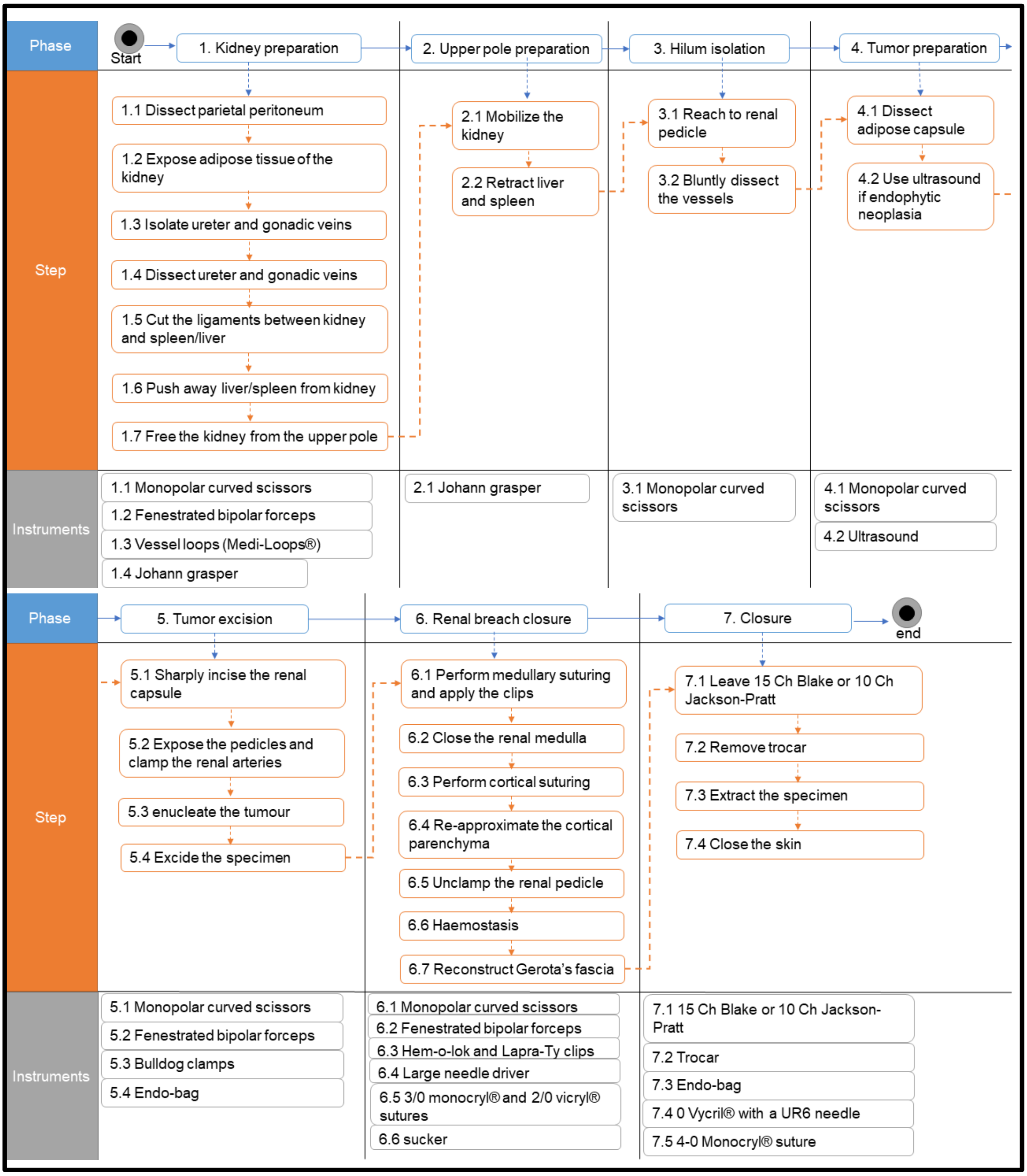
2. Robot-assisted Repair of Lateral Meniscus Tear (RaLMR)*



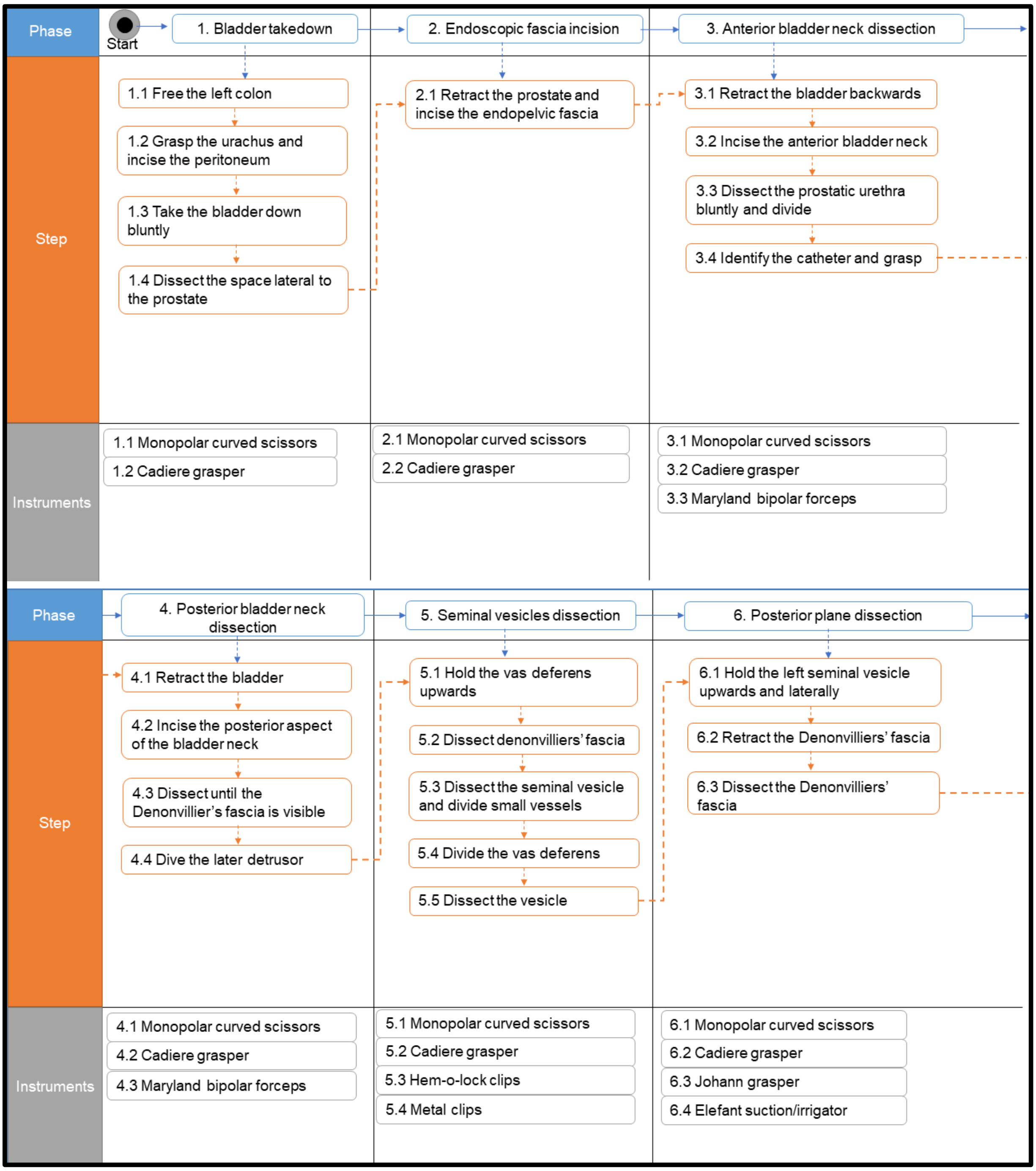
* This surgery is not currently robot-assisted so the name refers to the goal of the project demonstrator

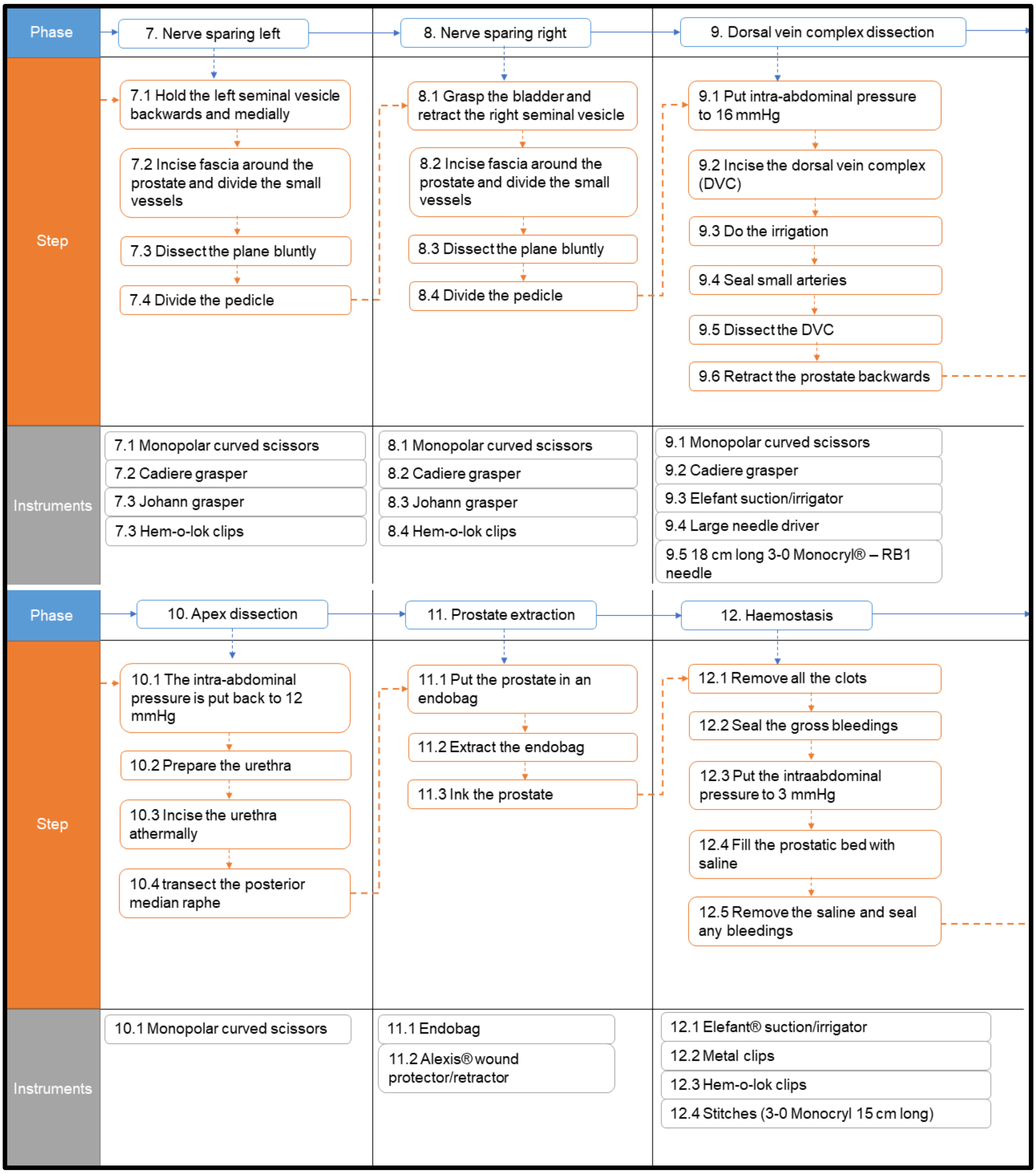
2.2 Urology use cases

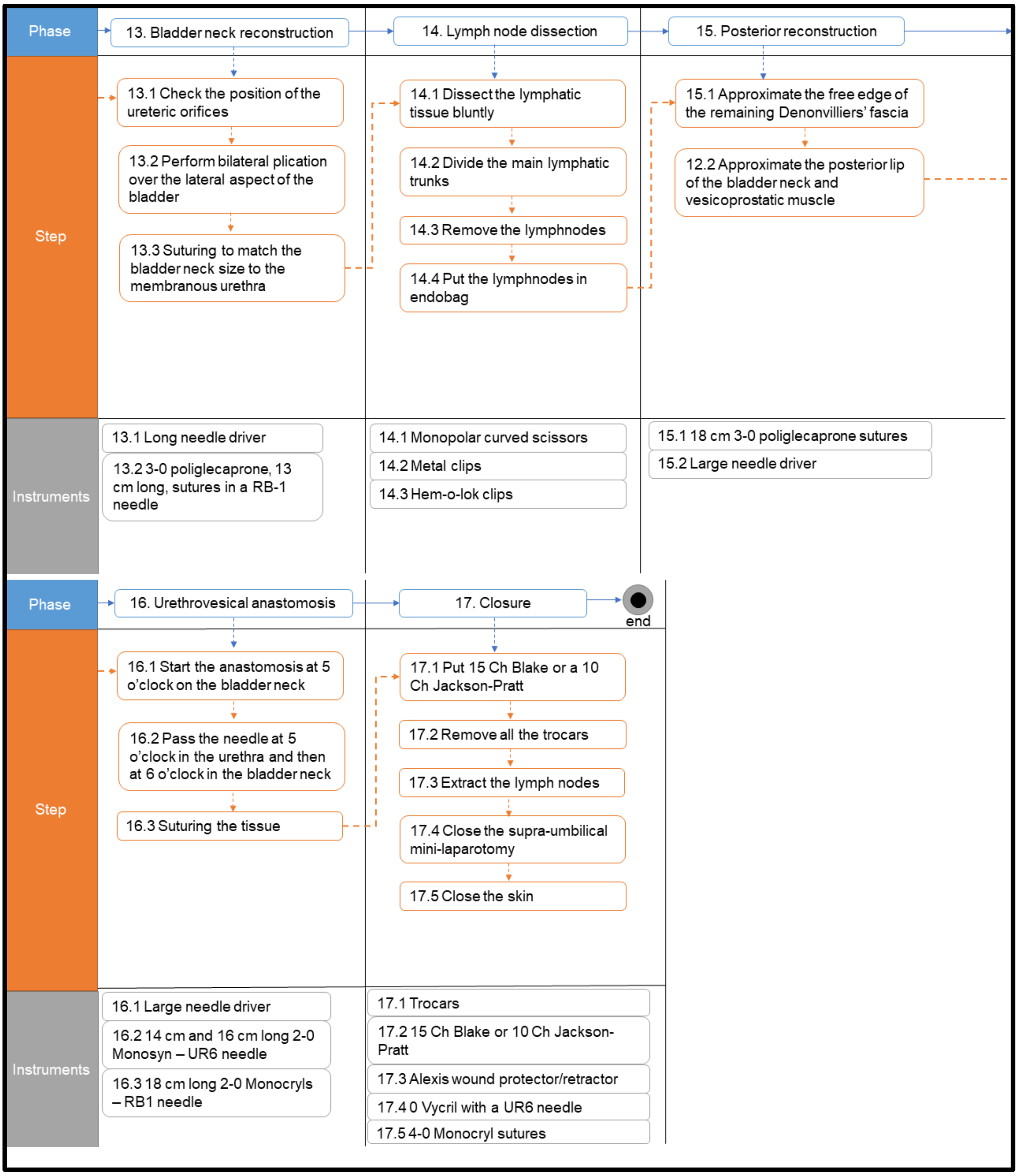
1. Robot-assisted partial nephrectomy (RAPN)



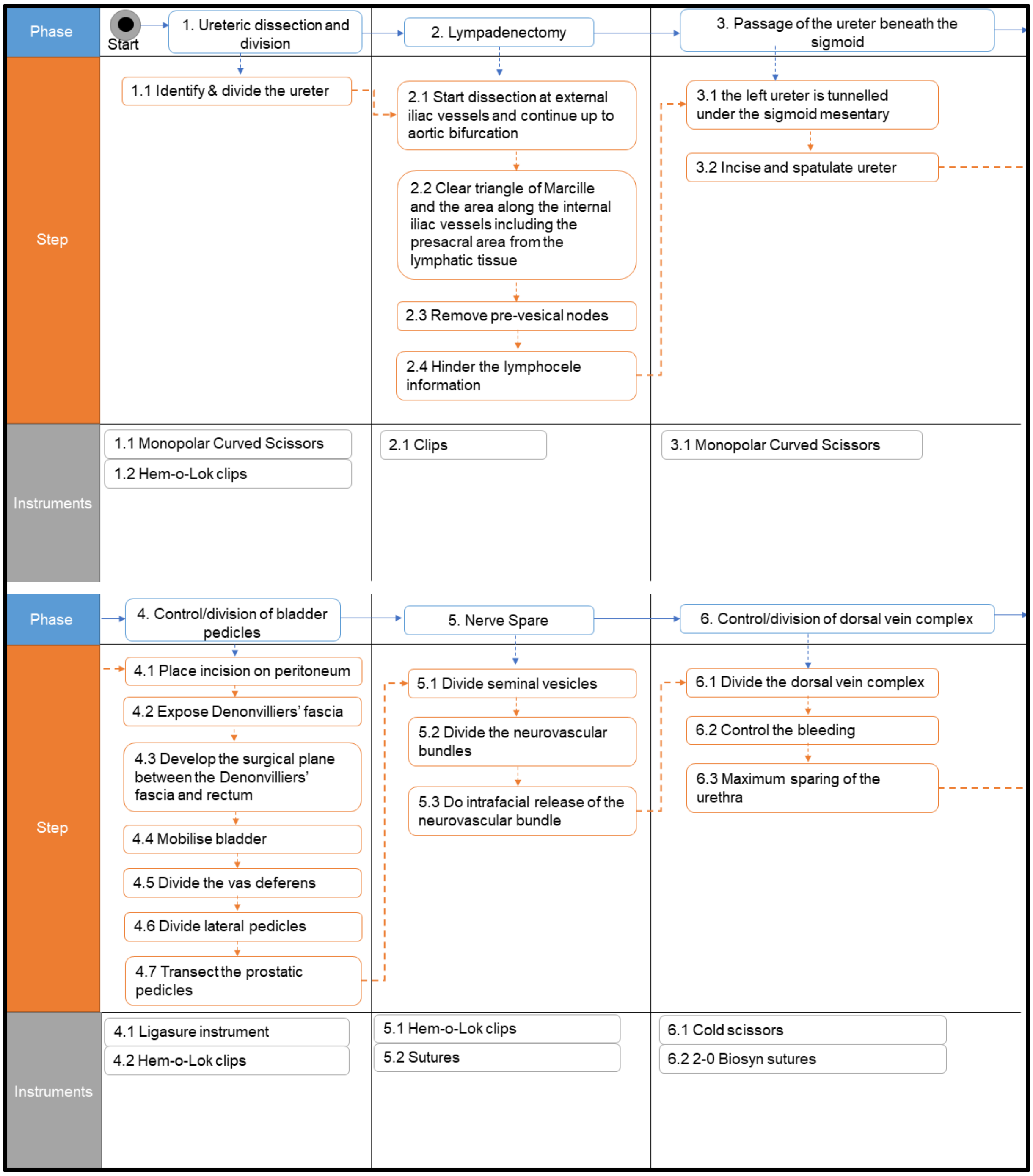
2. Robot-assisted radical prostatectomy (RARP)

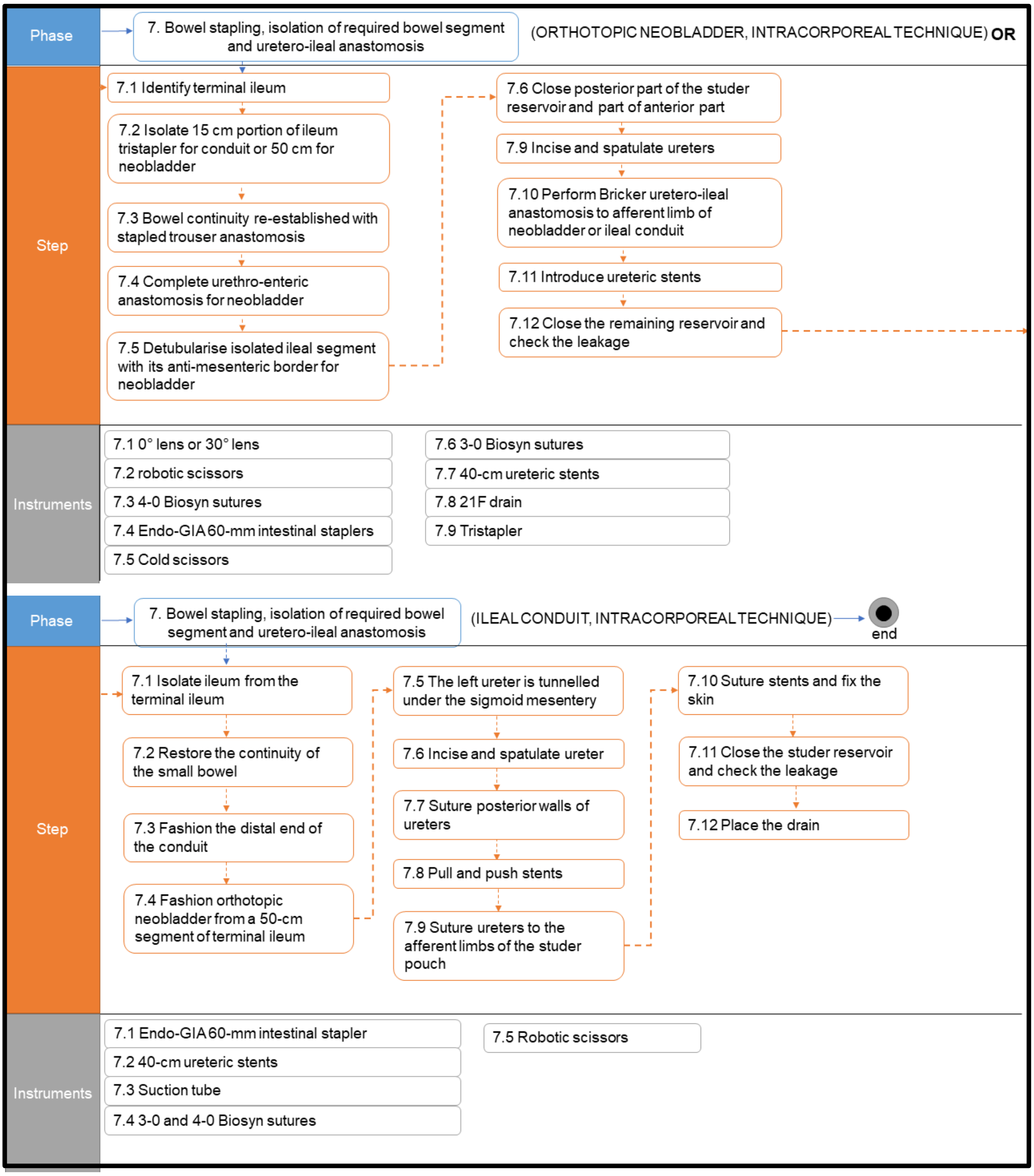



Phase
7. Nerve sparing left
8. Nerve sparing right
9. Dorsal vein complex dissection
Step
7.1 Hold the left seminal vesicle backwards and medially
7.2 Incise fascia around the prostate and divide the small vessels
7.3 Dissect the plane bluntly
7.4 Divide the pedicle
8.1 Grasp the bladder and retract the right seminal vesicle
8.2 Incise fascia around the prostate and divide the small vessels
8.3 Dissect the plane bluntly
8.4 Divide the pedicle
9.1 Put intra-abdominal pressure to 16 mmHg
9.2 Incise the dorsal vein complex (DVC)
9.3 Do the irrigation
9.4 Seal small arteries
9.5 Dissect the DVC
9.6 Retract the prostate backwards
Instruments
7.1 Monopolar curved scissors
7.2 Cadiere grasper
7.3 Johann grasper
7.3 Hem-o-lok clips
8.1 Monopolar curved scissors
8.2 Cadiere grasper
8.3 Johann grasper
8.4 Hem-o-lok clips
9.1 Monopolar curved scissors
9.2 Cadiere grasper
9.3 Elefant suction/irrigator
9.4 Large needle driver
9.5 18 cm long 3-0 Monocryl® – RB1 needle
Phase
10. Apex dissection
11. Prostate extraction
12. Haemostasis
Step
10.1 The intra-abdominal pressure is put back to 12 mmHg
10.2 Prepare the urethra
10.3 Incise the urethra athermally
10.4 transect the posterior median raphe
11.1 Put the prostate in an endobag
11.2 Extract the endobag
11.3 Ink the prostate
12.1 Remove all the clots
12.2 Seal the gross bleedings
12.3 Put the intraabdominal pressure to 3 mmHg
12.4 Fill the prostatic bed with saline
12.5 Remove the saline and seal any bleedings
Instruments
10.1 Monopolar curved scissors
11.1 Endobag
11.2 Alexis® wound protector/retractor
12.1 Elefant® suction/irrigator
12.2 Metal clips
12.3 Hem-o-lok clips
12.4 Stitches (3-0 Monocryl 15 cm long)


Phase
Step
Instruments
13. Bladder neck reconstruction
13.1 Check the position of the ureteric orifices
13.2 Perform bilateral plication over the lateral aspect of the bladder
13.3 Suturing to match the bladder neck size to the membranous urethra
13.1 Long needle driver
13.2 3-0 poliglecaprone, 13 cm long, sutures in a RB-1 needle
14. Lymph node dissection
14.1 Dissect the lymphatic tissue bluntly
14.2 Divide the main lymphatic trunks
14.3 Remove the lymphnodes
14.4 Put the lymphnodes in endobag
14.1 Monopolar curved scissors
14.2 Metal clips
14.3 Hem-o-lok clips
15. Posterior reconstruction
15.1 Approximate the free edge of the remaining Denonvilliers' fascia
12.2 Approximate the posterior lip of the bladder neck and vesicoprostatic muscle
15.1 18 cm 3-0 poliglecaprone sutures
15.2 Large needle driver
Phase
Step
Instruments
16. Urethrovesical anastomosis
16.1 Start the anastomosis at 5 o'clock on the bladder neck
16.2 Pass the needle at 5 o'clock in the urethra and then at 6 o'clock in the bladder neck
16.3 Suturing the tissue
16.1 Large needle driver
16.2 14 cm and 16 cm long 2-0 Monosyn – UR6 needle
16.3 18 cm long 2-0 Monocryls – RB1 needle
17. Closure
end
17.1 Put 15 Ch Blake or a 10 Ch Jackson-Pratt
17.2 Remove all the trocars
17.3 Extract the lymph nodes
17.4 Close the supra-umbilical mini-laparotomy
17.5 Close the skin
17.1 Trocars
17.2 15 Ch Blake or 10 Ch Jackson-Pratt
17.3 Alexis wound protector/retractor
17.4 0 Vycril with a UR6 needle
17.5 4-0 Monocryl sutures

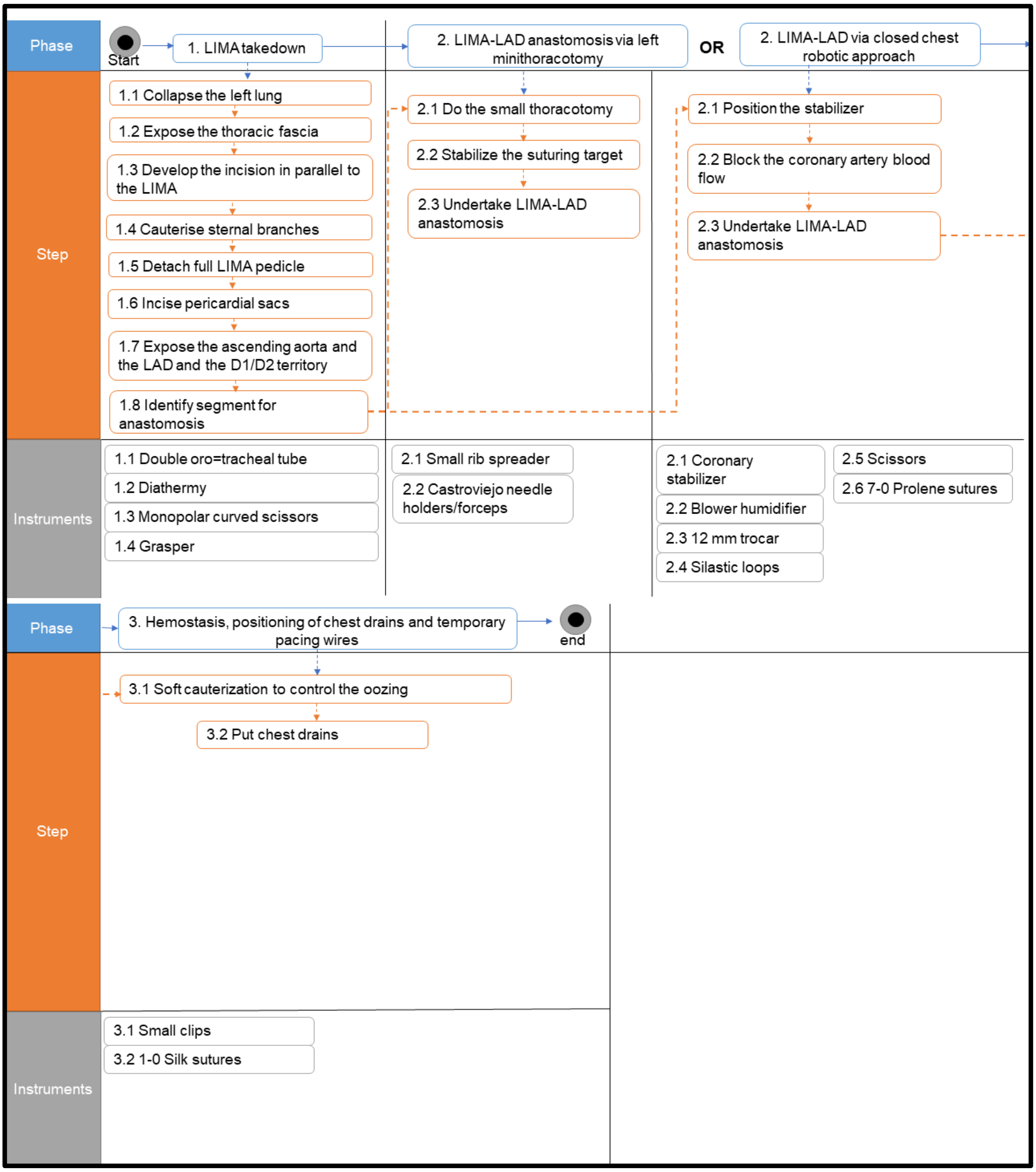
3. Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)




Phase
7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis
(ORTHOTOPIC NEOBLADDER, INTRACORPOREAL TECHNIQUE) OR
Step
7.1 Identify terminal ileum
7.2 Isolate 15 cm portion of ileum tristapler for conduit or 50 cm for neobladder
7.3 Bowel continuity re-established with stapled trouser anastomosis
7.4 Complete urethro-enteric anastomosis for neobladder
7.5 Detubularise isolated ileal segment with its anti-mesenteric border for neobladder
7.6 Close posterior part of the studer reservoir and part of anterior part
7.9 Incise and spatulate ureters
7.10 Perform Bricker uretero-ileal anastomosis to afferent limb of neobladder or ileal conduit
7.11 Introduce ureteric stents
7.12 Close the remaining reservoir and check the leakage
Instruments
7.1 0° lens or 30° lens
7.2 robotic scissors
7.3 4-0 Biosyn sutures
7.4 Endo-GIA 60-mm intestinal staplers
7.5 Cold scissors
7.6 3-0 Biosyn sutures
7.7 40-cm ureteric stents
7.8 21F drain
7.9 Tristapler
Phase
7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis
(ILEAL CONDUIT, INTRACORPOREAL TECHNIQUE)
end
Step
7.1 Isolate ileum from the terminal ileum
7.2 Restore the continuity of the small bowel
7.3 Fashion the distal end of the conduit
7.4 Fashion orthotopic neobladder from a 50-cm segment of terminal ileum
7.5 The left ureter is tunnelled under the sigmoid mesentery
7.6 Incise and spatulate ureter
7.7 Suture posterior walls of ureters
7.8 Pull and push stents
7.9 Suture ureters to the afferent limbs of the studer pouch
7.10 Suture stents and fix the skin
7.11 Close the studer reservoir and check the leakage
7.12 Place the drain
Instruments
7.1 Endo-GIA 60-mm intestinal stapler
7.2 40-cm ureteric stents
7.3 Suction tube
7.4 3-0 and 4-0 Biosyn sutures
7.5 Robotic scissors

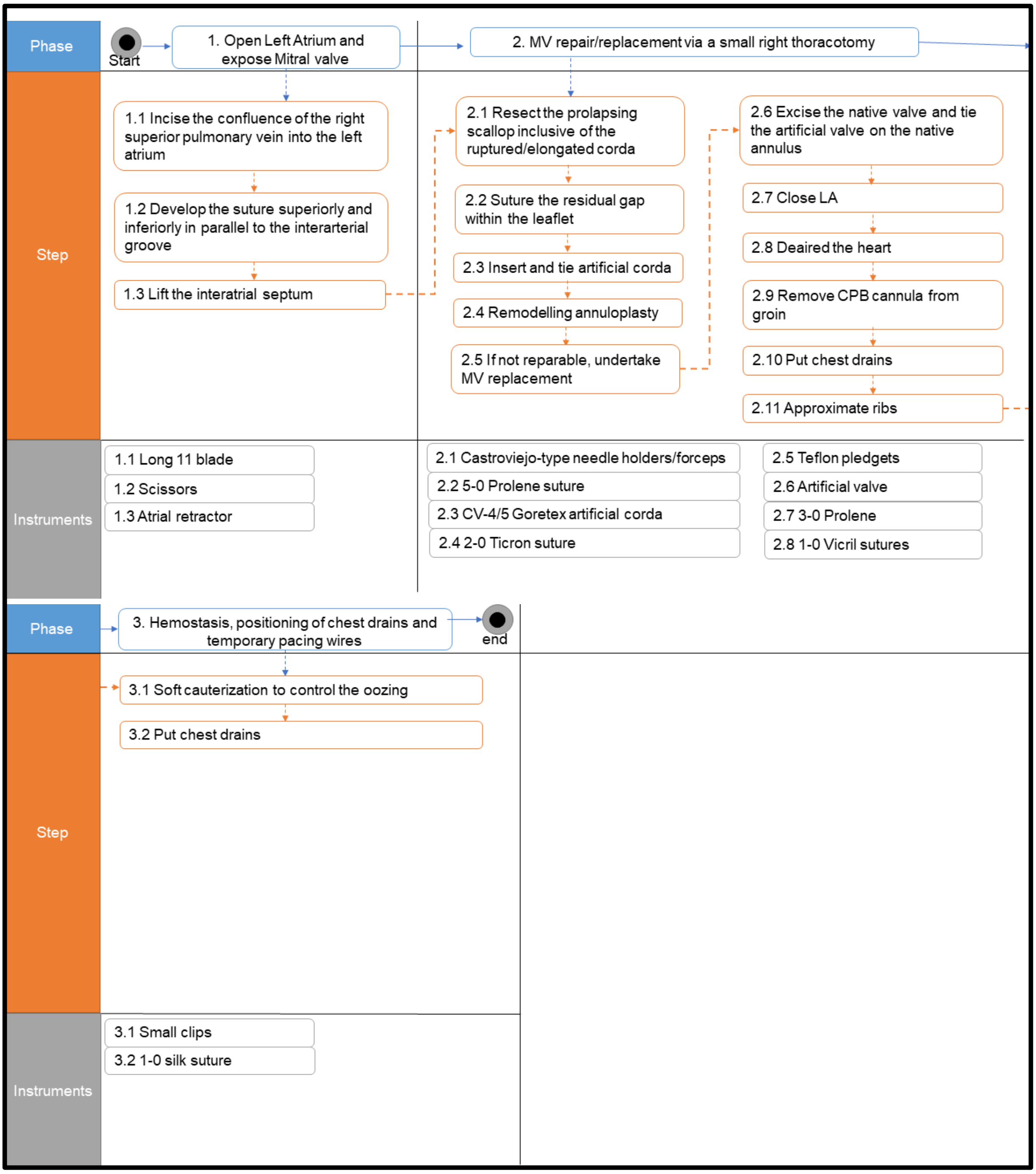
2.3 Cardiology Use cases

1. Robot-assisted coronary artery bypass grafting (CABG)*



* This surgery is not currently robot-assisted so the name refers to the goal of the project demonstrator

2. Robot-assisted Mitral Valve surgery (MV surgery) *



*This surgery is not currently robot-assisted so the name refers to the goal of the project demonstrator

3. Users requirements Analysis

3.1 Objectives and scope

The objectives of this chapter are to provide:

- The information on the qualitative analysis method
- 'Within-case analysis' of the user requirements e.g. individual use cases – Cardiac, Urology and Orthopaedics
- 'Across-case analysis' of the user requirements i.e. across the use cases
- Mapping with the System Blocks components

The scope of this chapter is to elicit the user requirements for each use cases and across the use cases and map with the system Blocks components.

3.2 Users requirements collection and analysis methodology

To obtain user requirements in minimally invasive robotic surgery, we interviewed junior, intermediate and senior surgeons. The expertise was collected as reported by surgeons in 'User Information Form' shown in APPENDIX B. Surgeons were asked about their views on the potential barriers, limitations, and improvements of the current surgical systems for minimally invasive surgery and robot-assisted minimally invasive surgery. Standardized interviews were conducted either face-to-face or online via Skype. In both the cases, interviews were recorded in the audio format as raw data. Participants signed informed consent and data collection procedure approved by Politecnico di Milano Ethical committee (Opinion n. 5\2017), see APPENDIX F, Fig. 9. University of the West of England similarly gained ethics approval from University Research Ethics Committee for this study. Politecnico di Milano and University of the West of England conducted interviews for use cases as explained in section 2.

To conduct the interviews, information on SMARTsurg project, documents related to data collection, consent forms, interview questionnaire set (see APPENDIX B, named 'Users requirement preparation questionnaire') and images, representing the system components, were sent to the participants via electronic mail. Thus, the interview participants were put in the position of understanding the context for the interviews and familiarize themselves with the questions. We asked the questions in the order specified in the questionnaire. For further analysis, interview data were collected in the form of audio recordings and verbatim transcription of the recorded interviews. Notes were also taken by the interviewer.

The raw interview data are organised and structured them for further analysis. Answers of different participants were grouped together for each question in the questionnaire. We assigned each surgeon an ID. The ID was mentioned as the first letter of each specialty followed by a number e.g. O1, O2, O3 and so on for Orthopaedic surgeons as shown in Table 1; U1, U2 and so on for urologists as shown in Table 2; and C1, C2 and so on for Cardiac surgeons. Two types of questions have been considered in the questionnaire:

1. "Open-ended questions", where surgeons expressed their opinions in the descriptive form;

2. "Close-ended questions", where surgeons gave the answers in the form of Yes/No or surgeons expressed the answers by selecting one or more options (categories/concepts).

The first analysis was conducted through 'within-case analysis' [2] method, where surgeons' responses for individual surgical case study were explored in detail, as a standalone entity, to discern patterns revealed in the individual interviews (e.g. 'within-case analysis' of collected interview data of Orthopaedic surgeons, Urologists and Cardiac surgeons separately). The 'within-case analysis' was used to identify common categories/concepts from each surgical use case. To construct the categories, we used manual open coding [3]. A code is a word, phrase, or a sentence that represents aspect(s) of data or captures essence or features of the data. The purpose of coding is to reduce the data into meaningful segments and assign names (codes) to those segments. The segments are highlighted in yellow colour in Table 1 & 2. The names of categories were defined by the domain expert in surgical robotics, or by participants' exact words or the literature sources relevant to study. The frequencies of category occurrence were also extracted and shown in the round bracket beside the category e.g. Anatomical problem (4). Table 1 & 2 summarise two examples of open coding for the interviews of Orthopaedic surgeons and Urologists, where codes are specified as the causal conditions only. Categories are then defined, which could be related to 1) the phenomenon under study, 2) the contextual, intervening-structural, and causal conditions, 3) the actions to handle the phenomenon and 4) consequences of actions and interactions related to phenomenon [4].

Question: What are the barriers of current methods that you use (open surgery/manual Minimally Invasive Surgery /Robot Assisted Minimally Invasive Surgery) in terms of:

- ✓ **Vision?**
- ✓ **Instruments (slave system: instruments and robotic arms)?**

Answers:
Vision -

		Codes	**Categories**
O1	Vision is currently not a barrier.	--	Anatomical problems (4) Image quality (1)
O2	• The assistants have to change the knee position for the desired view to see the knee compartments.	Knee position	
	• Sometimes it requires changing the camera ports for viewing. Generally, it has been decided by pre-operating imaging e.g. MRI	camera ports	
	• Sometimes soft tissues obstruct the vision and surgeons need inserting and removing the camera.	Soft tissue obstruction	
O3	Quality of the images	Image quality	
O5	Vision to the back of the meniscus is difficult	Vision behind tissue	

Instruments –

		Codes	Categories
O1	Current manual instruments are OK; however, they require modification or adjustments to be used in RAMIS.	Articulated instruments to negotiate the anatomical curves	Anatomical problems (2) Measurements (1)
O2	• Current instrument to measure the meniscus damage is not very efficient. • Probing, i.e. current method for measuring the damage, is not very useful.	Measurement of tissue damage	
O3	The smaller instruments than the current instruments, e.g. around 4 mm, may be helpful for the difficult regions in the knee.	Small instruments for difficult regions	
O5	We are familiar with the use of instruments. Generally, there is problem with the tissues e.g. thin meniscus. We may need smaller instruments. Instruments diameter is around 4 mm.	Tissue consistency	

Table 1. 'within-case' analysis example from interviews of Orthopaedic surgeons

Question: What are the barriers of current methods that you use (open surgery/manual Minimally Invasive Surgery/Robot Assisted Minimally Invasive Surgery) in terms of:

- ✓ **Vision?**
- ✓ **Instruments (slave system: instruments and robotic arms)?**

Answers:
Vision -

		Codes	Categories
U1	The vision is adequate. The surgeon was not sure if the vision could be improved with "ultra-HD".	"ultra-HD" vision	Image quality (2) Anatomical problems (2)
U2	For open surgery, there is the problem with the conditional low light and small	Conditional low light and small structures	

	structures. The surgeons conventionally use the loupes.		
U3	For open surgery, the vision is a barrier due to the close anatomical structures in the pelvis.	Close anatomical structures	
U4	For RAMIS, the camera needs frequent cleaning. The camera is smaller and the surgeons need to keep it close to the tissue.	Camera dimension	Dimension (1)

Instruments –

		Codes	**Categories**
U1	• The current instruments are good; however, the smaller needle driver is more beneficial. • Also, during the cystectomy, the bigger instruments would be needed to handle the bowel with the pro-Grasp forceps. Smaller instruments are not smooth on the bowel and injure the tissues generally. Anew instrument for bowel movement is needed with larger jaws and higher force.	Instrument dimension and better grasping method	Dimension (1)
U2	No barriers	--	
U3	The instruments are not very flexible.	Articulated instruments	Articulated instrument (1)
U4	There are no limitations.	--	

Table 2. ‘within-case’ analysis example from interviews of Urologists

Further on, a disaggregation of core themes/categories i.e. ‘axial coding’ was applied to the collected information [3]. Axial coding is the process of relating codes (categories and concepts) via a combination of inductive and deductive thinking. With the axial coding, we grouped codes to form categories as shown in Table 1 & 2.

For example, as shown, in Tables 1 & 2, anatomical problems are major barriers for the vision and the instruments in both Orthopaedics and Urology use cases. The grouped categories are then mapped to system block components (see APPENDIX D), whose development could overcome these limitations. The requirements could be elicited as shown in Tables 3 & 4.

Categories	System Block components	Requirements
Anatomical problems (6)	SLAVE INSTRUMENT L & R	Smaller instruments (Current instruments diameter around 4 mm)
Image quality (1)	CAMERA INTERFACE AND 3D RECONSTRUCTION	Better image quality
Measurements (1)	SLAVE INSTRUMENT L & R	Improvement to tissue probing instruments

Table 3. Requirements for current barriers with respect to vision and instruments for Orthopaedics use cases. (example, Number of participants (N) = 4)

Categories	System Block components	Requirements
Anatomical problems (2)	CAMERA INTERFACE AND 3D RECONSTRUCTION	Magnification
Image quality (2)	CAMERA INTERFACE AND 3D RECONSTRUCTION	Better image quality (e.g. ultra-HD)
Dimension (2)	SLAVE INSTRUMENT L & R	Changes in instrument dimensions (Small needle driver and bigger instrument to handle bowel)
Flexible instrument (1)	SLAVE INSTRUMENT L & R	Flexible instrument

Table 4. Requirements for current barriers with respect to vision and instruments for Urology use cases e.g. partial nephrectomy and prostatectomy (example, N = 4)

The closed questions, which inform explicit requirements in order to test surgeon's opinion on them, were analysed using the analytical approach. We found the requirements based on data analysis of the categorical data. Table 5 and Table 6 shows an example of such analysis with Orthopaedics and urology use cases.

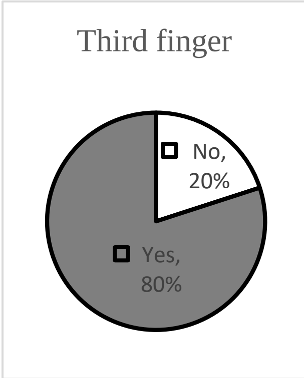
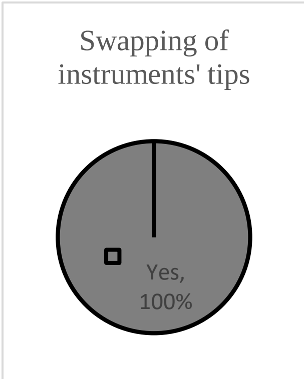
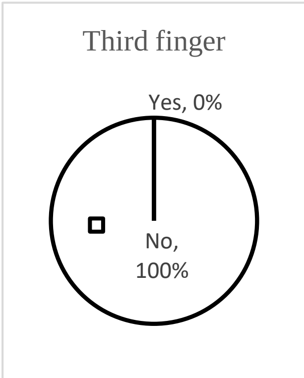
Questions	Analysis
• Would a third finger be of use?	
• Would you want the instrument to have tips that can be swapped over so that the same main instrument can perform as different tools if it has more than one digits?	

Table 5. Closed questions and its analysis from interviews of Orthopaedic surgeons (example, N = 4)

Questions	Analysis
• Would a third finger be of use?	

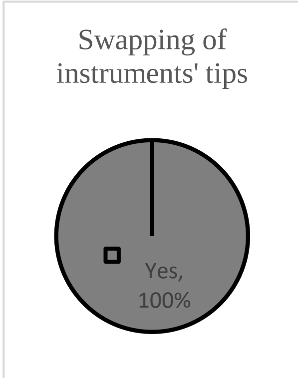
• Would you want the instrument to have tips that can be swapped over so that the same main instrument can perform as different tools if it has more than one digits?	

Table 6. Closed questions and its analysis from interviews of Urologists (example, N = 4)

After the 'within-case analysis', we performed the 'across-case analysis' [2]. To do the 'across-case analysis', first, each of the elicited requirements obtained using the 'within-case analysis', was assigned the priority as specified in Table 7. Then priorities of each specialities were combined with the same categories to determine the overall priority of the requirement. The priorities level for user requirements were obtained from consensus amongst the partners during the SMARTsurg 1st PC Meeting (Milan, Italy, 10-11 of July 2017).

Priority	**Score**
High	5
Medium-high	4
Medium	3
Medium-low	2
Low	1

Table 7. Priority-level and associated scores to elicit user requirements

As shown in Table 8, the priority scores from three specialities were summed up to obtain priorities for the user requirements, where we also decided a threshold to elicit the mandatory requirements for use cases and for the application scenarios.

<table>
<tr><th>Requirements</th><th>U</th><th>O</th><th>C</th><th>Total score</th></tr>
<tr><td>1. Superimposed preoperative images
<table>
<tr><td>U</td><td>Superimposed preoperative information is needed.</td></tr>
<tr><td>O</td><td>Superimposed preoperative information needed

(to cut the meniscus minimally)

Yes, it is needed.
However, pre-operative and intra-operative images are very different.
There are enough landmarks (e.g. trochlea, medial and lateral condyle of femur and tibia).</td></tr>
<tr><td>C</td><td>Information on physiological data and medical imaging needed</td></tr>
</table></td><td>5</td><td>5</td><td>5</td><td>15</td></tr>
<tr><td>2. Articulated instruments
<table>
<tr><td>U</td><td>(e.g. small and close structures in pelvis; anatomical area such as ridges of pubic bone; complex cases such as previous multiple pelvic or abdominal procedures or pelvic adhesions; peculiar shape of pubic bones)
(e.g. with at least two articulations; to make small movements in pelvis during radical prostatectomy)</td></tr>
<tr><td>O</td><td>Small articulated instruments needed.</td></tr>
<tr><td>C</td><td>(Difficult to reach or visualise some anatomical structures e.g. the operation access is anterior and mitral valve is on the posterior side; ventricles behind the mitral valve; cross clamping of aorta)</td></tr>
</table></td><td>5</td><td>5</td><td>5</td><td>15</td></tr>
</table>

3. Active constraints		5	5	5	15
U	Yes, it is needed. (e.g. not to damage nerves, small or big vessels e.g. aorta, vena cava and supplementary vascularisation e.g. extra renal artery; lymphadenectomy during prostatectomy; useful for training)				
O	No, it is not needed Possible use if implemented: (e.g. to prevent injury to rim of the meniscus, to remove only the damaged meniscus or meniscus flaps)				
C	Yes, it is needed (It could be very useful because there are so many critical structures in the heart e.g. vessels, nerves. For example, active constraints could prevent burning of left internal mammary artery while using the cautery)				

Table 8. 'Across-case analysis' (for example, priorities > 12)

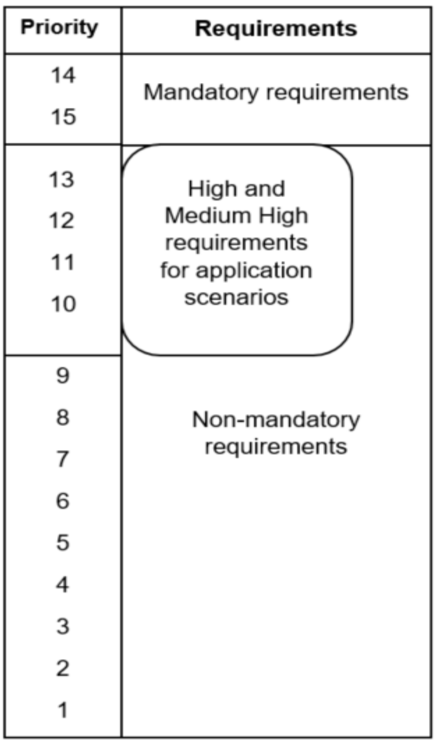


Figure 1. Priorities of user requirements

After obtaining the final requirements, these were mapped to the system components, referred to System Blocks description. Then we included the information in ‘Requirements’ table, which represents mapping of each System Block to one or more of elicited requirements, in [5]. To extract the application scenarios, elicited requirements for each speciality were mapped to the individual use case phases and steps considering ‘within-case analysis’ and ‘across-case analysis’. Information on the use case phases and steps were obtained from the use case workflows. In this document, as shown in Fig 1, the sequence of the requirements follows the priorities obtained using the ‘across-case’ analysis i.e. mandatory requirements (total score >= 14 as explained in ‘across-case’ analysis document) and non-mandatory requirements (total score <= 13). One or more scenarios are specified for each elicited requirement of the different use cases. Each scenario is numbered based on the abbreviated name of the use case followed by a number, for example, Robot-assisted Partial Nephrectomy – scenario – RAPN1, scenario – RAPN2 and so on. To analyse the scenarios further, we summarised a total number of elicited application scenarios for each use case. Further to that, as shown in Fig. 1, considering medium-high and high requirements (i.e. requirements with a total score >= 10 in ‘across-case’ analysis), we summarised a total number of the application scenarios for mandatory requirements e.g. until the user requirement no. 10 ‘3D images’ for Urology and Cardiology use cases and user requirement no. 8 ‘Haptics’ for Orthopaedics use cases. The overall requirement analysis methodology is shown in Fig 2.

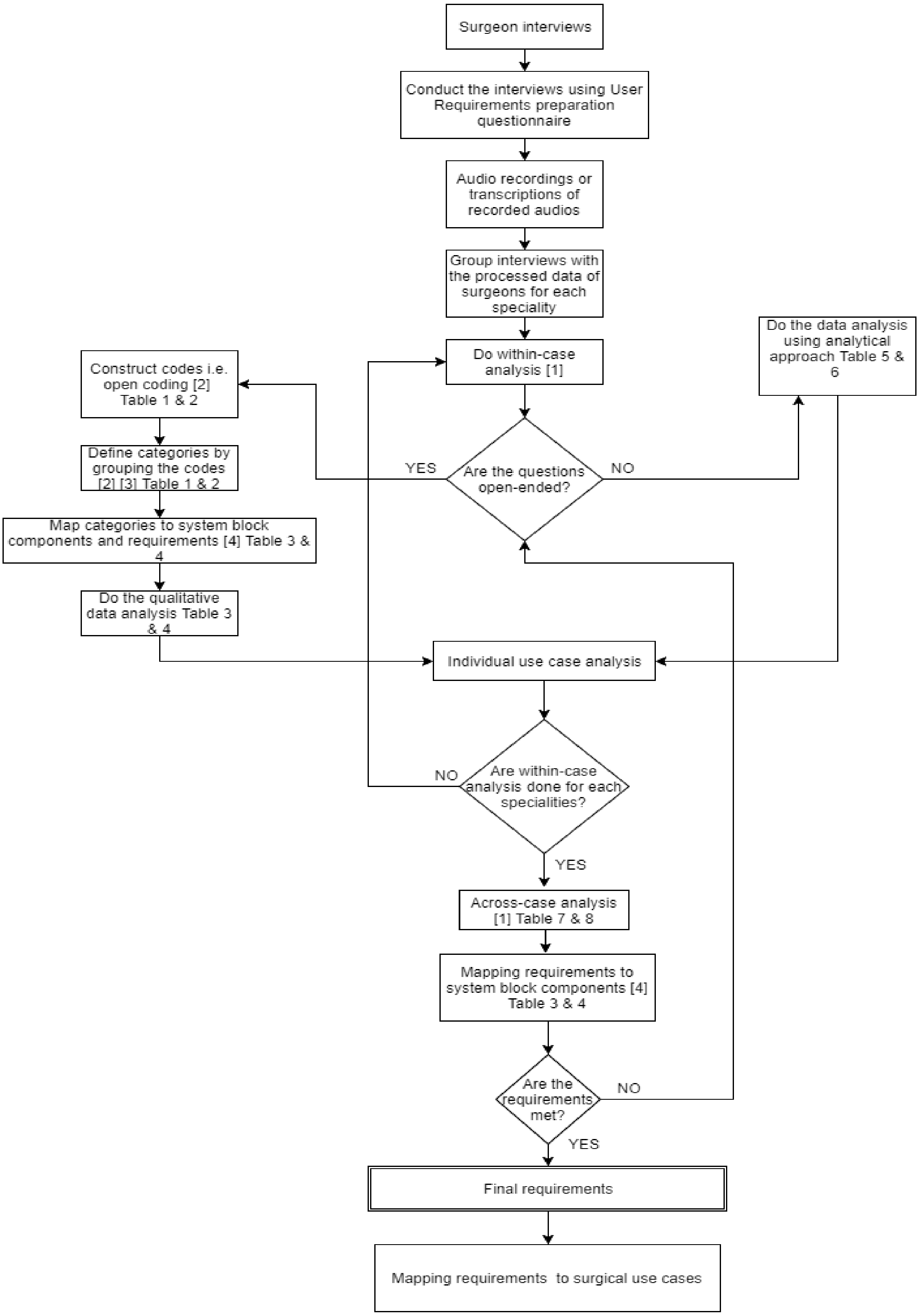


Figure 2. Requirements analysis methodology (tables refer to examples)

3.3 Processed interviews and requirements analysis

In this section, the processed interviews of each speciality are collated, corresponding to the user requirements questionnaire. The tables contain information on concise interview description, codes and its categories.

3.3.1 'Within-case' analysis

a. Orthopaedics use cases - processed interviews

Table 9. 'Within-case' analysis of Orthopaedics surgery (N = 6)

What are the barriers of current methods that you use (open surgery/manual MIS/RAMIS*) in terms of:

- ✓ Vision?
- ✓ Instruments (slave system: instruments and robotic arms)?
- ✓ Interface (master system that the surgeon uses)?

Vision –

	Interviewee description	Codes	Categories
O1	Vision is currently not a barrier.	--	
O2	• The assistants have to change the knee positions for the desired view to see knee compartments. • Sometimes it requires changing the camera ports to see knee compartments. Generally, it is decided by the pre-operating imaging e.g. MRI. • Sometimes soft tissues obstruct the camera vision and the surgeons need to insert and remove the camera.	-Knee position -Change of camera ports -Soft tissue obstruction to camera vision	-Anatomical problems (3)
O3	Quality of the images.	-Image quality	-Image quality
O5	Vision to the back of the meniscus is difficult.	-Vision behind the tissue	-Anatomical problems
O6	In arthroscopy, if surgeons have not chosen the right port, they could not be able to do meniscectomy. In MIS, camera is not a problem.	-The right camera ports	-Anatomical problems

Instruments –

	Interviewee description	Codes	Categories
O1	Manual instruments are OK; however, these instruments require modification or adjustments to be used in RAMIS.	--	--
O2	• Current instruments which are used to measure the meniscus damage are not very efficient. • Probing, i.e. current method for measuring the damage, is not very useful.	-Measurement of tissue damage	-Meniscus damage measurement technique
O3	The smaller instruments than the current instruments, e.g. around 4 mm, may be helpful for the difficult regions in knee.	-Smaller instruments for difficult knee regions	-Small instruments
O5	Surgeons are familiar with the use of instruments. Generally, there are problems with the tissues e.g. thin meniscus. We may need smaller instruments. Current instruments' diameter is approximately 2 cm.	-Small instruments to manage tissue consistency	-Anatomical problem -Small instruments
O6	O6 is left-handed surgeon and O6 finds it difficult to manipulate the tissues easily with the current instruments design.	-Instruments design for left-handed surgeons	-Manipulation with left-handed surgeons

Interface –

	Interviewee description	Codes	Categories
O1	• New interfaces require for robotics application. • As the area of operation is very small, teleoperation would be helpful for minimal meniscus resection. • Currently, to cut the meniscus minimally, the procedure is decided based only on the surgeons' intuition and pre-operative MRI images. There are MRI compatible instruments available to perform the surgery under the MRI as well. • For registration of pre-operative and	-New interfaces -Teleoperation -Surgeon's intuition and pre-operative MRI images -For image registration, many markers are available	-Teleoperation -Superimposed information

	intra-operative images, many markers are available for computer-assisted surgery. • Tolerable registration error in meniscus repair would be around 2-3 mm.	- Tolerable registration error e.g. 2-3 mm	
O2	• Lacking the soft tissue feeling. Currently, the kinesthetic feeling passes through the instrument handles.	-Missing of haptic feeling	-Haptic feeling
O6	• With respect to the position of the patient, it is same for the open or during MIS procedures.	-Surgeon's position	-Surgeon's position

What affects your surgical resilience during long procedures?

	Interviewee description	Codes	Categories
O1	• The procedures are not very long, so it is not very tiring, however the surgeon's posture is not very good during the procedure. • Teleoperation would helpful in this case.	-Surgeon's posture -Teleoperation	-Surgeon's position -Teleoperation
O2	It is tiring to keep the knee in correct position all the time.	-The correct knee position	-Anatomical problems
O5	The surgical time for both procedures is only minutes long, so it is not tiring.	--	--
O6	Yes, definitely. The surgeon finds assistance by not experienced assistants very tiring. If the surgery is complex, it is tiring too.	-Inexperienced assistants and complex surgeries	-Complex surgery -Inexperienced assistants

What feature(s) do you not have in manual MIS that you have in open surgery and that you wish you had?

	Interviewee description	Codes	Categories
O1	• The sense of touch and the sensation felt by holding the surgical instruments. • Tele-operation may reduce the sensation of touch. • Haptics is not very important for these two procedures. • Feeling of touch may be helpful to reduce iatrogenic complications to cartilages.	-Missing haptic feeling -Tele-operation may reduce the haptic feeling -Haptic not helpful but could reduce iatrogenic complications	-Haptic feeling (reduce iatrogenic complications)
O6	• Not so many. There is nothing to mention.	--	

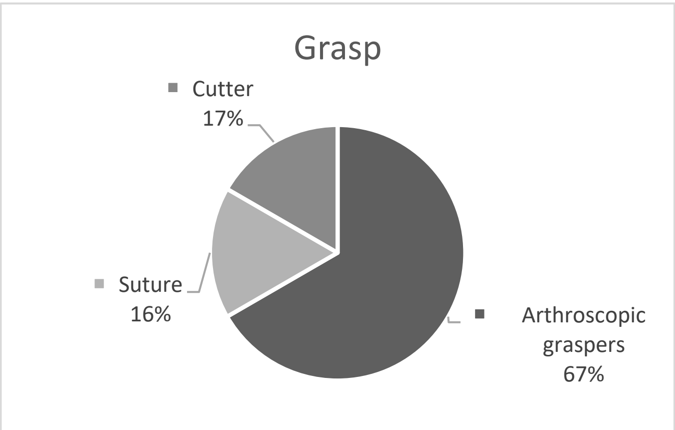
What are the barriers of current methods that you use (open surgery/manual MIS/RAMIS*) in terms of:

Surgical Instruments (Open/MIS/RAMIS – slave system: including robotic arm/instrument holder)

What kind of grasps do you use during open/MIS/RAMIS?

What different grasping methods/grasping instruments would you welcome?

	Interviewee description
O1	• Generally, the surgeons do not use the graspers. • Surgeons sometimes use the arthroscopic graspers.
O2	Surgeons sometimes use the arthroscopic graspers.
O3	Cutter and Grasper
O6	Yes and no -, with the manipulation of tissue with MIS is difficult. With MIS, there is less blood loss, but stretching of tissue is low, esp. subcutaneous tissue. Surgeons use sutures, and arthroscopic graspers Most of the time the grasping is not sufficient and surgeons lose the grasped tissue.



(See APPENDIX-E)

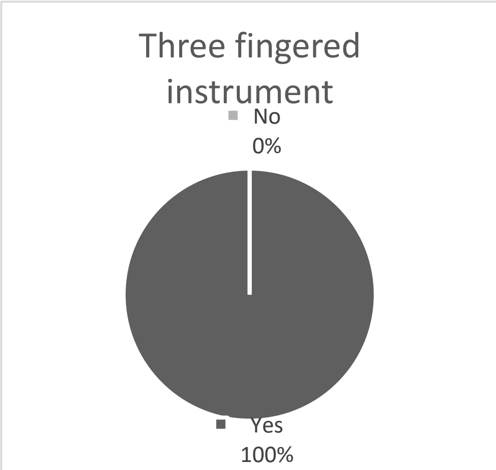
What would you change about current manual MIS/RAMIS instruments?

	Interviewee description	Codes	Categories
O1	Adding the needle holder would be of great help for suturing and meniscus repair.	-Add the needle holder	-Instrumentation
O2	• The current size of instruments is not an issue. • Smaller instruments would be useful for performing surgery through the medial meniscus posterior horn.	-Small instruments	-Small instruments
O4	• The current instruments are not flexible. Flexible instruments are useful for stitching on meniscus tear. • Smaller instruments are needed.	-Small and articulated instruments	-Small articulated instruments
O6	• More force needed during tissue manipulation. • Instruments are very delicate and unique for these surgeries. For left handed surgeons, the problems with manipulation still exists.	-Exaggerated haptic feeling -Problems with manipulation with current instruments for left handed surgeons	-Haptic feeling -Manipulation with left-handed surgeons

Would a third finger be of use?

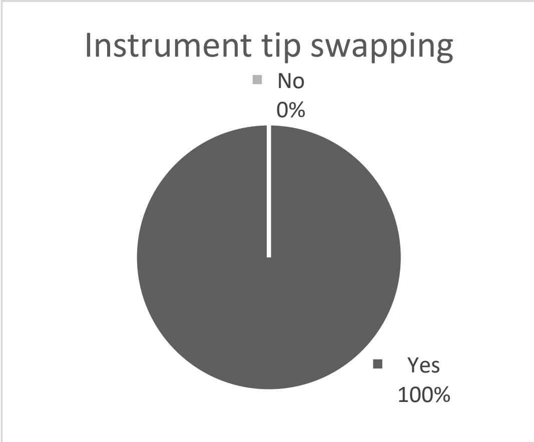
	Interviewee description
O1	Third finger may not be useful in these use cases. Third finger as a camera would be fine.
O2	Third finger may be useful e.g. to stabilize the meniscus and other fingers could be used to cut it, however the small working space may be an issue. Third finger would be helpful, especially for the meniscus repair. Third finger would solve the issue of changing the position of knee and camera adjustments, to view knee compartments. **O2** thinks, it would save time and make repair more secure.

O3	It may be useful e.g. to cut the free cartilage pieces and take them out without using the ordinary grasper and two fingers.
O4	Yes, it is a good idea for the stability. One instrument could be used for the stability, while the other two could be used as the surgical instruments.
O5	Yes.
O6	For the arthroscopic vision, it could be useful. For manipulation, it could too. In these use cases, to repair tendons and nerves, it could be helpful.



Would you want the instrument to have tips that can be swapped over so that the same main instrument can perform as different tools if it has more than one digits?

	Interviewee description
O1	Very good idea
O2	Very good for reducing the infection and for improving the vision system.
O3	To avoid some extra movements for instruments' replacement
O4	To remove the need to replace the instruments e.g. shavers. It could decrease infection.
O5	It would be prefect
O6	Yes, of course, it could be helpful.

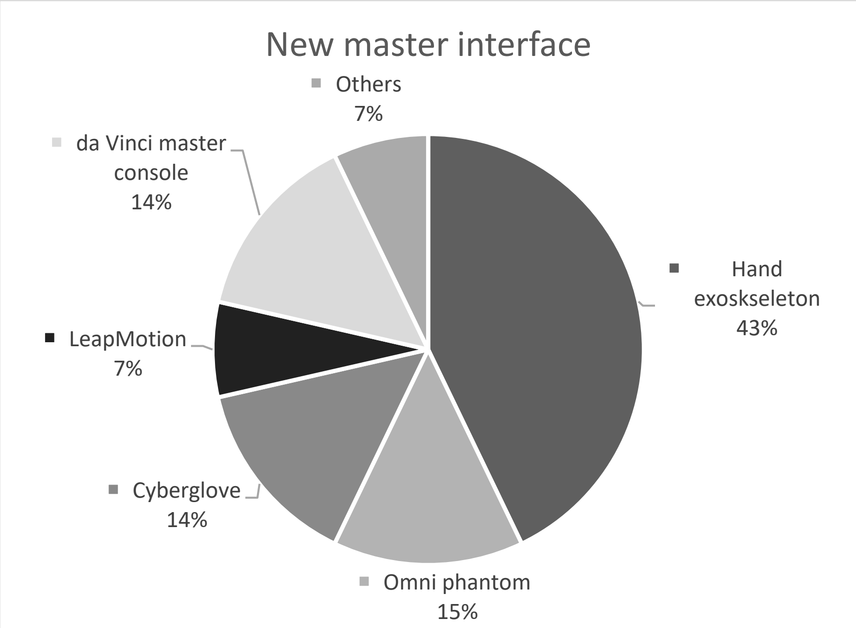

Instrument tip swapping
No
0%
Yes
100%

Master system

Note: the master system is the device used to tele-operate the instruments.

How would you prefer to control the instruments? Using tele-operation? What kind of interface?

	Interviewee description
O1	• Exoskeleton with haptic feedback, at least in one hand. Exoskeleton in both hands are excellent. • da Vinci single port if it is available in the future. Single entry is preferable.
O2	• Leap motion or exoskeleton for replicating the hand movements.
O3	• Omni phantom or exoskeleton devices
O4	• Exoskeleton or CyberGlove; da Vinci like console is also better
O5	• Oculus rift; exoskeleton
O6	• Omni phantom because it is of its pen like interface e.g. the incisions with the scalpel or grasping with the forceps • Cyber glove and hand exoskeleton are very promising.



Vision

Do you use cameras/endoscopes/laparoscopes?

Arthroscope (**O1, O2, O3, O4, O5, O6**)

(**04**) 3D might be better

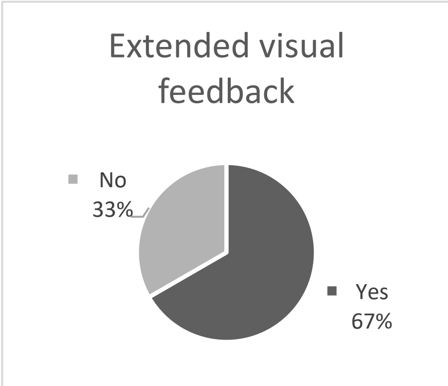
(**05**) 3D is not necessary but may give more information.

(**06**) The surgeons can't see all the area of the knee. The surgeons have the partial vision of the knee only. The instruments are too big for higher articulation to see these regions. The surgeons could damage tissues like the cartilage.

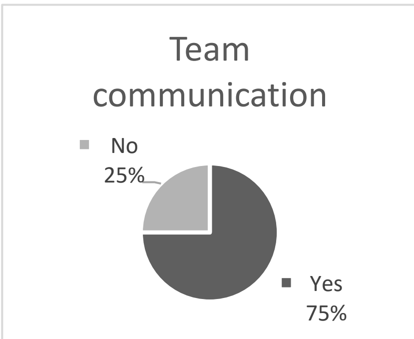
What are your requirements in terms of field of view?

	Interviewee description	codes	Categories
O1	The operative field of area is less than 5 cm. The space is sometimes less than 1 cm. There are no problems with the current instruments.	-Less than 1 cm – 5 cm -1 - 3 cm -1.5 – 2 cm -4 to 6 cm -4 cm^2	Field of view
O2	Field of view is approximately around 1 - 3 cm. Camera movements are between around 30° – 60° degrees.		
O3	Field of view is around 1.5 – 2 cm. The total operative field of area is around 8 cm. 2 cm viewing area is sufficient to visualise the whole knee compartment. Larger field of view is helpful to identify the parts of meniscus, to avoid complication e.g. damage to peroneal nerve. It may be helpful in the beginning.		
O4	The operative field of area is around 4 to 6 cm. Bigger field of view would be helpful but the space of joint is very limited.		
O5	O5 could not make a specific statement.		
O6	The operative area is around 4 cm^2.		

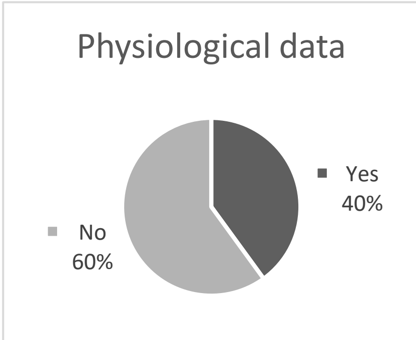
Do you need visual feedback in wider areas e.g. behind obstacles (other organs)?

	Interviewee description	
O1	No, don't need the visual feedback.	
O2	• Yes, visual feedback is needed during the meniscus repair to put the suture through the meniscus and to feel the correct length. • To see the suture and its correct position e.g. start and end position. • MRI superimposed to current intra-operative image would behelpful.	
O3	More narrow or flexible cameras would be helpful to see anatomic obstacles.	
O4	Preferred but it is not very difficult if you know the anatomy.	
O5	It would be good to see the obstacles. Articulated camera could be helpful.	
O6	In the knee, we have a popliteal artery that we don't want to touch or hurt. It is behind the knee ligaments. While dissecting from the posterior horn, you need to take care not to injure it.	

When operating, do you communicate efficiently with the rest of the surgical team?

	Interviewee description	
O1	Yes, Need the efficient communication for team work.	
O2	Not really	
O4	Yes, for the team work	
O6	Yes	

In this respect, would you welcome such information displayed in your vision during surgery? If yes, what kind of information (e.g. physiological data)?

	Interviewee description	
O1	No, it is not required.	
O2	Superimposed pre-operative image e.g. MRI to intra-operative images would be helpful.	
O3	Patient's blood pressure	
O4	Monitoring patient's vital parameters is a duty of the anesthetist but O4 would like to see it. Pressure inside the knee would be interesting to see during the surgery. The pressure inside the lateral compartment sometimes goes up.	
O5	Usually surgeons do not need to see this information. Generally, it is a duty of the anesthetist.	
O6	If it is 3D vision with articulation, it is useful. Immersive stereo viewer is helpful and smart glass for assistants may be helpful. We don't need to see physiological data.	

Camera control

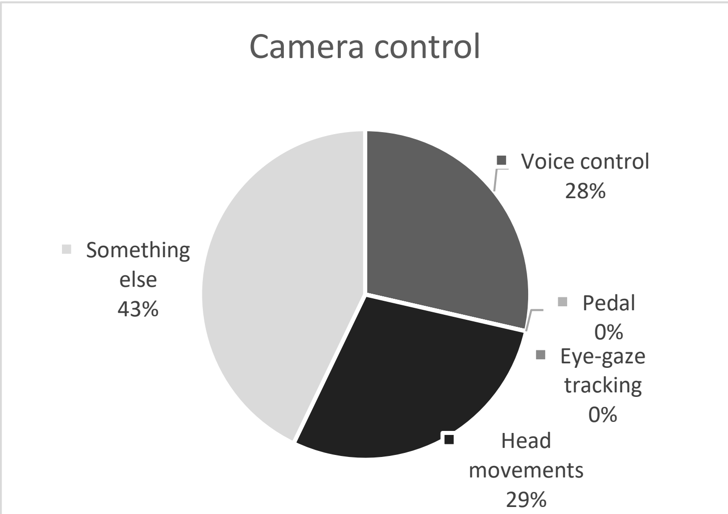
In manual MIS, the surgeon communicates with the surgical assistant for positioning of the camera. Da Vinci has a clutch system for controlling the camera using the master handles.

Is a teleoperated camera holder required?

Yes (**O1 O2 O3 O4**) No (**O5**)

How would you prefer the camera was controlled (e.g. voice commands, eye gaze tracking, head movements, foot pedal, other)?

	Interviewee description
O1	Voice control would be very good.
O2	• Voice control would be very difficult and time consuming. • Eye tracking would be tiring as it requires to constantly at certain regions. • Hand control is preferable.
O3	Not sure. Using the head movements may be helpful.
O4	Others - joystick or exoskeleton system
O5	It would be helpful.
O6	Voice command is helpful. Head movement is the alternative to voice but it is OK.



Would you wish to move, extend or focus the field of view by moving your head around?

	Interviewee description	
O1	Yes	Smart glasses
O2	Extension to the field of view with smart glasses.	
O3	Oculus rift	
O4	Smart glasses	

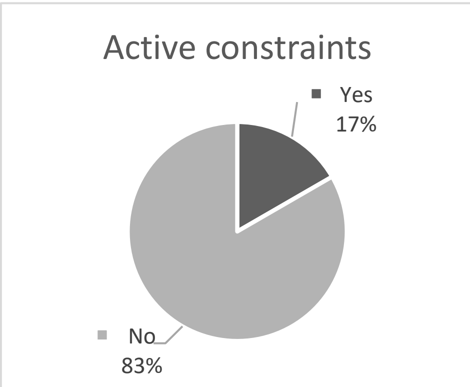
Active constraints/No-go zones

Note: ‘Active constraint’ is the process of labelling regions of the patient's body, e.g. a vessel or a nerve bundle, with one of the four possibilities: safe, close, boundary and forbidden. Surgeons label safe regions the regions that are appropriate for the robot to be and to operate in. One way to use them is to stop the instrument from entering forbidden zones by force resistance exerted by the master device. The other way is to highlight by augmented reality those zones and/or signal with alternative sensory channels as auditory or vibration.

How could ‘active constraints’ help you during a surgical operation?

Would you like knowing that the instrument would not enter or even touch the boundaries of forbidden regions and/or tissues labelled by you (the surgeon) in a preoperative and operative stage?

Would you like the robot to keep the instrument at a certain angle, e.g. normal to the operating path, specified by you to help you guide it?

	Interviewee description	
O1	• Active constraints are not very important. • Damage to the cartilage could be avoided with active constraints while doing the meniscus resection. • The surgeon should have ability to override the functionality.	
O2	• Active constraints would avoid the injury to cartilage but there is not enough space to implement the active constraints. • It would be preferable to override the functionality and the ability to stop the system.	
O3	• There are no such ‘no-go’ zone. There is a peroneal nerve damage, that could have been avoided but it is small nerve and there is no practical help. It might be helpful to avoid injury to cartilage but it is very difficult to access the narrow space because the surgeons have to cut the cartilages.	
O4	• No need for active constraints, it is just an extra thing	

O5	• No need for active constraints during the meniscus surgeries.	
O6	• It is very helpful. • While using the cautery, if a surgeon is very near to the nerves, physiological signs like the movement of the legs would occurs. Active constraints are much better and safer in those cases. • **O6** like to have alternative signal such as noise from the instrument.	

Haptics

Note: Haptics is the tactile-kinaestetic feeling, which is presented in the interaction with the body through the instruments.

How important is haptic feedback during surgery for you?

Yes, very important

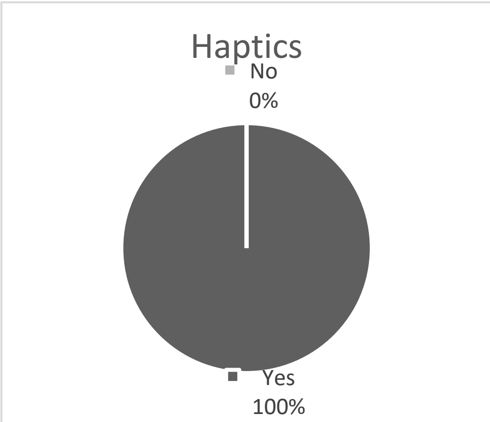
What type of haptic feedback would be useful to you (e.g. force feedback of pulling/pushing tissue and surrounding structures or of the thread tension during suturing, force feedback during grasping, texture, temperature)?

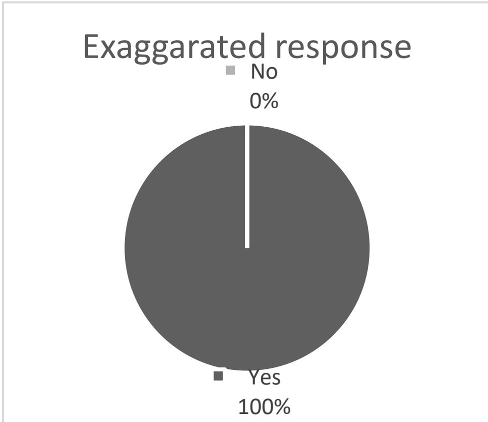
Would it be helpful to 'exaggerate' this feeling, i.e. scaled up from the measured exerted force on the tissue? Important not very.

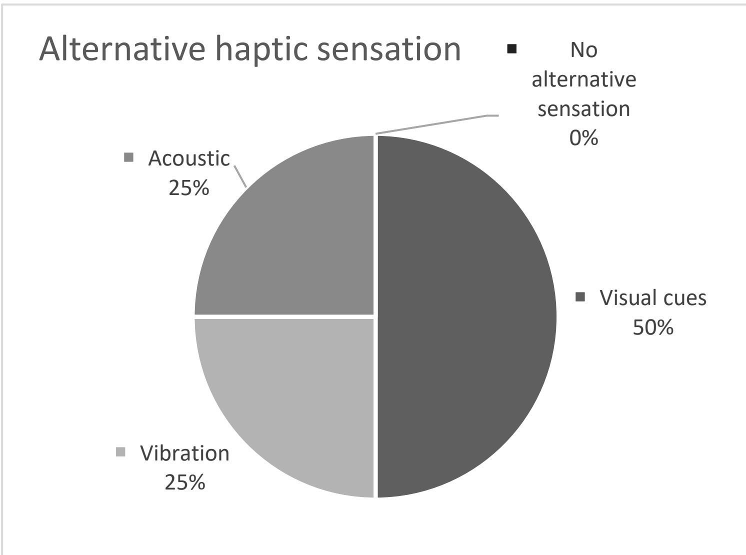
Would alternative sensory information be useful as a replacement to haptic feedback or as complimentary to it (e.g. acoustic signals/visual cues/vibration proportional to the exerted force on the tissue or as alarm for over-the-threshold forces)?

	Interviewee description	
O1	Visual cues as an alternative sensory information would be very helpful. Currently, the haptic feedback and force are low. Exaggerated feeling is helpful. Different scaling is good.	
O2	It would be good if it replicates the touch, vibration is more preferred. Not sure on 'exaggerated' feeling on touch.	
O3	Yes, it would be very helpful.	

O4	Preferred alternative sensory information would be vibration or voice control or the visual cues e.g. colour bars It could be helpful to verify if the tissue is strong or thin. To feel the grasp and the thread tension during suturing.
O5	Visual cues would be better It is very important for tension for sutures. Temperature is very helpful. High temperature during cauterisation in arthroscopy damages the cartilage.
O6	Yes, exaggerated response will help in less damage. Visual or acoustic feedback.







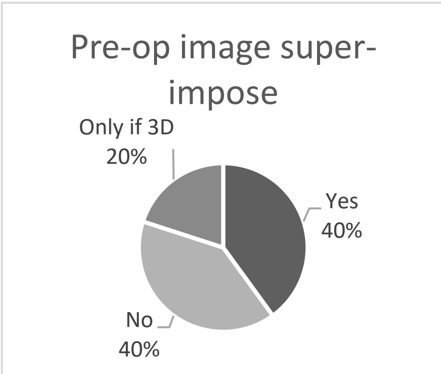
Pre-op Images

Do you use pre-operative images? If yes, what type and why?

Yes, MRI (**O1 O2 O3 O4 O5 O6**) CT (**O6**)
X-Ray (**O3**)

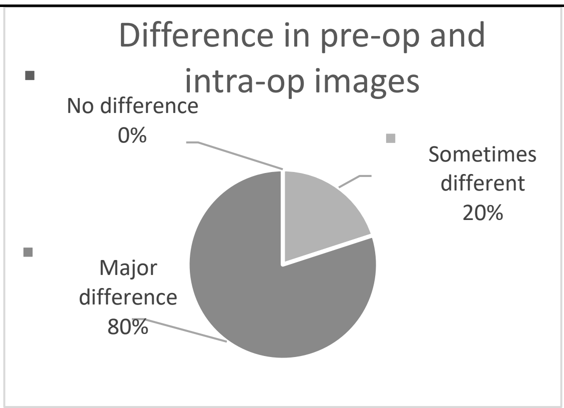
When would you need to super-impose such images on the vision of the laparoscope (e.g. to guide/help you identify structures in the abdomen)?

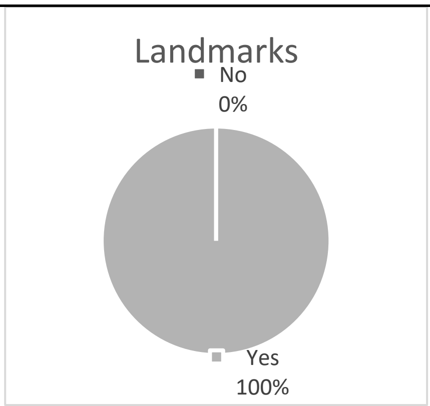
	Interviewee description
O1	It is not necessary.
O2	Very good
O3	Yes, it is helpful.
O5	No, it is not necessary
O6	It will be very helpful but 3D registration needed.



How different is the operating field from the pre-op images (e.g. in terms of tissue deformation)?

O1	• Yes, there is a lot of difference. • Enough landmarks (EP) are available for registration of pre-operative and intra-operative images.
O2	• Yes, there is a lot of difference. Sometimes the pre-operative images are taken before some time e.g. a month. • Enough landmarks – Yes e.g. Anterior Cruciate Ligament.
O3	• Pre-operative images and camera images are very different. Both the images are not identical. • Enough landmarks available.
O4	• Sometimes it is different. • Enough landmarks available.
O5	• It is different. The origin of the ACL or the medial femur condyle.


Difference in pre-op and intra-op images
No difference 0%
Sometimes different 20%
Major difference 80%


Landmarks
No 0%
Yes 100%

General questions

How do you expect a system like SMARTsurg will improve in new surgeons' training?

	Interviewee description	
O1	• Yes, it would be helpful. Although, there should be the same training paradigm; first would be the conventional training, then robot-based training and then the new system training.	
O2	• If the system would implement the virtual reality operations, and presents the different scenarios then it could be helpful as a simulator, like a video game, for training.	
O3	• It may help significantly.	
O4	• Yes, it would be helpful. Although, there should be the same training paradigm; first would be the conventional training, then robot-based training and then the new system training	
O5	• It is difficult to training. For new surgeons, if the new surgeons train on robot, it may be helpful. It would be an improvement.	
O6	• It could be used as a simulation for the operation. For observations, it is very helpful. For the training, it is helpful but some components like AC is a limit.	

Closing remarks

Any other concerns about the technology?

	Interviewee description	
O1	Technology would be helpful to do more things in less time with the less morbidity. For example, it would save more meniscus during resection and it will be the major improvement.	-Cost -Telesurgical implementation
O2	Orthopaedic surgeons would not like the technology. There will be objections in the beginning. There are advantages in terms of time, surgical safety, efficiency and money.	
O3	• Cost • Tele-surgical implementation is not preferred.	
O4	Someone needs to train the surgeons, otherwise it could be difficult in the beginning.	
O5	It could be accepted. RAMIS would provide more efficient surgical treatment. The technologies would help more to assistants. Assistants are more important.	
O6	No, **O6** does not have any concerns. **O6** prefers to have the robotic system. The mistakes are low.	

b. Urology use cases – processed interviews

Table 10. 'Within-case' analysis of Urology use cases (N=17)

What are the barriers of current methods that you use (open surgery/manual MIS/RAMIS*) in terms of:

- ✓ Vision?
- ✓ Instruments (slave system: instruments and robotic arms)?
- ✓ Interface (master system that the surgeon uses)?

Vision –

	Interviewee description	Code	Categories
U1	The vision is adequate. The surgeon was not sure if the vision could be improved with "ultra-HD".	-Image quality	Image quality Image type
U2	For open surgery, there is the problem with the conditional low light and small structures. The surgeons conventionally use the loupes.	-Image quality - Small anatomical structures	Image quality Anatomical problems
U3	For open surgery, the vision is a barrier due to the close anatomical structures in the pelvis.	-Close anatomical structures in pelvis	Anatomical problems
U4	For RAMIS, the camera needs frequent cleaning. The camera is smaller and the surgeons need to keep it close to the surgical site.	-Small camera dimension and cleaning of lens	Image quality
U5	For RAMIS, the vision is perfect and there are no limitations.	--	--
U6	Open surgery, it does not provide good vision especially for the anterior part of the prostate – apex, urethra, venous plexus and the cleavage between the prostate and rectum. It is not easy to have a field of vision. It is like a tunnel and narrow area and needs to move the neck to look at it properly. Loupes do not solve this problem. The area is about 20 cm wide and 10-15 cm deep which is not very well accessible.	-Not good vision with the anterior part of the prostate -Articulated scope to see anatomical regions	Anatomical problems

	For RAMIS, we use scopes with angles. We change different scopes, which is time consuming. We need the scope which can change the angle of view. There are some anatomical regions e.g. ridges such as pubic bone that you need to overcome.	-Flexible camera	
U7	Open surgery, vision is not on the same axis with respect to hand. In MIS and RAMIS, it is on the same axis and it is better. MIS, they use 2D. but 3D is also available for MIS but you need special glasses. The problem is image quality but it is better with RAMIS.	-Image quality	Image quality
U8	Open surgery, the vision of the problem. With MIS, we don't have clear definition of the anatomical site. Vision is good but coordination with vision is difficult. You lose your anatomical objective. In Open, you use landmark (Santorini approach or urethral approach) to reach to objective.	-Vision coordination is difficult	Field of view
U10	The vision is very good.	--	--
U11	Vision is not magnified.	-Magnified vision	Magnified vision
U15	In some men who have had multiple pelvic procedures beforehand or abdominal procedures, it wouldn't be technically possible to do a minimally invasive procedure. If they have had multiple or pelvic adhesions, which would make it technically more challenging, perhaps the benefits of MIS would be outweighed by the potential increased risks associated with MIS	-Multiple previous surgeries; problems with changed anatomy and pelvic adhesions	Anatomical problems
U16	Vision is quite good. The problem is with its unidirectional view.	-Vision is unidirectional	Field of view

Instruments –

	Interviewee description	Code	Categories
U1	• The current instruments are good; however, the smaller needle driver would be more beneficial. • Also, during the cystectomy, the bigger instruments would be needed to handle the bowel with the pro-Grasp forceps. Smaller instruments are not smooth on the bowel and injure the tissues generally. The new instrument for bowel movement is needed with the larger jaws and the higher force.	-Smaller needle driver -Big instruments to handle the bowel with larger jaw and higher force.	Instrumentation
U2	No barriers	--	--
U3	The instruments are not very flexible.	Instrument flexibility	-Articulated instruments
U4	There are no limitations.	--	--
U5	With current instruments, there is no force feedback.	Haptic feeling	-Haptic feeling
U6	For open surgery, very good instruments. It may not be very precise as RAMIS.		--
U7	With RAMIS, there are some limitations. Some patients have peculiar shape of pubis bone which make the movement of the instruments harder to stay near the camera view. We get the friction between the instruments and pubic bone. If you have two points of articulation then we could overcome this. In the case of small areas, we need flexible instruments.	-Manipulation problem due to anatomy -Flexible instruments with two point of articulation	-Anatomical problems -Articulated instruments
U8	The coordination of the moves and vision is difficult.	Hand-eye coordination is difficult	-Field of view
U9	The surgeons need to go through the skin, right to actually go through the skin are the wires, which are tiny they are no bigger than a needle and the needle doesn't make a permanent scar, so in theory the surgeons could have some very thin instruments containing the cabling to go through the skin.	-Miniaturization to allow instrument insertion	-Instrumentation

	So, the surgeons need miniaturization to perform the surgery with less invasiveness.	through the skin	
U10	The instruments are very good.	--	--
U11	The instruments are inflexible and the support of the instrument is relatively far from the area being acted upon especially in "big" surgeries and especially because in radical prostatectomy the area is difficult to reach and moving the instruments is a real problem even in open surgery since in open surgery there is no interface. The possibility of moving around and making small movements, eliminating tremors that would otherwise be amplified by the length of the tool.	-flexible instruments for making small movements in pelvis	-Articulated instruments
U15	U15 thinks it possibly would be an advantage of having a separate instrument to retract the tissues out of the way, a bit like in traditional open surgery where the assistant or fellow surgeon could retract tissues. So, there is a need for a better form of retraction and retraction methods are limited. There are also the problems with changing instruments which causes risk of collateral damage. The instruments are also expensive.	-A new instrument for the retraction of the tissues -New retraction methods	-Instrumentation
U16	The surgeons need bigger graspers capable of broader movements. The scissors are pretty poor quality in the sense that they don't cut very well without diathermy. Because they do use diathermy, there are areas particularly in prostatic dissection where you really don’t want to cut like cutting the bowel, cutting the ureter. The scissors don't allow good ‘cold’ cutting The da Vinci scissors are not good for cold cutting. Bowel anastomosis is at the moment a bit clumsy. The robotic instruments have more or less movements. So, it depends a lot on how good the assistant is in applying the staples.	-Bigger grasper with sort of a broader movements -Poor quality scissors -Difficulty with bowel anastomosis and need of an assistant for applying the staples.	-Instrumentation

U17	Suturing is different from open surgery where the surgeon holds the instrument tip and have the haptic feedback.		

Interface –

	Interviewee description	Code	Categories
U1	• As the area of movement is limited , clutching mechanism is not very favorable, for example during stitching or dissection • Anatomical referral points, e.g. during nephrectomy, the surgeon needs to know the relative anatomical locations e.g. where the tumor is or where the ureter is. In this case, superimposed images would be helpful. It would also make the surgery safer. • The current sitting position on da Vinci console is not very comfortable.	-Clutching mechanism -Superimposed information for knowing relative anatomy -Sitting position	-Clutching mechanism -Superimposed information -Surgeon's position
U2	• Clutching mechanism is not a problem.	--	--
U3	• The interface is very good, but it lacks the tactile feedback.	Haptic feeling	-Haptic feeling
U4	• Clutching mechanism is good.	--	-
U5	• da Vinci controller is good but the problem is the clutching mechanism. Arms collide in the master very often. It requires frequent clutching and hand reaches its workspace limitations. If clutching mechanism is removed or if we require to use less clutch, it would be better.	-Clutching mechanism	-Clutching mechanism
U6	At the certain point, you need to clutch in the area you are comfortable with. There are conflicts in the console and limited workspace. Clutching is very straight forward.	-Clutching mechanism	-Clutching mechanism
U7	There are no problems.	--	-

U8	RAMIS, the coordination of your moves in the little space in the master's console is difficult.	-Clutching mechanism	-Clutching mechanism
U11	There is the collision between the arms because of the anatomy of the patient or because the arm of the robot must be put in a certain way.	-Anatomical problems	-Anatomical problems
U13	There is no back rest on the surgeon's seat so some surgeon who prefer to wheel around while he using the robot and some other not. Ergonomically, in terms of the robot console, itdepends at where you are within it. There is a da Vinci chair but it is not widely used in UK.	-Sitting position	-Surgeon's position
U14	if we could make the console smaller in size just with the camera, this will make the position for the patients better, so the surgeons could sit comfortably. The surgeons need just the camera and instruments so they don't need this large machine.	-Sitting position -Smaller console	-Surgeon's position -Console size

What affects your surgical resilience during long procedures?

	Interviewee description	**Code**	**Categories**
U1	• The sitting position on the da Vinci console is the main problem during long procedures.	-Sitting position	Surgeon's position
U2	• During the open surgery, the usage of pedals is very hard while standing for a long time. It is also associated with the backache. • For RAMIS, cognitive load is mostly tiring.	-Standing position -Cognitive load	-Surgeon's position -Cognitive load
U3	• There is not anything which affects the surgical resilience.	--	-

U4	• RAMIS is better than the open surgery. However, for the longer procedure, like the cystectomy, the sitting pose on da Vinci console is not very good because it hurts the back and the neck.	-Sitting position	-Surgeon's position
U5	• Tiring, pain and redness of eyes. It may be because of 3D vision. With 2D vision, eyes tiring is reduced. Sitting position in RAMIS is more comfortable than MIS or open surgery.	-3D vision	-Image type
U6	Ergonomic sitting position open surgery is more tiring than RAMIS. With RAMIS not tiring. It is just noisy and you get stressful when the case is more challenging.	-Complex surgery	-Type of surgery
U7	Perhaps when you have conflicts of instruments how to move to overpass the problem it is tiring. It happens when pelvis is narrow during prostatectomy.	-Manipulation problem in the pelvis	-Anatomical problems
U8	In the initial learning phase, I was very focused on how to define approach and steps of the surgery. Hand-eye coordination is tiring. After many hours at the console, it is very tiring.	-Cognitive load	-Cognitive load
U9	Well certainly on the long procedures you get tired; it's quite exhausting because of the levels of concentration. the Da Vinci robot system is certainly more comfortable than what it used to be- standing up and leaning over the patient at an awkward angle, so the fact that you are sitting down straight means that you can operate for longer.	-Standing up leaning over position	-Surgeon's position
U10	Probably the cognitive load, thinking and sitting position	-Cognitive load -Sitting position	-Surgeon's position -Cognitive load
U11	about open or laparoscopic surgery, the position, standing, hunched, the requirement to apply force, the length of the procedure is tiring.	-Sitting position	-Surgeon's position

U12	Surgeon's standing position in open and MIS surgery is tiring. While with the RAMIS, there is nothing that could create fatigue	-Standing position in open surgery	-Surgeon's position
U13	The surgical resilience probably related to youth and fitness and no problems with concentration span, but things that effect the surgical resilience can include things like lack of sleep the night before or other things that are going on in the theatre or are going on clinically, peripherally. One of the advantages of doing primarily robotics is, everyone has to concentrate on what they are doing.	-Physical or mental conditions	-Surgeon's wellbeing
U14	Most likely the position of the surgeon because the surgeon is standing up and then you have to tilt your shoulder all the time to work with the pelvis, so it is very difficult and the surgeon starts to get tired within just 30, 45 mins - an hour	-Standing up position in open surgery	-Surgeon's position
U16	Complicated surgical cases, which make the duration of the surgery longer, which would be true even for open surgery.	-Complex surgeries	-Type of surgery

What feature(s) do you not have in RAMIS that you have in open surgery and that you wish you had?

If you are a da Vinci user, is there anything specific that you cannot do using the Da Vinci surgical system? Please think of examples. What would enable you to tackle this challenge?

How could each scenario be different? (extend it, change it)

	Interviewee description	**Code**	**Categories**
U1	• Bigger forceps are not available in RAMIS. Miniaturization is not always helpful i.e. it could be helpful for the kidneys and bowels.	-Bigger forceps in RAMIS	-Instrumentation
U2	• Instruments can be developed to do more precise surgery. • There should be improvement with the camera because camera often gets dirty. The vision is significantly poorer with the	-Vision is poor with zoom	-Image quality -Latency

	zoom. • Response of the system, sometimes there is a bit of latency, however it could be useful in the training e.g. to prevent wider movements. • For the experts, the latter could be the problem. There are options for motion scaling e.g. normal, precise, very precise, but the surgeons mostly use the normal configuration.	-Latency with da Vinci system	
U3	• It would be good to have tactile feedback in RAMIS. • With da Vinci, if the surgeons need to operate in the larger field of view, they need to change the ports repeatedly. As there is a limitation in the field of view, it could be solved with the flexible instruments and access to the surgical site e.g. trocar position.	-Haptic feeling -Limitations in the field of view -Articulated instruments	-Haptic feeling -Field of view -Articulated instruments
U5	• Feeling of touch	-Haptic feeling	-Haptic feeling
U6	• You can touch and have the haptic feedback. • You start performing surgery after training on the console. Knowing what to do, you study but then RAMIS does need the training.	-Haptic feeling	-Haptic feeling
U7	• Large instrumentslike trocars are not available in MIS or RAMIS. There are some devices that allow bigger incisions in order to take out specimen.	-Trocars not available in RAMIS	-Instrumentation
U8	The vision and anatomic definition is really different between open and RAMIS. da Vinci was only difficult in the beginning to adapt to RAMIS from a lot of details to little details. In open, it is easy to identify or plan surgical approach e.g. nerve sparing which is difficult in	-Surgical approach	-Surgical approach

	open surgery. Santorini approach is difficult for a young surgeon to complete.		
U9	There is no tactile feedback and the surgeons have to change the instruments to cut and to suture.	-Haptic feeling -Not interchangeable instruments tips	-haptic feeling -Interchangeable instrument tips
U10	If there is adherence, the surgeons could not do RAMIS. Haptic feeling. Initially I was not able to do nerve sparing because you need to find a plane between prostate and neuro vessels.	-Anatomical problems -Complex surgeries -Haptic feeling	-Anatomical problems -Type of surgery -Haptic feeling
U11	The da Vinci system should have some video interfaces. The surgeons should have the possibility to overlay the videos on the monitors all the images of the patient and load all the treatments of the patient. For example, the surgeon would diagnose something with an MRI. They would do a fusion with the biopsy and that biopsy then orients me in the space and tells them where I am relative to the MRI. It could be possible with CT too.	-Superimposed information on a separate monitor with MRI or CT images.	-Superimposed information
U12	The surgeon could feel the tissue when they are doing open surgery but not in laparoscopy. Robotics is anyway a laparoscopic procedure, and lacks the feeling.	-Haptic feeling	-Haptic feeling
U13	In conventional surgery or open surgery, it is very useful to have your hand inside to be able to feel the planes between prostate and rectum.	-Haptic feeling	-Haptic feeling

U14	There is no tissue feeling with the robotic surgery. The surgeons don't have that pulling, pushing feelings. The surgeons don’t have the feeling of the thread, the tension of the thread and all this stuff. While during open surgery for example the surgeons are in control and these features are not present nowadays in the robot system. The surgeons are using their hands for tissue dissection, for control of any bleeding and for pulling and for pushing and this advantage is not present in the robot, so in the robot if you are dealing with some tissue doing cutting or traction or doing tension on the thread you don't know exactly how much force you are applying and what's the exact tension, so the surgeon should get the clues by either feeling or having an information regarding what's exactly the tension strength and how much he is pulling and he is pushing.	-Haptic feeling	-Haptic feeling
U15	Haptic feedback is missing. With open surgery, in certain situations, the surgeons use it to manipulate tissues more easily and to alter the field of vision as well. Robotic instruments have currently limited capacity in terms of retraction, whereas in open surgery it is easier to use surgical instruments or your own hands or assistant’s hands to be able to retract tissue planes and that is one of the big things missing with the robotic surgery.	-Haptic feeling -Easily alter field of vision in open surgery -Tissue retraction with robotic instruments are limited	-Haptic feeling -Field of view -instrumentation
U17	Surgeons miss the tactile feedback from the tissues but everything else on the robot side is much better.	-Haptic feeling -Lack of speed in changing the instruments	-Haptic feeling -Interchangeable instrument tips

	Lack of accessibility for perhaps and lack of speed in changing instruments or delivering new tools inside the abdomen		

What are the barriers of current methods that you use (open surgery/manual MIS/RAMIS*) in terms of:

Surgical Instruments (Open/MIS/RAMIS – slave system: including robotic arm/instrument holder)

Do you find the manipulation of tissues using MIS instruments restrictive as compared to your own hand?

Is this the case for RAMIS instruments?

	Interviewee description	Code	Categories
U1	• The current system is even better than manipulation with the hands.	--	--
U2	• It is mostly similar, while the RAMIS is very precise. RAMIS is actually more precise than hands.	--	--
U3	• Manipulation with MIS instruments are very precise. With the RAMIS, the movement is not the restrictive.	--	--
U4	• It is similar as the RAMIS.	--	--
U5	• With MIS, manipulation of tissue is more difficult than with hands • With RAMIS, there is no difficultly in manipulation of tissue, however the feeling of touch is less.	-Haptic feeling	Haptic feeling
U6	• Definitely, if you have your own hands it is easier to grasp the tissue. When you do open surgery, you barely hold any structures with hands. With RAMIS, manipulation is easier than in open because you have three arms, which is big advantage. The hands are very accurate too.	--	--

U7	• In the beginning, there is no tactile sensation. The tissue is masticated in the beginning. Perhaps you have the friction of the prostate tissue. Remove seminal vesicles only by the traction.	-Haptic feeling	-Haptic feeling
U8	It is the same after more procedures due to visual perception.	--	--
U9	No, the manipulation is about the same. Manipulation is good with the robot and have more degrees of freedom of movement than the wrist, but you can do better with your hands.	--	--
U10	Yes, there is a difference between the hands and with MIS instruments.	--	--
U11	Yes, the manipulation with respect to hands is restrictive because we could not reach at certain anatomical region and the sensitivity of hand is incomparable. Tissue manipulation is best with hands.	-Anatomical problems to reach at certain regions -Haptic feeling	-Anatomical problems -Haptic feeling
U12	The disadvantage of robotics is the feelings. The instruments are not that flexible, which is a disadvantage: Flexible means one cannot turn the wrist 360 degrees like you can do in robotics for instance.	-Haptic feeling	-Haptic feeling
U14	**U14** states the difference between feeling of tissue, the feeling of pushing, tying, thread tension and not having any feeling during t robotic surgery. This is really what is missing. With open surgery, you are in control.	-Haptic feeling	-Haptic feeling
U15	Absolutely, it's the particular procedure that I do- the lymph node sampling where we sample lymph nodes from around the blood vessels and the nerve fibres to see if there is any metastatic spread to the lymph nodes.	-RAMIS instruments retraction capacity is limited e.g.	-Instrumentation

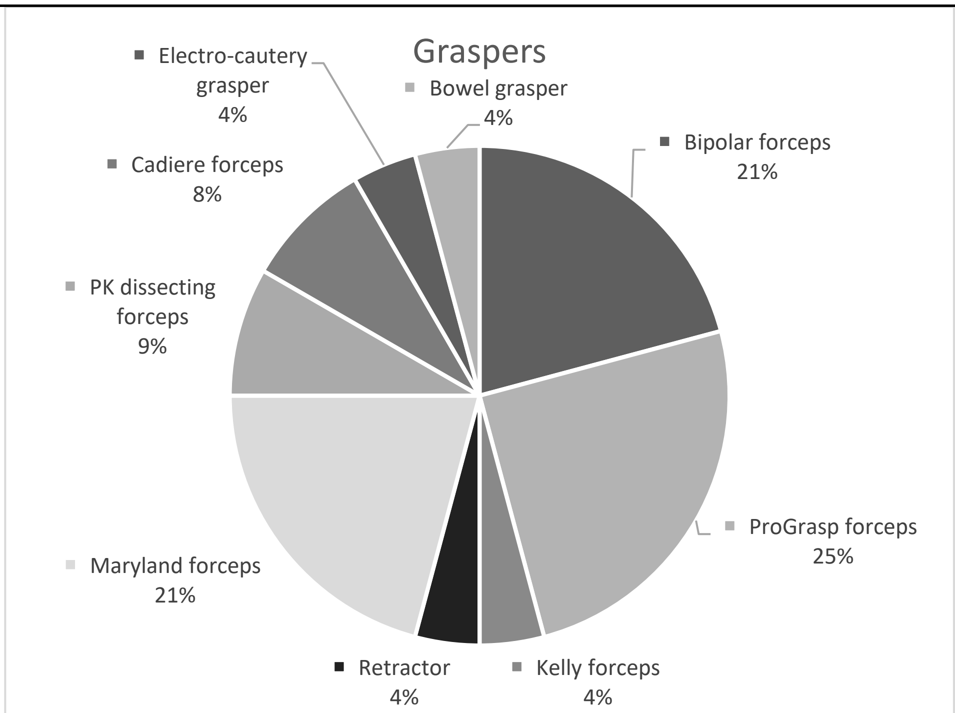
	This part of the procedure is so much easier to do in an open operation because you can physically manipulate the blood vessels and the nerves out of the way to allow you to surgically reset the tissues and it is much more difficult with a da Vinci instrument even though they're more manoeuvrable than traditional laparoscopic equipment, even so the capacity for retraction is rather limited.	during lymph nodes sampling in cystectomy	
U16	Some of the broader movements with your hands, like for example when you are trying to move the bowel while doing part of the anastomosis. It is particularly quite annoying when trying to move the caecum off and you get the terminal ileum when you're measuring levels, because there is not sufficient range in the instruments to do this, like there is in open surgery. We only use three or four instruments per case, usually small scissors, as there is nota variety of scissors and every scissor we use is the same scissor- there is no big, small , or sharp scissor.	-Less articulated and variety of instruments	-Instrumentation -Articulated instruments
U17	In minimally invasive surgery and the robot surgery the surgeons don't have tactile feedback. The surgeons don't have the sense of the tissues that they are manipulating and it affects the patient overall, including suturing.	-Haptic feeling	-Haptic feeling

What kind of grasps do you use during open/MIS/RAMIS?

What different grasping methods/grasping instruments would you welcome?

	Interviewee description
U2	• With RAMIS, we use Bipolar forceps or ProGrasp forceps. • With open surgery, Kelly forceps, retractor etc.

U3	• With the RAMIS, ProGrasp forceps. • Sometimes the hand is better than RAMIS.
U4	• ProGrasp forceps, Maryland forceps • **AB** would like something that informs the grasping feeling.
U5	• PK dissecting forceps, Maryland forceps, Bipolar graspers • PK dissecting forceps like grasping mechanism is fine.
U6	• Cadiere forceps, ProGrasp forceps • Maryland forceps, PK dissecting forceps, Fenestrated bipolar graspers. • If instrument is used so many times, it does not work.
U7	• Maryland forceps, Cadiere or ProGrasp forceps
U8	In open hands, scissors for decision, the laparoscopic graspers. The current grasping mechanism is simple for me.
U9	A coagulation electro-cautery grasper bowel grasper (Pinch but never closes completely to prevent blood supply to bowel). The traction is to move things around the pelvis. Needle holder which provides pinch grasp. In open, hands to grab big tissue. Prograsp (Maybe more like one centimetre, 1.5cm), the bowel graspers are actually too big, they are about this sort of size. The surgeons would like the smaller bowel graspers which are more manoeuvrable.
U10	Bipolar graspers
U12	Bipolar scissors, bowel graspers, which provides pinch mechanism that does not cause any trauma to bowel.
U14	In robotic and in laparoscopic surgery, there is Maryland, which do the pinching manoeuvre but in open surgery, the surgeons have everything. The surgeons can apply pressure, put clips, tie if they found anything for example like bleeding or injury to adjacent structures or organs, they can- any movement and use what they want The feeling during the MIS or the robotic surgery is missing - the feeling of the tissue, the feeling of the tension.



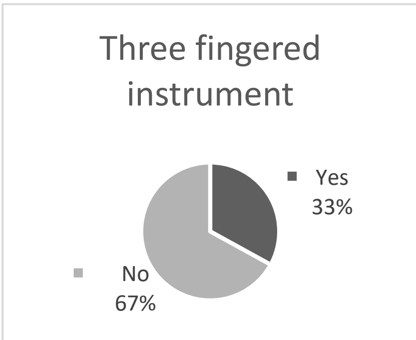
(See APPENDIX-E)

What would you change about current manual MIS/RAMIS instruments?

	Interviewee description	Codes	Categories
U2	• There is no need of the instruments. One of the most needed the instrument to change was to mobilise the bowel but da Vinci provides it with da Vinci Xi system.	--	--
U3	• Grasping of the tissue or the needle holder could be improved. The force generated by the instruments sometimes is very less and could be more during grasping the tissue. There is no control of the force during the grasping with the traditional MIS instruments.	-Grasping of tissue or needle holder could be improved. -Less force generated by instruments during grasp.	Grasping mechanism
U4	• There is nothing to change.	--	--

U5	• No particular opinion	--	--
U6	No, I don't want to change	--	--
U7	Easier system to put clips or haemolocks. Forceps get wear off. It is better to have disposable instruments too.	-Disposable instruments	Instrumentation
U8	No, I do not want to change.	--	--
U10	No, I do not want to change.	--	--
U17	It wouldn't be single port, but to be able to bend the instrument or have even an already bent instrument.	-Articulated instruments	-Articulated instruments

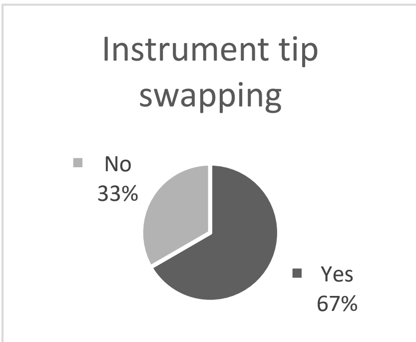
Would a third finger be of use?

	Interviewee description	
U1	It would be user unfriendly. It would be great for the mono-port surgeries and it could help in dissection.	
U2	**U2** would like to try it first. Not have the clear idea.	
U3	It may not be useful. **U3** would like to try it first before the comments.	
U4	**U4** would like to try it first.	
U5	Yes, it would be of use.	
U6	I think, we do not need it at all. For vision, single port is OK but there are conflicts with the instrument arms. This would just complicate the things.	
U7	Yes, it may be interesting because of more than one articulation.	
U8	I think, three fingered instruments in prostatectomy no, in nephrectomy, it is helpful. It could be used to grasp the kidney and others could be used for suturing. This approach could simplify suturing for the	

	partial nephrectomies. Another example is to grasp Gerota's fascia.	
U9	Three fingers are not really that useful and the only reason that the surgeon want that is the possibility to have many different instruments at the end. But the wristed articulation is missing.	
U10	I do not have opinion about it.	
U11	It may be helpful in nephrectomy (for example, move the intestine, I take it and move it. Now I need to pick it with an arm and move it like this. I take it with two grippers but without a lot of force I don't have grip and I risk damaging it. If I can take it, grab it without pressing too much ...like I can with my hand ... I need to take the kidney ... I need to take the kidney from the fat, ripping it away. The kidney is wrapped in this adipose capsule ... either I move it as I was telling you or I take a piece of fat that I grab on and pull it here or there ... but I don't have good grip. I don't put it exactly where I want, I put it where I can. If instead I had an instrument with a little grip, if it has grip I can pick the kidney, take it there and work on it). If the gripper is only slightly larger than the gripper of a forceps it would be good.	
U12	No, no you don't need that kind of thing in robotics, it's fine.	
U13	Surgeons could adapt to it and it would make a difference. For example, holding a needle in the plane during the stitching. It could help to grasp or do something it a better way then for different operations it might add something.	

U14	A third finger for stabilising, for instrument stabilisation would not be a good idea, but it could be useful for camera.	
U15	U15 feels it is less helpful and could not provide the same articulation as da Vinci single port.	
U17	For the suturing, the instruments for the suturing with the robot are fine, they don't need to be increased in terms of range-wise or size-wise. The change of the size or the articulation would not make a huge difference in these tips.	

Would you want the instrument to have tips that can be swapped over so that the same main instrument can perform as different tools if it has more than one digits?

	Interviewee description	
U1	It could be nice.	
U2	It would be great.	
U3	Yes, of course. For example, to change monopolar curved scissors to robotic needle driver during the partial nephrectomy.	
U4	Yes, it will be helpful.	
U5	Yes, it is good.	
U6	Yes, that could be a good idea.	
U7	Yes	
U8	There is no preference for changing the tips	
U9	Clipping and cutting with the same instrument for example that could definitely save time and if it could also change into a	

	needle holder and do some stitching and that the needle would somehow be delivered at the end of that instrument particularly if the assistant is junior, which often they are- they are not used to putting the instruments in so you often find that you have to take the camera back to find out where they are bringing the instrument in from, follow them in, next time grab it and take it out. That would be useful or even if you would have scissors and needle holders- that would be something.	
U10	Yes, probably it is helpful because you change the instruments every time.	
U11	No, it would not be of help.	
U12	Well, yeah. This is a good idea and could definitely save some time.	
U13	The surgeons could cut accidently with such complex instrument. So, if we can do something like single port would be a fantastic change.	
U15	It depends on the surgical team but it may reduce the time.	
U16	It could be useful because there are some areas where **U16** would prefer to use the fenestrated like lymph node dissection and for nerve sparing areas **U16** would prefer to use a finer Maryland.	
U17	For the stitches or to control the bleeding. This could be useful, especially for people just starting with robotic surgery.	

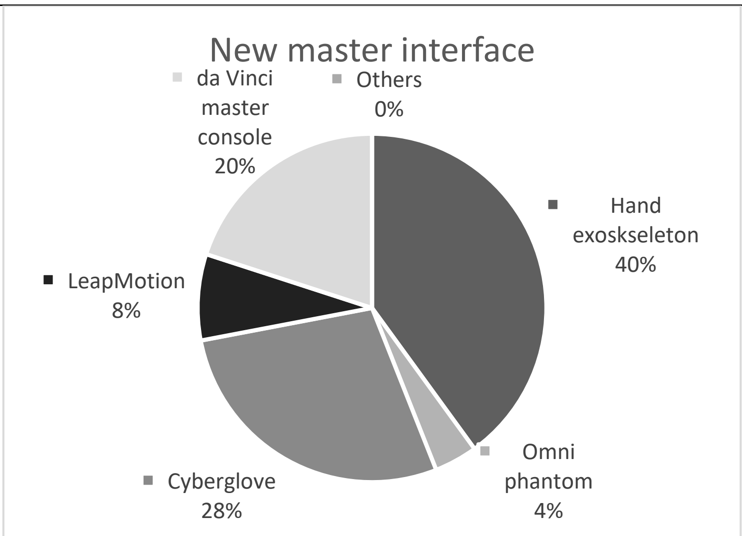
Master system

Note: the master system is the device used to tele-operate the instruments.

How would you prefer to control the instruments? Using tele-operation? What kind of interface?

	Interviewee description
U1	• Cyber-gloves, exoskeleton, or leap motion • Wires and other things in exoskeleton are not very favorable. • Tactile feedback is very important but not necessary. • Perfect position would be like the 'drummer' with the good back-rest and free hand movements.
U2	• Hand systems are very interesting. Joysticks are not preferable. With da Vinci, the surgeons get more concentration as it creates the parallel reality. GC prefers the da Vinci console as well. • Sitting position on da Vinci console is very comfortable.
U3	• da Vinci master is good to control the instruments. • Cyber-glove • Exoskeleton is good but weight of the controller could be the problem for longer surgeries.
U4	• da Vinci master is good but exoskeleton and cyber-grasp could be helpful.
U5	• If master system is near to patient, it is preferable. • Hand exoskeleton is preferred
U6	• da Vinci console • If it is possible to transform the movement of all hand and replicate the movement of arms omni phantom and then exoskeleton are desirable.
U7	• Da Vinci system is like a virtual reality console. You do not need to think how to move the master console. Possibility to move all your fingers. Exoskeleton. The weight should be small and it needs the arm rest.
U8	Cyberglove and hand exoskeleton
U9	Yeah, I mean operating remotely is fine
U10	da Vinci, Hand exoskeleton
U11	Exoskeleton but less weight
U12	The image quality is not good. Cybergloves are good. The console should be small and the arms should be more flexible.

U13	From a hygiene perspective, it's attractive to be away from the patient; you look instantly look at the Da Vinci and think: Reliable, have been using that for a while and know exactly what you are getting It might be for example using a glove or two bands around the fingers for the three-fingered instrument rather than having a constraint of the console but the arm rest gives the surgeons almost the triangulation to work Oculus rift - that would probably work. if you're sitting down that means you will have to keep your hands steady in front of you for a long period of time unless you design a special chair in which you can sit comfortably.
U14	BRL exoskeleton or the Cyberglove or this one for the features because every surgeon has different hand size and different feeling, so it should be adjustable.
U15	The leap motion is obviously far more natural, where basically a computer monitors location of your digits. Or the glove device, where you can have different glove sizes



Vision

Do you use cameras/endoscopes/laparoscopes?

Laparoscopes (**U1 U2 U3 U4 U5 U6 U7 U8**)

Are they 2D/3D?

2D (**U1** 3D (**U9**) 2D and 3D (**U12**) 3D (**U16**) 3D (**U8**)

2D (transurethral partial prostatectomy (**U5**) **U3 U4**)

What are the barriers in the laparoscope of the daVinci/laparoscopy and how do you think they could be overcome?

	Interviewee description	**Codes**	**Categories**
U1	The camera frequently gets dirty.	-Camera gets dirty	Image quality
U3	The current laparoscope is not very flexible	-Flexible camera	Flexible camera
U4	The camera frequently gets dirty. The camera could be positioned at a larger distance and with a fixed focus.	-Camera gets dirty	Image quality
U5	da Vinci Xi's laparoscope is good. da Vinci Si's laparoscope was not as good and vision was not clear. Camera gets frequently dirty and need to be removed for cleaning during longer procedures.	-Camera gets dirty	Image quality
U6	I would like if the scope could be flexible to see better.	-Flexible camera	Flexible camera
U7	With da Vinci Xi, the laparoscope is small and gets dirty. da Vinci Si's surface is larger, but with Si, you could not use different arms i.e. fourth arm.	-Camera gets dirty	Image quality
U8	There are no problems.	--	
U9	Articulated scope would be good to be able to look around corners. Moving the camera around is a different concept than the 0 to 30 degrees e.g. flexible cystectomy, flexible sigmoidoscopy, colonoscopy – good if automatic	-Flexible camera	Flexible camera

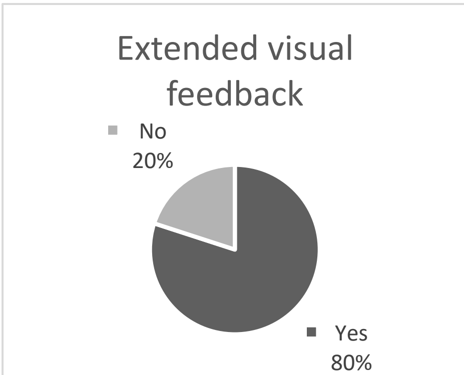
U10	Camera gets dirty but it is normal.	-Camera gets dirty	Image quality
U11	The lens is very small and fogs up easily. The miniaturisation in a smoky area must be taken into consideration.	-Camera gets fog easily	Image quality
U12	Image resolution could be better. The camera always need to be warm otherwise everything becomes blurry in the abdomen,	-Camera gets dirty	Image quality
U13	It would be good to define nerve bundle when doing prostatectomy or pelvic surgery. da Vinci system's camera is very long (30 cm) and it clashes with assistant instruments.	-Camera is very lengthy	Camera length
U16	No, I am very pleased with the vision of da Vinci.	--	--

What are your requirements in terms of field of view?

	Interviewee description	**Code**	**Categories**
U1	Pelvis size would be around 15 cm.	Around 15 cm	Field of view
U2	Operative area would be around 20 - 25 cm, while the actual working area would be smaller.	20 -25 cm	
U3	Pelvis is between 10 – 20 cm. It is about the same. Magnification is not helpful. The surgeons would like to maintain the same vision e.g. without the magnification, during operation time. The current field of view is sufficient.	10 -20 cm	
U4	Pelvis is about 20 cm.	20 cm	
U5	10 cm^2 or less for both prostatectomy and partial nephrectomy. With some surgical	10 cm or less than 5 cm^2	

	phases like nerve sparing, the area is much smaller, less than 5 cm^2.		
U6	10 cm^2 when doing a close surgery. The overall scenario would be 20 cm^2	10 cm^2 to 20 cm^2	
U7	10 cm^2	10 cm^2	
U9	A wider field of view would be useful to remove the need for an assistant instrument surgeons' to move the camera.		
U10	10 cm	10 cm	
U11	10 cm – 15 cm more or less	10 cm – 15 cm	
U12	The same field of view	--	
U14	No, I am happy with it.	--	
U17	The vision gets darker and the surgeons cannot see well. But in terms of field of vision, it is ok.	--	

Do you need visual feedback in wider areas e.g. behind obstacles (other organs)?

	Interviewee description	
U1	Not needed. 3D perception is more than enough.	
U2	• It would be useful in selected conditions e.g. working on the bowels or longer structures. • To look behind obstacles, it could be useful esp. in radical proctectomy or trans-corporeal reconstruction where the surgeon needs this extra information.	
U3	Yes, it would be helpful. For example, to see the big vessels, renal vein or arteries behind the fat.	
U4	Yes, absolutely.	

U5	Yes, it would be helpful to get visual feedback on arteries or veins that I could not find in my operative field.	
U6	Yes, of course. First of all, knowing where the vascular structures are, for kidney veins and arteries. For other surgeries, functional aspects, tumor lymph nodes close to vena cava or aorta where the nodes are exactly located and to be sure for example retroperitoneal lymphadenectomy PET scan.	
U7	Yes, it should be interesting. U7 knows some systems which could identify arteries and veins on superimposed CT.	
U8	It is important for me to have a visual feedback. For example, in kidney surgery.	
U9	It would be great to be able to see where the tumour is in real time during the operation with MRI scans, superimposing that onto the prostate to see where the tumour is, so surgeons have 3D images of the prostate cancer in actual images.	
U10	Probably, it is helpful. Immersive stereo viewer.	
U11	I need to see the structures relative to each other e.g. kidney behind the intestine. I would like to see it like Google street view.	
U12	No, the surgeons have to take the bladder down to see prostate. There are some steps in the robotic prostatectomy like anastomosis where the angles are a bit weird and even if we know we have 360 degrees, it is a bit difficult to do everything and the anastomosis well.	
U13	The main complications after a radical prostatectomy or pelvic surgery is damage	

	to the vascular bundles, which are the nerves that go to the penis to enable erection and incontinence which comes from damage to the pelvic floor muscles or damage to the nerve supply to them.. To protect them. Some men do get – for the same reasons- damange due to how their bowel works. To prevent this, the surgeon should distinguish between the tissues that goes to those structures. Fusing MRI scan to the vision would be useful extra visual information.	
U14	In Nephrectomy, the surgeon doesn't have any problems and in cystectomy it is always better to have flexible instruments e.g. flexible camera or flexible scissor or flexible Maryland. However, at this point, flexible camera would not change the prostatectomy or cystectomy or partial nephrectomies procedures. smart glasses is not a good idea.	
U15	You would be able to alter your field of vision depending on your surgical needs - sometimes you do need a large field of vision and occasionally you do need to be able to visualise to look beyond structures which are, not perhaps accessible or manoeuvrable.	
U17	Apart from robotic prostatectomy, the surgeons do not really need to go behind organs.	

When operating, do you communicate efficiently with the rest of the surgical team?

	Interviewee description	
U1	Mostly the verbal contact.	
U3	Yes	
U4	Yes	
U5	Yes, very easily.	
U8	Yes, I could communicate very efficiently.	
U9	Senior assistants do assistance without asking anything.	
U10	Yes, I communicate	
U11	Smart glasses for assistants would be helpful.	
U12	Yes, the teleoperation is fine.	
U13	The communication is OK and **U13** does not feel separated. Smart glasses would be a distraction.	
U14	Yes, communication is very good	
U15	The consultant surgeon is often in the corner of the room, there's no eye contact with the rest of the team, the team can't take any visual cues from the surgeon. The audio equipment on da Vinci system is terrible.	
U17	Yeah, absolutely, I can really communicate with the rest of the team. Smart glasses would be a bit distracting and it's not going to make a difference. What is important is what's inside the patient not what is outside.	

If you are a da Vinci user, do you feel immersed in the da Vinci console?

If yes, do you welcome this or would you prefer to also have greater awareness of your surrounding environment?

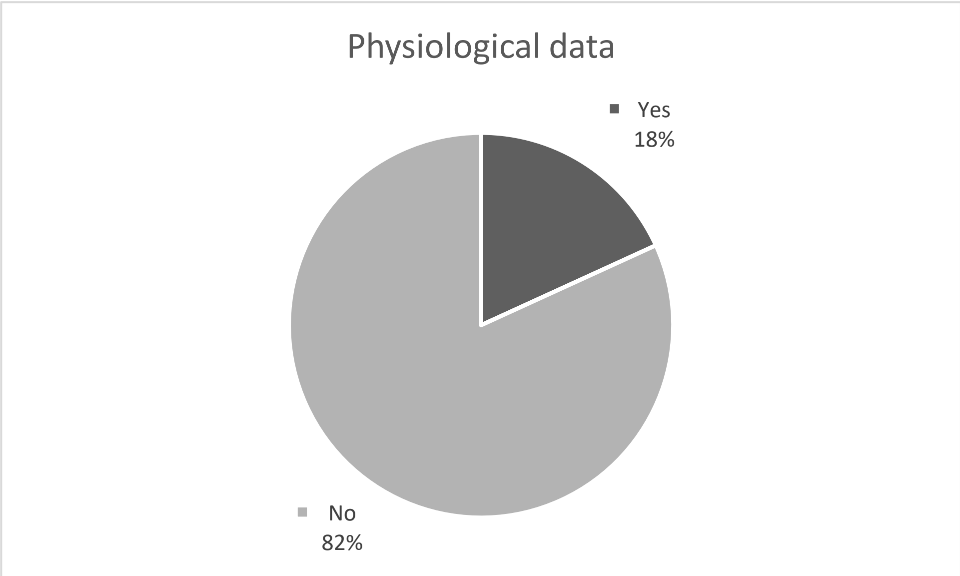
	Interviewee description
U2	Any kind of immersed feeling is good to remove the distractions. So, the devices like immersive stereo vision is preferable.
U3	Immersive stereo vision because the surgeons generally need to concentrate and communication is mostly verbal with the team. Smart glasses would be more beneficial for the assistants.
U4	Yes, AB feels immersed with da Vinci system. AB turns off the lights when operating on the da Vinci. The immersive stereo vision could be good.
U5	Yes, I feel inside the patient and often too much. Ideally, during surgery, there is no relation with others. There is no problem with the immersion because you can remove the head. If the master system is in the other room, then it is the problem.
U6	Yes, I feel immersed. Smart glasses is not a good idea. Immersive stereo viewer coupled with instruments movement would be an improvement. Stereo viewer with exoskeleton is a good idea. With assistants, smart glasses is a good idea. Greater awareness is good for the surgical training e.g. to learn the surgical steps.
U7	At the beginning, but immersion disappears after using it for a long time. Immersive stereo device and smart glasses could be the solutions. There is a problem with the head movement that we do not have with da Vinci. In open surgery, we do not move the head and hand at the same time. It is very difficult to give the opinion. Of course, we need greater awareness.
U8	Yes, I feel immersed with da Vinci console. Oculus rift could be helpful.
U9	Yes, I don't think it's a big issue to be honest, I mean they are only 3 metres away, sometimes you can't hear them very well and the sound system is not very good especially if it gets a lot of feedback so everyone turns it off.
U10	Yes
U12	Immersed - Not at all.
U15	If the team wear the headsets they will be more engaged with the surgical procedure and the environment rather than trying to get the surgeon more incorporated into the theatre environment.

	There is a potential advantage but from an ergonomic perspective, wearing a pair of oculus headset all day would be cumbersome and there is not any advantage relative to the da Vinci console. The oculus will not allow the surgeon to interact as easily with the theatre environment. The surgeon would have to keep taking it on and off.
U16	It is more detached, but it sorts of addresses the issue with the dual consoles, but those are very expensive at the moment. With the dual consoles, certainly the training is bit more difficult. The trainees should definitely have access to 3D visualisation as well to be giving them a feel as well of what is going on. The fact that the trainees see in 2D and the surgeon sees in 3D, it is not fair to the trainee to get sort of, to appreciate the full anatomy, so that would be something to definitely look at, to have 3D for the assistants.
U17	No, one of the main advantages of the da Vinci is that you are just seeing inside the patient, you are kind of in another room and you don't know what's happening in the theatre, you have guided contact with assistant, your patient is just next to you, This is a very good thing.

In this respect, would you welcome such information displayed in your vision during surgery? If yes, what kind of information (e.g. physiological data)?

	Interviewee description
U3	For urological surgeries, it is not very helpful but for intra-abdominal pressure information would be helpful.
U5	No, it is not important as we are near to anesthetist's monitor.
U6	No, we don't need it
U7	Yes, it should be interesting
U8	I do not want to see the physiological data.
U9	No, it is not for me It is too much information.
U10	Yes, of course but not in the view. A lot of information is not good. I could ask anesthetist.
U11	No, it is of no interest.
U12	Information on blood loss would be very useful.

U13	I don't want to see the physiological data, that is what for anaesthetist.
U14	No, I don’t think so. U14 is interested to know if there is bleeding or if there are any problems that U14 needs to know. Information about blood pressure or heart rate, are available from the anaesthetist. Data regarding tissue manipulation, for instance, would be helpful.
U15	I would like to know the blood pressure and blood loss.
U16	An image, that represents physiological data, that could be projected onto the prostate, I would be very distracting. There should be a switch on and off for that.



Camera control

In manual MIS, the surgeon communicates with the surgical assistant for positioning of the camera. Da Vinci has a clutch system for controlling the camera using the master handles.

If you are a da Vinci user, how would you rate the Da Vinci’s system in terms of efficiency and ergonomics?

	Interviewee description
U1	95% efficient
U3	It is efficient. It is time consuming to change the position of the camera.

U4	It is good.
U6	It is pretty easy.
U9	Yes, it's very good. you cannot look around the corners very well.
U10	100% efficient

Is a teleoperated camera holder required?

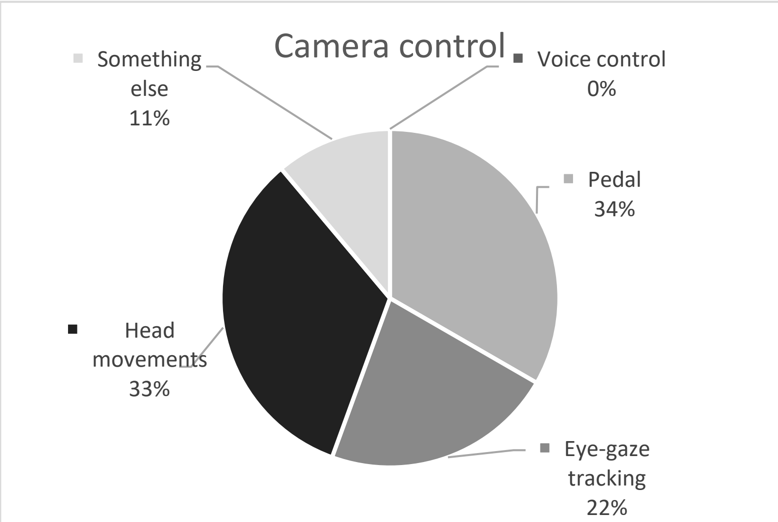
	Interviewee description
U2	It is good to have the manual movement of the camera.
U4	It would be better than clutching
U5	No, the current camera control is comfortable. No, automatic tele-operated camera is needed. The autofocusing functionality is more important than automatic control.
U6	Yes, but not automated
U8	Yes, the automated camera is needed.
U9	Sometimes, the surgeon is not be able to see at 30-degree angle of the camera and that requires to change the viewpoints. The solution could be the articulation or double cameras. If there is a camera that could move and articulate around the corners that could be quite useful actually. Self-camera control is better.
U10	Yes, it would be helpful.
U12	Yes, it would be helpful.

How would you prefer the camera was controlled (e.g. voice commands, eye gaze tracking, head movements, foot pedal, other)?

	Interviewee description
U2	Voice commands and hand control are annoying, while the foot pedal is preferable.
U3	Eye gaze tracking, and head movements (it is difficult for longer surgeries).

U4	Eye gaze tracking, and head movements would be helpful.
U5	Eye gaze tracking, and head movements. Head movements could be useful but it is not comfortable.
U6	Pedals are very good. Voice commands are not at all. Eye gaze tracking and head movements may be but still we need a clutch. Without clutch it may not be very ergonomic.
U7	I prefer to control the camera with my head but I would like to have a camera fixed without using a pedal.
U8	Foot pedal would be needed.
U9	Pedal - it's pretty good Head movement - of course, but that can lead the surgeon to awkward angles and the surgeons needs to move around in the theatre which is not good for the sterile environment. 3D googles - I am not sure.
U10	Foot pedals are good.
U11	A pedal to activate the head tracking process to move the camera and release it afterwards, it would be fine.
U12	Foot pedal **U12** says that this is the least of his problems right now.
U13	Eye-gaze tracking - so for instruments or moving, the simplicity of moving the instrument with your hands and keeping things at the centre of your vision is the priority, so if you have something that for example tracked your eyes, ok Head movements is not a good approach unless the console is fundamentally changed because head movements means we will all be moving our heads around and that's not good for our necks and everything else, but if you had something that tracked the eyes, you know the natural field gaze to move around, then that would be interesting
U14	Head movements would be needed and helpful.
U15	A static wide field and then perhaps having a magnified view of where you are actually focused might be helpful.
U16	No, I'm quite happy with the hand controls. I think hands are good. The clutching with the finger is much better.

U17	Clutching would allow surgeons to focus on other things during the surgery like diathermy. Head movements could remove the need for an assistant.



Would you wish to move, extend or focus the field of view by moving your head around?

	Interviewee description
U2	Yes, with the immersive stereo vision
U3	Yes, but the head movements are difficult for longer surgeries.
U7	Yes, I would like to
U14	In the da Vinci Xi, one can manipulate the instruments to for the whole procedure with two fingers and at any time if you have blurred vision or abnormal vision you can choose to use the index finger to adjust the vision. if I can move the camera with just head movements for example and, if I want to look to the right now I should press on the camera and direct my instrument to the right side. If I want to look to the right side, then the camera will go direct to the right side.

Active constraints/No-go zones

Note: ‘Active constraint’ is the process of labelling regions of the patient's body, e.g. a vessel or a nerve bundle, with one of the four possibilities: safe, close, boundary and forbidden. Surgeons label safe regions the regions that are appropriate for the robot to be and to operate in. One way to use them is to stop the instrument from entering forbidden zones by force resistance exerted by the master device. The other way is to highlight by virtua reality those zones and/or signal with alternative sensory channels as auditory or vibration.

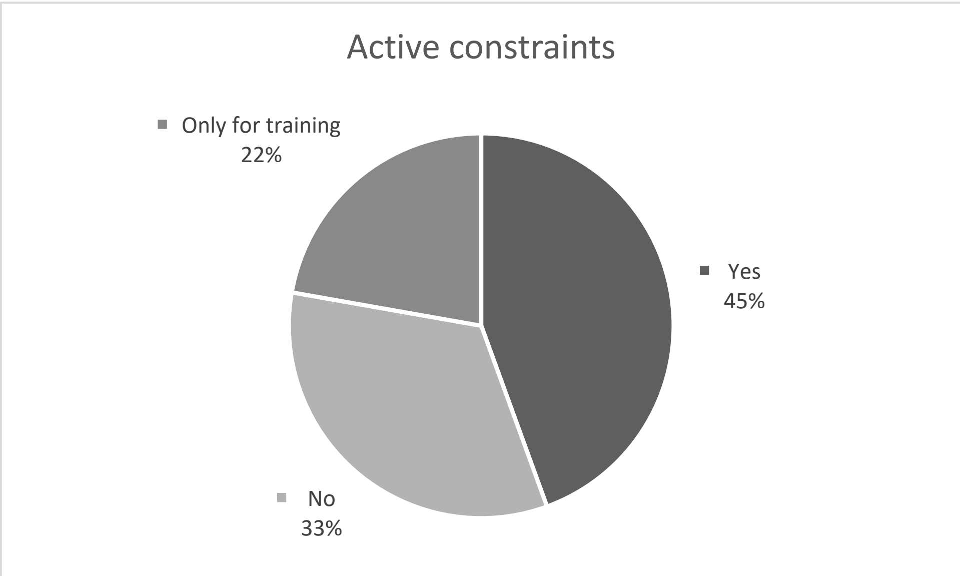
How could 'active constraints' help you during a surgical operation?

Would you like knowing that the instrument would not enter or even touch the boundaries of forbidden regions and/or tissues labelled by you (the surgeon) in a preoperative and operative stage?

Would you like the robot to keep the instrument at a certain angle, e.g. normal to the operating path, specified by you to help you guide it?

	Interviewee description
U1	• If the functionality was there, the overriding functionality would be needed.
U2	• It is not preferred to have active constraints and limitations with the landmarks. • Overriding capacity is also not needed. • Active constraints would distract attention to the task.
U3	• It may be very useful for younger surgeons or for the training. For experts, free movement of instruments is preferable. • It may be useful for preventing the damage to big vessels.
U4	• It could be helpful during the proctectomy to prevent injuries to nerves and small vessels. • Overriding capacity is needed.
U5	• Yes, it could be useful. • Putting active constraints labels on the regions may increase the surgery time. • Sometimes we use the third arm for the traction. Arteries and veins are generally not visible, active constraints could prevent these injuries.
U6	No, active constraints would not be helpful. It will only be helpful in training. Except that, it is more dangerous to obstruct surgeon's actions. Active constraints with colours would be very interesting, but so far, we did not find it useful. Surgery is not same as the pre-operative field.
U7	Yes. There are many things nerves, arteries, veins during lymphadenectomy where active constraints could be helpful. Yes, it should be interesting if we can override it. Blocking of actions is not desired but just an awareness is enough, for example using visual information. Active constraints should just put the limitation, not full repulsive force.
U8	For prostate surgery, it may not be helpful. For kidney surgery, it could be used for renal arteries, anonymous vascularisation with supplementary artery. There is no danger in neurovascular dissection.

U9	Active constraints could be helpful. For example, during prostatectomy, the surgeons have to push the blood vessels to the side to get the lymph nodes out so the barriers could be there and the surgeons could not touch the blood vessels. Then the surgeons could to go to the blood vessel and take the tissue just above the lining of the blood vessel. If for example these vessels supply the blood to the leg, and the surgeon couldn't touch those, then the nodes cannot be taken out properly. In prostatectomy, the surgeon could label the rectum as an alarm system, and to be warned when getting close. Active constraints would not, be necessary at the moment. Instruments at certain angle would not be helpful because the surgeons always change the path to get the thing out, so it wouldn't be helpful.
U10	It could be helpful in lymphadenectomy during radical prostatectomy.
U11	It's something that can be more useful when you're in training. You have difficulty orienting yourself, understanding where you are, orient yourself in space relative to the organs so having a satnav relative to an organ can help you, but at the beginning of the training. When you're a more expert surgeon, it can be used for example not to hit the spleen.
U12	It would be extremely helpful when you are training someone with the simulator and drawing a line with Si is also possible.
U13	Active constraints could be helpful for planning wise and it could be useful for the nerve sparing procedure.
U14	In prostatectomy surgery, you have something called accessory vessels coming from the pelvic-side wall to the prostate and you try all the time not to touch this vessel, not to cause damage or bleeding at this point. It may add some benefit, but it won't be a huge step. In kidney surgery, it could be helpful because sometimes you are dissecting the artery and vein away from the vena cava and the aorta and if you want to label the aorta and cava as no-touch areas, it could be good. I prefer to just have total control on the procedure and not to have the robot adjusting the instrument angles.

U15	Yes, that would be useful especially-as a trainee that would be particularly helpful. I think that having the warnings would be useful. People who are experienced at procedures may not necessarily need it but it would be a good training tool. You have isolated the nerves you know where they are, so marking them out intra-operatively would help. Pre-operatively it would help the trainee, butit would not help the senior experienced surgeon.
U16	If you get too many inputs it might get a bit confusing so one will have to try. If there are many inputs, that gets annoying as well.
U17	I'm not so certain how this could be helpful.
	

Haptics

Note: Haptics is the tactile-kinaestetic feeling, which is presented in the interaction with the body through the instruments.

How important is haptic feedback during surgery for you?

Not need it really (**U1**)

Not very important (**U4**)

Not very important (**U6**)

Yes, it is important **(U7)**

What type of haptic feedback would be useful to you (e.g. force feedback of pulling/pushing tissue and surrounding structures or of the thread tension during suturing, force feedback during grasping, texture, temperature)?

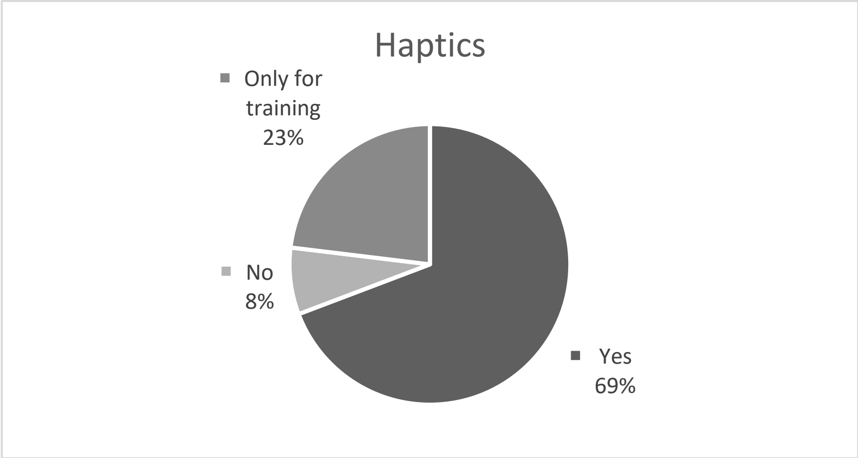
Would it be helpful to 'exaggerate' this feeling, i.e. scaled up from the measured exerted force on the tissue? Important not very.

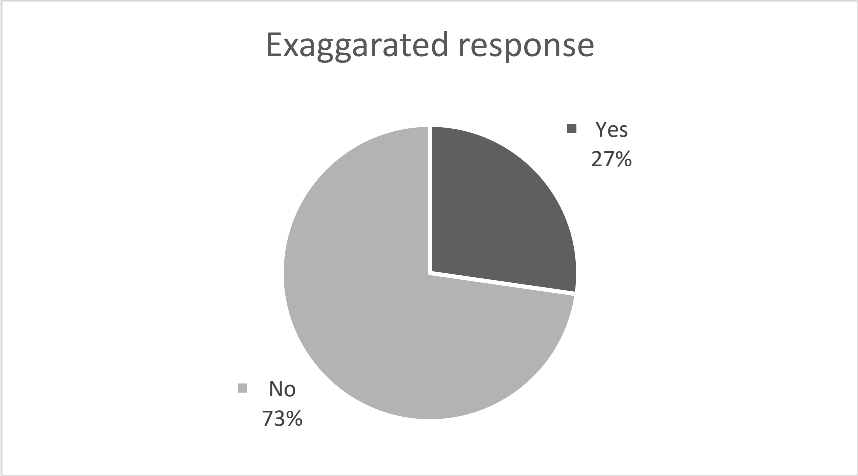
Would alternative sensory information be useful as a replacement to haptic feedback or as complimentary to it (e.g. acoustic signals/visual cues/vibration proportional to the exerted force on the tissue or as alarm for over-the-threshold forces)?

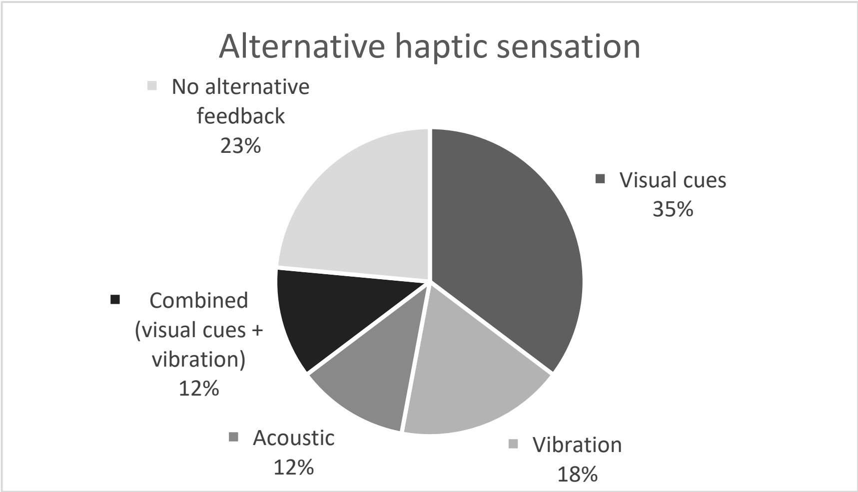
	Interviewee description
U1	• Tactile feedback could be useful with the training e.g. to identify the public bone. • Tactile feedback could be useful for the advanced and large tumors e.g. to identify the remaining tumor.
U2	• No, tactile feedback is not needed, only welcomed if it is easy to use. • Surgeons generally develop visual perception and learn how machine reacts. It would also not be helpful with the training. • Sound could be annoying. It may be helpful to have visual cues.
U3	• Yes, haptic feedback is desired. All type of forces is required to understand the consistency of the tissue. • Exaggerate feedback is not needed. It would be good if it gives the realistic haptic feedback. • Alternative sensory information is not needed and it will create information overload. Surgeons need only realistic tactile feedback.
U4	• Yes, exaggerated feedback is good. Scaling functionality could be the good functionality. • Visual cues would be helpful.
U5	• Haptic feedback is important for all the maneuvers • No, the scaling is not needed. • If we can have the real perception, that is perfect. Alternative sensory information is not needed.
U6	• Exaggerate feeling is a good idea. • Vibration and Visual cue could be good alternative feeling
U7	• Yes, during the dissection of two organs or dissection of nerves and so on. It should be good to have a good feeling. Visual cue is the best. Vibration is also interesting. Two types of feedback on visual and vibration the same as in the open surgery.

U8	Suturing the parenchyma in kidney surgery. This could be used in lymphadenectomy in radical prostatectomy during the dissection. No exaggerated feeling would not be needed. Acoustic signals are good.
U9	At the moment, it is not a big issue and the surgeon can certainly do without the haptic feedback. It may help more about the tension (suturing thread), for example, tying the knots. Alternative haptic sensation the visual cue would help. No, I think probably normal force would be fine, but no the exaggerated.
U10	Yes, it is helpful. Force feedback with puling/pushing tissue Exaggerated feedback – no Probably vibration is a good sensation as an alternative feedback
U11	It could be more useful to feel the tissue texture and consistency than temperature of the tissue.
U12	Haptic feeling for thread and tissue pulling. Exaggerated force: In practice U12 cannot tell right now. I think that all these things could be useful during the learning curve but at some point, they are probably not that important.
U13	Alternative haptic feedback would be distracting. It would be useful to get a feel for the feeling in between the fingers. Exaggerated response: It is an unnecessary potential distraction because you are exerting too much force for this tissue
U14	Yes, of course In many cases, when we do urethral anastomosis which is done the prostate surgery which is connection of the urethra to the bladder, sometimes we tie too much and we cut the thread and we have to repeat the whole step from A to Z and it would take another 20-30 minutes to repeat all these steps. If I can have for example an alarm rather than a feeling. Yes, visual information for example 'you are tying too much, you are pushing too much, so visual cues would be helpful. Exaggerated feeling should be just the same.

U15	Haptics could help to differentiate the different tissue types and pathological processes. The other advantage of haptics is that it allows to manipulate tissues with haptic feeling. It would allow to handle the tissues and the enhanced retraction it offers relative to robotic instruments. Exaggerated feeling – yes, it would be helpful in terms of a potential warning to the surgeon, but you have to handle that tissue with greater care- so it could almost be used as a warning to be more delicate in that area. On and off function - Switch on and off, I think it would be potentially a great surgical training tool.. Alternative sensory - visual alarms would be better. An audio alarm if it was an absolute emergency my preference would always be feedback through the hands as a surgeon because it is such a tactile specialty.
U16	Haptics could be helpful as the force feeling between your fingers or when you are pulling and pushing tissue, or the thread of the suturing In the early learning curve, it would be a tremendous advantage. It would be an addition particularly for very difficult cases. Off and On functionality is Okay. Exaggerated feeling would not be needed. Alternative visual feedback should be visual, with a big light maybe. You could even have a combination of the two. Because sometimes even now with the robotic instrument, you got too much tension, it does tell you, uh when you are sort of over-using the wrist, but that doesn't tell you about the tension and the actual suture, so I think visible would be better.
U17	Haptics would be helpful as force feedback, force feeling between your fingertips or when you are pulling, pushing organs or pulling pushing thread.







Pre-op Images

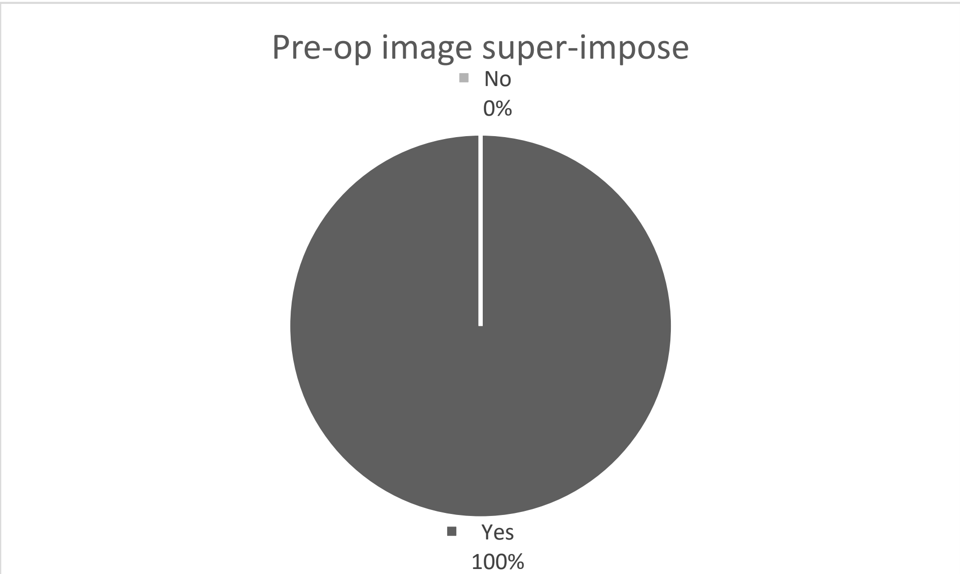
Do you use pre-operative images? If yes, what type and why?

CT, USG, MRI (U1 U3) CT, MRI (U2) MRI for the prostate, CT for nephrectomy (U4)

CT MRI (U5) MRI, CT (U6) MRI, CT (U7) MRI is the best imaging, you can use ultrasound scanning (U9) MRI and CT scans (U12) Ultrasound and MRI (U13) So for kidney we use CT scan as pre-op imaging, for prostatectomy you use MRI scan and for bladder we don't usually use pre-op imagining so it depends on the histopathology (U14) for the prostate we use an MRI and the MRI is a multi-barometric MRI (U17) MRI (U8) MRI, CT (U10)

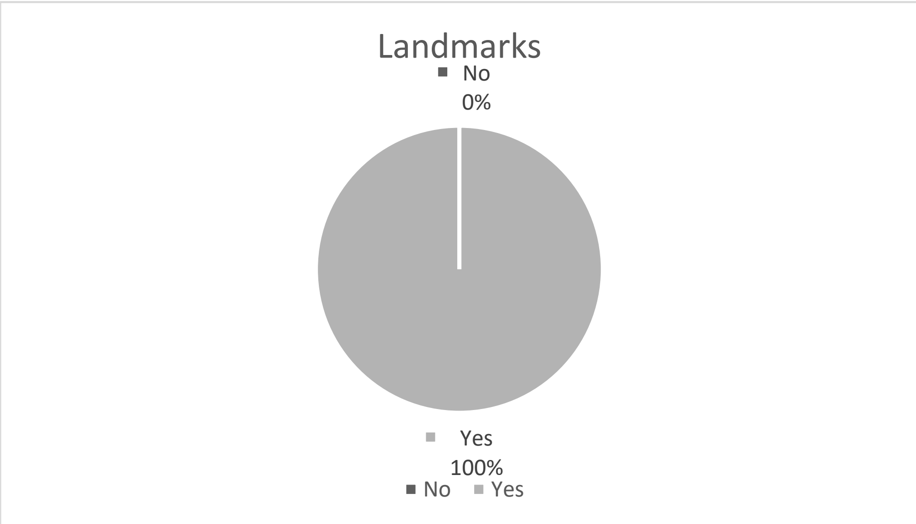
When would you need to super-impose such images on the vision of the laparoscope (e.g. to guide/help you identify structures in the abdomen)?

	Interviewee description
U2	It would be great. However, for the kidney surgery, the sonography is enough.
U3	To identify prostate tumour
U4	It would be great.
U5	Yes
U6	Yes. It is still better than what we have. When we performing the nerve sparing we need it.
U7	Yes, it would be needed.
U8	It is useful to define the tumor and dissection plane.
U9	Yes, that might help.
U10	Yes, I would like it.
U11	In renal tumours, the hardest things are to find the artery, the vein and tumour. Knowing where I am increase my spatial perception. We also use a 3D printer to make a model of the prostate to see where the tumour is. The information representation should be semi-transparent, I do `click`, overlay, see where it is with the overlay, When I press I'm not interested in where it is any more. I want to see it again, `click` it appears. We also do 2D ultrasonography to identify the tumour, which current projects on another screen during RAMIS.
U12	I would say that it would be useful because especially in partial nephrectomies the surgeons need to check medical images repeatedly, 3 to 4 times, so it would be helpful to have images integrate on the system.
U14	With MRI scan of the prostate intraoperatively can allow like nerve sparing, since it is visible on the MRI scan, as well as the tumour so it is possible to go

	very superficial on the tumour side and very deep on the other side to be perfect in prostate surgery. In kidney surgery, it's difficult to integrate the CT scan, because it's not 3D.
U15	It would be very helpful, but it's difficult because pre-operative imaging has to be malleable, it has to be able to change with the manipulation of the surgical fields. It would be useful, but it would be very challenging to deliver it in a useable way. It would be very useful to know exactly where the tumour is in the vicinity of the cancer, you can then leave a little bit of extra tissue on the prostate and do a partial nerve sparing in specific regions. Occasionally enlarged lymph nodes are in unusual locations, perhaps in locations in which you don't normally operate in. So, being able to incorporate pre-operative imaging would be helpful in those situations.
U16	Having an image projected onto the prostate, would be distracting, and there definitely needs to be a switch on and off for that.
U17	Superimposing images would be helpful to identify cancer margin from MRI. Currently, the surgeons do it cognitively.
	

How different is the operating field from the pre-op images (e.g. in terms of tissue deformation)?

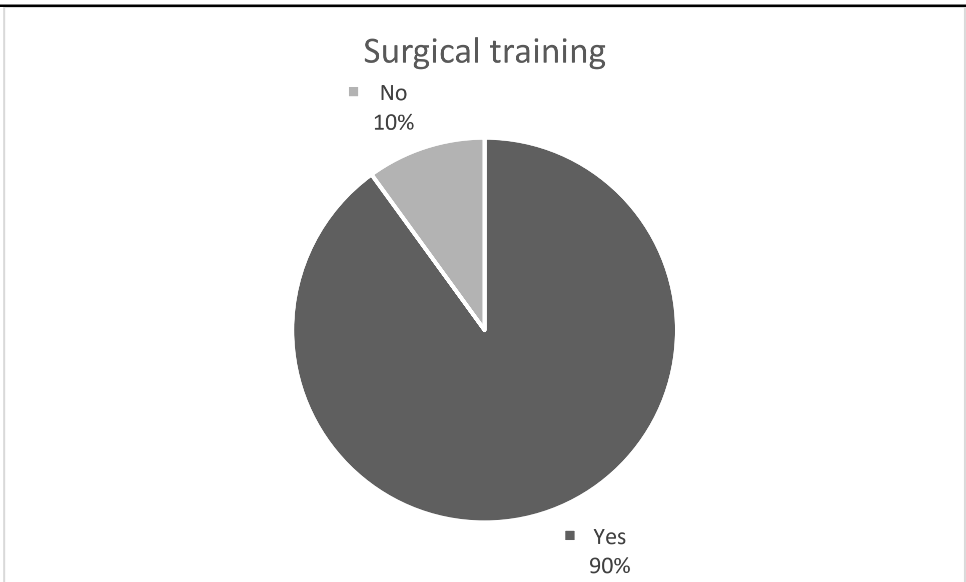
	Interviewee description
U1	• Tumor is always in a different position e.g. especially if it lies on the posterior side. • Anatomy is always little different. • Patient position and pre-operative and intra-operative images are different during the use case procedures. • Landmarks e.g. vessels, lower and upper poles of the kidney do not change so much during the pre-operative and intra-operative images e.g. **U1** would tolerate the difference of around 2 cm. • The surgeons use the ultrasound to identify the tumor. • Tumor sizes are generally 2 cm to 10-12 cm.
U2	• There is not much difference for parenchymal organs while the images could change for the organs like peritoneum. • Landmarks – big vessels, bones etc., for specific use cases, prostate, bladder generally won't move. The kidney moves with the respiration but not much because it is separated from the ligaments and the patient is under the anesthesia.
U3	• There is not much difference. • There are enough landmarks.
U4	• There is not much difference. • There are enough landmarks. For prostatectomy, for example, the nerves in MRI, seminal vesicles, apex
U5	• Yes, the images could be fused. The images are different only where there are pathological changes.
U6	• We pull and, move the prostate. In those cases, the prostate changes its shape. 7cmx 5cm could become 9cmx 4cm. Not so much change. Less than a cm would be a tolerated registration error. • Bones e.g. public bones, vascular structures and edges of the organs could be used as landmarks. Upper poles and lower poles of the kidney.
U7	• It is not very different. It is possible to fuse the images. • Kidney landmarks are easier e.g. spleen • For the prostate, it is difficult to find landmarks but could be the base of prostate apex.
U8	• Both the preoperative and intraoperative images are different.
U9	No, not really the problem is that when you do the operation the prostate moves, so I have to move it to the side, move it down to stitch a vein to the front. It's moving- so I don't know how you would get the image fixed, when you move the prostate, the image moves, and we are talking millimetres here, so I suspect that real time imaging is going to be almost too difficult. So again, I'm going to say it's

	one of those aspirational things and that what we really need is something that is going to label the tumour cells It could be different because the imaging just is not good enough at the moment.
U10	Probably there are some landmarks.
U11	Landmarks – we could make some pigmented points on the outer surface. On the bone structures, which are visible in MRI and CT. 1 cm registration error is fine. The prostate doesn't move, it mostly moves because the patient moves and breathes but the anatomy doesn't change much. We can see the pubic symphysis is above the prostate and the distance between it and the prostate doesn't change.
U12	Well actually, it would match the size the shape the middle lobe.
	

General questions

How do you expect a system like SMARTsurg will improve in new surgeons' training?

	Interviewee description
U2	• Generally training starts with the proctectomy. There is not any use.
U3	• It could help the young surgeons. It still needs supervision of the expert surgeons, as currently, the surgical training sometimes done with the dual consoles. It is difficult to improve the current surgical training regime.
U4	• Yes, it would improve the current training system.
U5	• Yes, it could be useful. You can use it with only the simulator or dry lab. The anatomy could not be understood without the animals or corpses.
U6	• Yes, it would be helpful for surgical training
U7	• The space to move the instruments are larger. Yes it should be better for training.
U8	• This system could improve the surgical training
U9	It would be better if the assistant has a 3D glass for the training for example, the assistant has Oculus Rift and the surgeon use the da Vinci system. If we summarise- 3D glasses for the assistant needed.
U10	Yes, it could be useful for the surgical training. Probably the assistive technologies could help with the learning curve.
U11	We did not have good simulators. I think, for training, it is a useful system.
U12	Oculus rift would be needed for the training.
U15	There is potential to provide enhanced feedback in terms of the technology telling the surgeon on a surgical team, what tissue types they are actually handling, whether it is nerve tissue or small vessel vascular tissue, pathological or normal tissue. It would be helpful if you could use traces which could isolate central nodes and potential microscopic metastasis it would be particularly helpful.



Closing remarks

Any other concerns about the technology?

	Interviewee description	Code
U1	• Being user friendly and easy to learn. • Synchronised movements of patient's surgical table and the slave system.	-User friendly -Synchronised movements of surgical table and the slave system
U2	• Preventing to learn the traditional open surgery. • The main problem is the planning of the surgery, the disease, or the specific case. • Best knowledge of anatomy would come with the RAMIS.	-Surgical planning is difficult
U3	• The size of the system is a concern.	-System size
U4	• Cost is a concern.	-Cost
U5	• Only concern is the movement of the arms in the console and it does require a lot of clutching to move instruments.	-Clutching mechanism

U6	• There are no other concerns. Just related to cost only.	-Cost
U7	• Instruments need to change when they are not good. Often, they lose their properties.	-Instruments need quick replacement
U8	• No concerns	--
U9	That's potential, that would be good and that would save time, because having all three at once in is a bit clumsy.	--
U10	Not, at the moment, there are no concerns.	--
U11	With certain pathologies, the robotic system would not work.	-Complex cases
U16	The concerns are price and the range of instrumentation. The surgeons have merely 100 instruments open when we do a cystectomy, where at the moment we are operating with 5 instruments, I mean there is such a contrast. There is a different level of dissection you need for doing the nerve-sparing or to do a lymph node dissection, or to do a plane between the back between the rectum and the prostate and we have to just use the same instrument. It makes it quite tedious.	-Cost -The range of instruments movement

c. Cardiac surgery use cases – processed interviews

Table 11. 'Within-case' analysis of Cardiac surgery use cases (N=4)

What are the barriers of current methods that you use (open surgery/manual MIS/RAMIS*) in terms of:

- ✓ Vision?
- ✓ Instruments (slave system: instruments and robotic arms)?
- ✓ Interface (master system that the surgeon uses)?

Vision –

	Interviewee description	Codes	Categories
C1	• RAMIS should allow 3D vision, especially for the reconstruction of mitral valve or for the coronary anastomosis. • It requires the same level of vision of the conventional loupes. • It requires 2.5x or 3.5x magnification.	-3D vision -Vision of the conventional loupes -Magnification	Image quality (3)
C2	In open surgery, vision is quite good. There are no limitations with the loupes but it is with the anatomical structures e.g. in mitral valve surgery, the valve is in the awkward position. The access is anterior, while the valve is on the posterior side. The surgeons also sometimes need to see inside the ventricles behind the mitral valve e.g. to replace the chordae. Papillary muscles and smaller anatomical structures, very difficult to see both in the open surgery and MIS procedures.	-Anatomical problems	Anatomical problems
C3	Vision is 2D and it is difficult to perceive the depth. 3D vision is required.	-3D vision	Image type
C4	The size of the camera port is large e.g. da Vinci Xi system's camera port size is around 8 mm.	-Camera size	Camera mechanical size

Instruments –

	Interviewee description	Codes	Categories

C1	• RAMIS would have to replicate as much as the current instruments for doing the refined procedures. • Traditional instruments are not progressed very much. • Smart stabilizer, in the case of coronary anastomosis.	-Replicate the current instruments -Stabilizer for coronary anastomosis	Instrument size
C2	With the open surgery, it is very easy to do the surgery. There is the haptic feeling as well. With the MIS, fulcrum effect limits the movements. Physical access is limited and hand-eye coordination is not optimal. There is no haptic feeling. For MIS or RAMIS, we need to feel some structures, like calcium deposits, valve annulus, or ascending aorta, which are more or less impossible to feel during MIS/RAMIS.	-No haptic feeling	Haptic feeling (2)
C3	Instruments do not provide 360° rotational movements. It is difficult to move the full arm. If you use them for small incisions on coronary surgery, there should be haptic feeling. In open surgery, there is a tissue resistance that the surgeons do not feel it in MIS.	-Restricted instruments movement -No haptic feeling	-Haptic feeling -Articulated instruments

Interface –

	Interviewee description	**Codes**	**Categories**
C1	• RAMIS could allow safer cardiovascular surgery. However, C1 could not comment on the interface at the moment. It should be the smaller interface, which could provide lesser invasiveness. • If the surgeons were doing the beating heart surgery, they need a smart stabilizer, with the filtering of tremors would be of nice functionality.	-Smaller Interface -Filter tremoring	Interface size
C2	• There are limitations to do the maneuvers in certain angles. There are limitations of wrist movements even in open surgery. The anatomical structures are in the awkward position and sometimes it is needed to move the patient body to adjust	-limitation in wrist movements	Master controller design

	the angles. With RAMIS, it could be the big advantage and it may be possible to get rid of the awkward angles e.g. 360° rotations with the needle holder.	-Anatomical problem -Less flexible instruments	
C3	• In open surgery, you can move the hands but you could not bend the instruments to reach at the certain anatomical areas. With your arm, you can even manipulate at the back of the heart.	-Hands cannot reach certain anatomical location	Anatomical problems
C4	• It is quite good in da Vinci surgical system.	--	--

What affects your surgical resilience during long procedures?

	Interviewee description	Codes	Categories
C1	• During a long procedure, surgeons generally stand in the area of 40 cm^2 for minimum of 2 hours and maximum 5 hours with wearing all the things constantly, for examples the loupes. The latter is not healthy for the surgeons with two procedures in a day. It would be helpful if the surgeries could be more comfortable. • There is no arm-rest. The surgeons generally rest the elbow, attach to the body, and keep the mobility, and thus resting, of the forearm to reduce the tremors and to do the precise surgeries. So, in RAMIS, if this could be done, it will be helpful.	-Standing position -No arm rests	-Surgeon's position -Hand position
C2	• In open surgery, there is nothing that affects the surgical resilience. But in MIS, vision is adjusted by the assistant and the arms needs to be adjusted by the surgeons, and this causes the tiredness in long procedures. Assistants also required to know, e.g. what are you doing, which complicates the surgery.	-Vision adjustment by the assistants	Teleoperated camera
C3	• In less invasive surgery, due to keyhole surgery, limited instruments movements, repeated actions, and limited vision and haptic feeling reduces the concentration and	-limited instruments movements	-Flexible instruments

	increases the learning curve. With the open surgery, if there is a complication, it is tiring because it increases the surgery time.	-repeated actions -limited vision -limited feeling	-Image quality -Haptic feeling
C4	• C4 think, fatigue or comfort level should be higher if the surgeon sits at console. If the system is not easy to use, it requires a lot of concentration. If the procedure is complex, it is more tiring. During the heart surgery, if surgeon could be able to do the surgery in sitting position, it is comfortable. Sitting position helps with the resilience.	-Comfortable sitting position	Surgeon's position

What feature(s) do you not have in RAMIS that you have in open surgery and that you wish you had?

	Interviewee description	Codes	Categories
C1	• The conventional setting must be controlled by the surgeon in the RAMIS too. The heart pumping function should not be affected during the open-heart surgery. Surgeons require to focus on the vital signs e.g. heart rate, at every 5-6 minutes. It would be beneficial to transmit such kind of information to vision loupes. • Before each cardiovascular surgery, the patients might have taken around 5-6 types of scans e.g. 2D echocardiogram. It would be nice to recall all these scans in the 'magic' loupes automatically. • Loupes provide 3.5x magnification for the coronary surgery and 2.5x magnification for the valve surgery. A pair of loupes could be replaced with the smart loupes by superimposing other information. • The smart loupes should also provide the functionality of recording or taking the pictures. Ideally, to be in the focus, the target and loupes position was kept around 60° degrees, and the glass and the target distance would be	-Physiological information e.g. heart rate on loupes -Pre-operative scans on loupes -Functionality of recording or taking pictures from loupes -Voice controlled camera	-Superimposed information -Tele-operated camera control (2) -Anatomical problem -Image quality

	always kept similar for loupes to be in focus. • If the system of voice control for camera was reliable, then it would be ideal.		
C2	• The surgeons should be able to adjust the vision themselves. There are less available angles as compared to open surgery.	-Manual vision adjustment by surgeons	
C3	• It is difficult to deliver retrograde cardioplegia in MIS because it is hard to cross clamp the aorta in MIS. If retrograde cardioplegia is not done properly, the heart would not stop the beating. • Mitral valve spreader is used to properly see the mitral valve through the atrium.	-Difficult to cross-clamp aorta in MIS	
C4	• The camera always gets dirty, that is the disadvantage of MIS. The dexterity as well. It provides the limited field of exposure.	-The camera gets dirty	

What are the barriers of current methods that you use (open surgery/manual MIS/RAMIS*) in terms of:

Surgical Instruments (Open/MIS/RAMIS – slave system: including robotic arm/instrument holder)

Do you find the manipulation of tissues using MIS instruments restrictive as compared to your own hand?

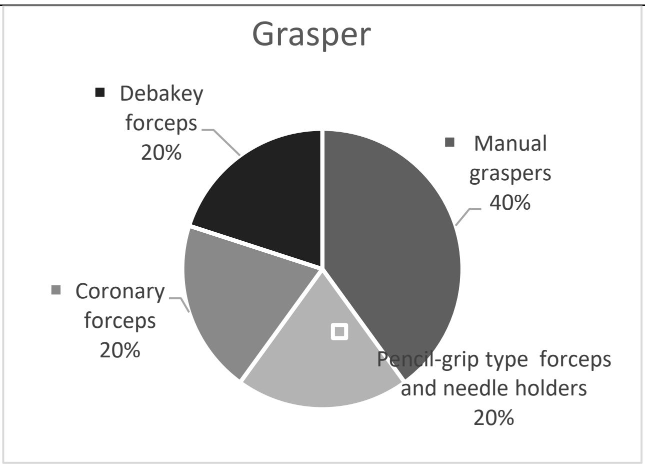
Is this the case for RAMIS instruments?

	Interviewee description	**Codes**	**Categories**
C2	Manipulation of tissues is less informative because the instruments are longer and your manipulation is indirect. It is easier to manipulate in open surgery, where you get the direct feeling on your fingers.	Indirect manipulation and haptic feeling in open surgery	-Haptic feeling (2) -Instrument jaw grip
C3	The feeling is different. With open surgery, you feel more but with the MIS, the feeling of	The feeling of touch is less	

	touch is less. Surgeons should be trained on haptic feeling with MIS.		
C4	I think, it is. It should be like the da Vinci instruments, for example getting the suture in the right place. For RAMIS, it is not as you get more dexterity and 7 DOF, and better tissue manipulation than MIS. RAMIS instruments are as good as hands but you just need a pencil grip.	Pencil grip	

What kind of grasps do you use during open/MIS/RAMIS? What different grasping methods/grasping instruments would you welcome?

	Interviewee description
C1	• Pencil grip instruments needed for forceps and needle holders. It is used for a clear majority of cardiovascular surgeries. It follows the fingers for manipulation. The force is replicated with the tip, which are always fine or ring-type and light titanium-based. • Needle holder are of different lengths, light, and titanium-based with the locking mechanism.
C2	• Manual laparoscopic graspers
C3	• Normal or toothed forceps • Coronary forceps – very tiny forceps
C4	• Forceps; Debakey forceps

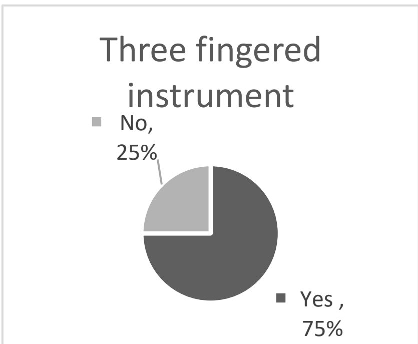


(See APPENDIX-E)

What would you change about current manual MIS/RAMIS instruments?

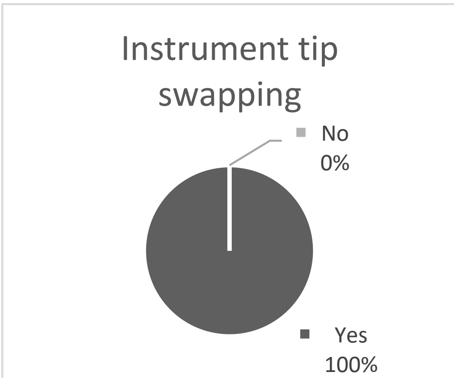
	Interviewee description	Codes	Categories
C1	• For penetrating to the cardiovascular field, the principles of pencil grip are critical. • The needles, 7-0 or 9-0 Prolene sutures, the threads, are very thin. The RAMIS instruments would allow the same mechanical strength of these instruments.	-Principles of pencil grip	-Instrument jaw grip
C2	• Only big problem is the access to the operation site. There is really no need to change anything big. We can basically improve the tactile feedback and the range of movements.	-Difficult access to operation site -Tactile feeling and range of wrist movements	-Anatomical problem -Tactile feeling

Would a third finger be of use?

	Interviewee description	
C1	• For cardiovascular surgery, it would be of great use. Third finger could be used for the rotational movements obtained using the pencil grip. • The interface, the robotic arm should reflect the movements of the surgeon then the end-effector should mimic the movements of the fingers e.g. the Castroviejo-type interface.	
C2	• Yes, it can be helpful. • With the Castroviejo-type forceps, the surgeons use four fingers.	
C3	• Yes, it is helpful. Two fingers are enough. We generally use one instrument at a time. It would work for the Castroviejo-type instrument.	
C4	• I do not think it would be of great advantage. Each of these forceps could have needle holders and forceps. The instruments should be micro-instruments. It is pretty similar concept as the da Vinci single port.	

	Current instruments give the pencil grip or needle holder, but the surgeon does not see any help with three fingered instruments. In RAMIS, for the mitral valve surgery, two robotic arms and two bed side assistants – two surgeons are required. Three fingered instruments, the surgeon still does not see how it would solve the problem of this assistants. It could be useful to cut the sutures through the needle drive with right arm and assistant go down with a pair of scissors. If you have little pair of scissor, put suture and the surgeon could use the third finger to cut the sutures.	

Would you want the instrument to have tips that can be swapped over so that the same main instrument can perform as different tools if it has more than one digits?

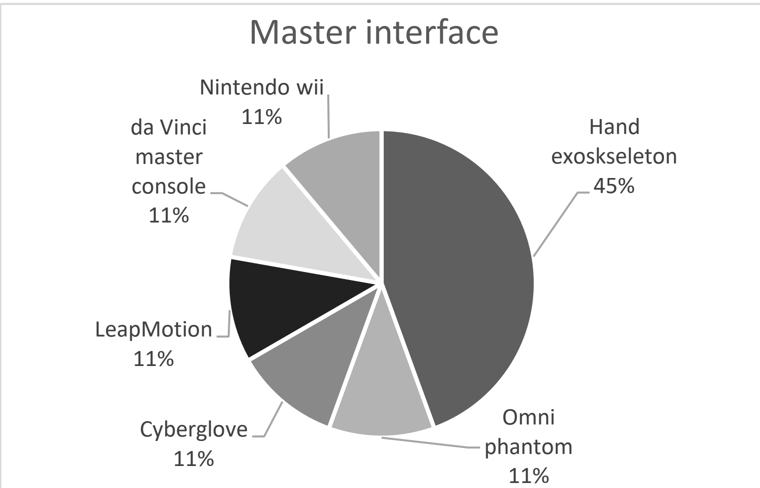
	Interviewee description	
C1	• It would be clearly an advantage and save the time.	
C2	• It is a big advantage.	
C3	• Yes, it would be helpful.	
C4	• It is a great idea. It could be also helpful for cutting the sutures that are required to be cut by the assistants.	

Master system

Note: the master system is the device used to tele-operate the instruments.

How would you prefer to control the instruments? Using tele-operation? What kind of interface?

	Interviewee description
C1	• Omni phantom – 1st preference. It could capture the pencil-grip like mechanism. The movements would be very precise. • Exoskeleton – 2nd preference. It could be helpful for three fingers-type manipulators. • Leap motion – 3rd preference. • The surgeons should be able to get the feedback. The surgeons should be in the loupes and influence their powers to the interfaces. • If the movements could be replicated in the millimeter dimensions, it is good. • Tactile feeling is very important and these interfaces should have that functionality.
C2	• CyberGlove and exoskeleton are very attractive choices because they allow the movements with what the surgeons are already very comfortable.
C3	• The master system should be in the same room and there should be the possibility to convert the surgery in open if it is required. • da Vinci system could be good and it could be improved. Nintendo wii could be helpful. Hand exoskeleton looks best to C3.
C4	• Anything that add haptic feedback is an advantage. • Exoskeleton is a great idea.



Vision

Do you use cameras/endoscopes/laparoscopes?

loupes with magnification lenses (**C1 C2 C3**) Endoscopes (**C3**)

Are they 2D/3D?

2D (**C1 C2 C3 C4**)

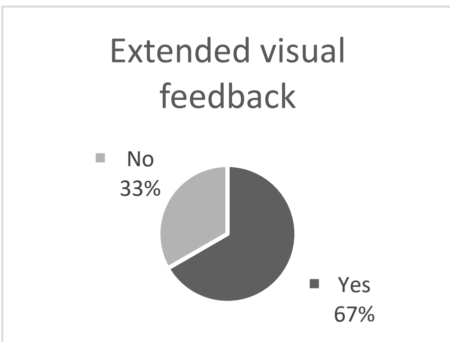
What are the barriers in the laparoscope of the daVinci/laparoscopy and how do you think they could be overcome?

	Interviewee description	Codes	Categories
C1	The concept like flexible bronchoscopes, e.g. finger moving, should be captured to optimize the vision.	Flexible bronchoscope like concept	**-**Flexible camera -Image quality (2) -Superimposed images -Flexible camera
C2	Depth perception is awkward at the beginning with 2D screens. 3D perception is needed.	3D perception	
C3	The surgeons use the endoscope during the vein harvesting in the legs. As replacement to loupes, probably smart glasses could be helpful for providing further information e.g. CT scan or angiograms. In coronary surgery, loupes and magnification is essential. In valve surgery, it is not very helpful.	-Smart glasses for superimposing preoperative images -Loupes with magnification	
C4	Probably the size of the camera that could go inside the chest wall. Current camera is bulky. The tip is not deflectable, which is a limitation.	-The size of the camera -The camera tip is not deflectable	

What are your requirements in terms of field of view?

	Interviewee description	Codes	Categories
C1	• Valve size is around 5/6 cm^2. Area for the coronary anastomosis is around 2-3 cm^2. • Camera could be pulled out or stayed in and capturing the focused magnified view, from the 2–3 cm distance, of the surgical site, not as a separate port but with other instruments.	Field of view around 2-3 cm^2 to 5-6 cm^2	**Field of view (4)**
C2	• The size of area changes continuously. It needs zooming functionality e.g. coronary anastomosis area is less than 1 cm^2. After the coronary bypass grafting, the surgeon needs to see the whole graft. Generally, for the planning, the surgeons need to see bigger areas, and for stitching, the area is smaller.	Field of view less than 1 cm^2	
C3	• For mitral surgery, 5 cm^2 • For CABG, 1.5 – 2 mm^2	Field of view from 1.50-2 mm^2 to 5 cm^2	
C4	• The field of view is not very big, for mitral valve surgery, it is 5 – 6 cm. But you could adjust it with the zooming.	Field of view around 5-6 cm^2	

Do you need visual feedback in wider areas e.g. behind obstacles (other organs)?

C1	• It is not necessary. • If there are the flexible cameras and there are not major technological changes, then it would be fine. If there is the miniaturization, then it should be around half the size of the flexible bronchoscope.	
C2	• It would be very helpful in MIS and RAMIS. In open surgery, you can manipulate the heart by hands. For the vision system, da Vinci and immersive stereo viewers are the most attractive. It removes the need of an assistant to control your vision.	

C3	• Augmented/Virtual reality could be helpful but it is a very standardized surgery. It is a very replicative type of surgery and you don't need to be guided. For heart surgery, it is less helpful.	

When operating, do you communicate efficiently with the rest of the surgical team?

	Interviewee description	
C1	• Yes, a lot of communication – with anesthetist, perfusionist, scrub nurses. • There are specific protocols for the communications to work on the same goals. • Head in the da Vinci console is still fine. The smart glasses should provide the same vision as the loupes.	
C2	• Yes. Surgeons communicate to know the physiological information e.g. heart rate. In cardiac surgery, communication is very important. Cardiac surgeons and anesthetist talk continuously.	
C4	• There is a lot of communication and it is a key. With da Vinci, it is not a problem.	

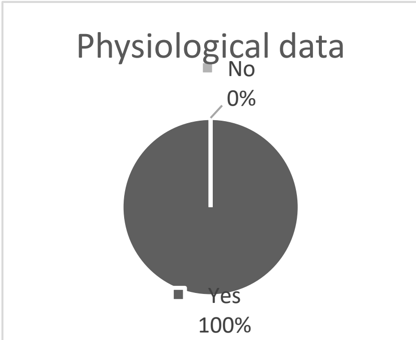
If you are a da Vinci user, do you feel immersed in the da Vinci console?

If yes, do you welcome this or would you prefer to also have greater awareness of your surrounding environment?

	Interviewee description	
C1	• The immersive stereo viewer could be used to see the surgical area. It could probably be the interface with the augmented reality e.g. with the information on physiological data and pre-operative images. • It has to give the feedback as the magnified loupes. • 3D view and good exposure (light) is also important. • If all above is captured, immersive stereo viewer is great.	• Immersive stereo viewer
C4	• Immersive stereo vision is a great	

	idea.	

In this respect, would you welcome such information displayed in your vision during surgery? If yes, what kind of information (e.g. physiological data)

	Interviewee description	
C1	Yes, the physiological data would be needed.	
C2	Yes, the physiological data would be needed.	
C3	Yes, e.g. the heart rate; blood pressure; oxygen saturation, CVP	
C4	Yes, that would be helpful.	

Camera control

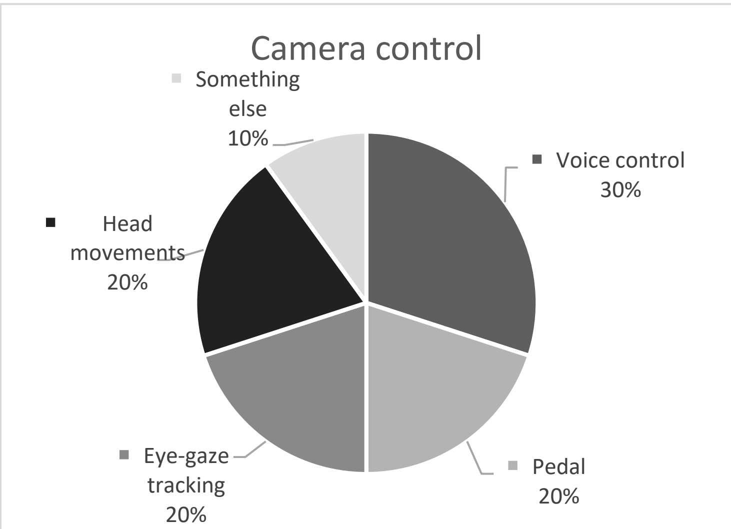
In manual MIS, the surgeon communicates with the surgical assistant for positioning of the camera. Da Vinci has a clutch system for controlling the camera using the master handles.

Is a teleoperated camera holder required?

Yes (C2 C3 C3)

How would you prefer the camera was controlled (e.g. voice commands, eye gaze tracking, head movements, foot pedal, other)?

	Interviewee description
C1	Voice control would be very good.
C2	Voice control would be easier. Foot pedal is good but we don't use pedals in cardiac surgery. Head movements is only helpful with the fix focused view without the magnification.
C3	Eye gaze tracking can damage the organs. Pedal or something else. No, head movements are not preferred.
C4	Eye gaze tracking are good. The voice commands and head movements both would work.



Would you wish to move, extend or focus the field of view by moving your head around?

Yes (**C4**)

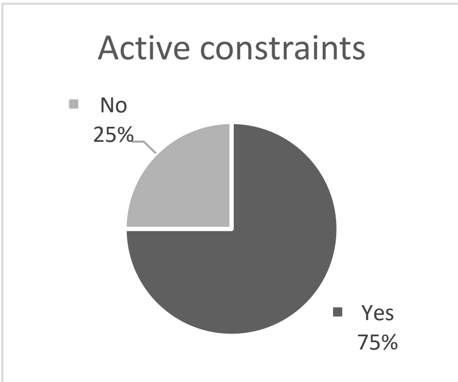
Active constraints/No-go zones

Note: ‘Active constraint’ is the process of labelling regions of the patient's body, e.g. a vessel or a nerve bundle, with one of the four possibilities: safe, close, boundary and forbidden. Surgeons label safe regions the regions that are appropriate for the robot to be and to operate in. One way to use them is to stop the instrument from entering forbidden zones by force resistance exerted by the master device. The other way is to highlight by augmented reality those zones and/or signal with alternative sensory channels as auditory or vibration.

How could ‘active constraints’ help you during a surgical operation?

Would you like knowing that the instrument would not enter or even touch the boundaries of forbidden regions and/or tissues labelled by you (the surgeon) in a preoperative and operative stage?

Would you like the robot to keep the instrument at a certain angle, e.g. normal to the operating path, specified by you to help you guide it?

	Interviewee description	
C1	• Yes, it would be very useful as there are so many critical structures in the heart e.g. vessels, nerves. • There are different ‘no-go’ zones in both the use cases.	
C2	• For cardiac surgeries, it is less useful. It is a tool for cancer e.g. prostatic cancers or nerves to preserve. • We do not have important ‘no-go’ zones. • There is nothing to be removed or spared. • It may be the great tool for abdominal surgeries. • There is only one ‘no-go’ zone, which is a conduction system e.g. SA node but it is not easy to label.	
C3	• Yes, it would. The surgeons see damaging the vital structures. • The problem is to define the safety region. • For somethings like coronary anastomosis, coronary artery is an important ‘no-go’ zone but you cannot stop the instrument.	

C4	• The surgeons have to be cautious not to get close to LIMA while cauterising and not burn it. • Active constraints could be helpful for the left internal mammary artery harvesting.	

Haptics

Note: Haptics is the tactile-kinaestetic feeling, which is presented in the interaction with the body through the instruments.

How important is haptic feedback during surgery for you?

Yes, it is very important (C1 C2 C3)

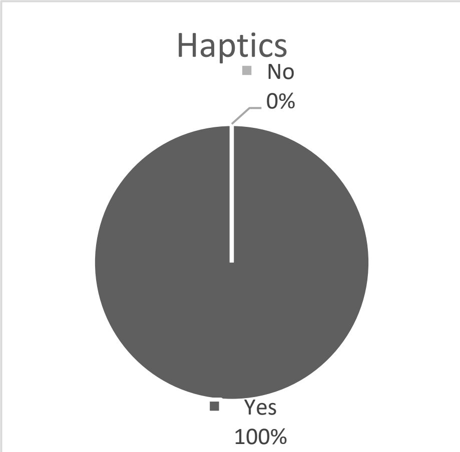
What type of haptic feedback would be useful to you (e.g. force feedback of pulling/pushing tissue and surrounding structures or of the thread tension during suturing, force feedback during grasping, texture, temperature)?

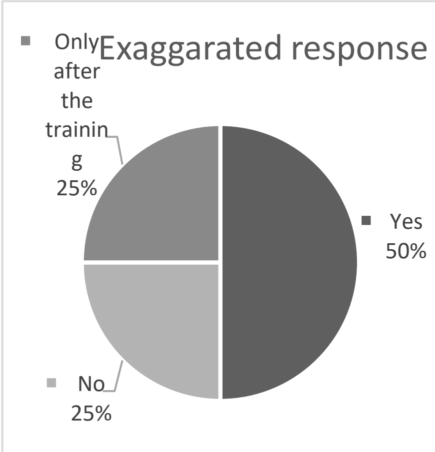
Would it be helpful to 'exaggerate' this feeling, i.e. scaled up from the measured exerted force on the tissue? Important not very.

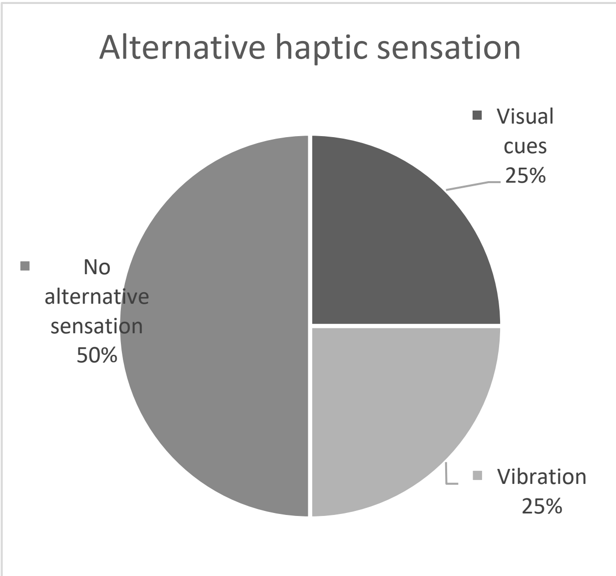
Would alternative sensory information be useful as a replacement to haptic feedback or as complimentary to it (e.g. acoustic signals/visual cues/vibration proportional to the exerted force on the tissue or as alarm for over-the-threshold forces)?

	Interviewee description
C1	• Exaggerated response would be of an additional value and it is good. • Visual cues could be considered.
C2	• Yes, absolutely because it is one of the disadvantages of MIS. • For repair, the surgeon needs to feel the tissue quality. It is required to do stitching on the diseased tissue. It could be useful to feel the calcium deposits, for example. It is difficult to understand suturing on the coronary artery just only by the vision. • Scaling functionality, of the haptic feeling, would be misleading in the beginning. It would be OK after the surgeons trained properly. • There should be no alternative information, the haptic feedback should be real.
C3	• Visual cues would be very important. Exaggerated feeling would make **C3** less confident. • Probably vibration is the best alternative sensory information.
C4	• **C4** thinks, it is very important. It is helpful for novice surgeons. It is very useful for robotic mitral valve surgery. • Exaggerated response is good.

- Nature feeling is better than the alternative sensory information, if it is mechanically possible to build. Just the force feedback is needed.





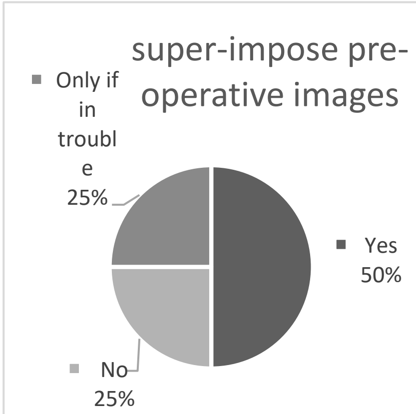


Pre-op Images

Do you use pre-operative images? If yes, what type and why?

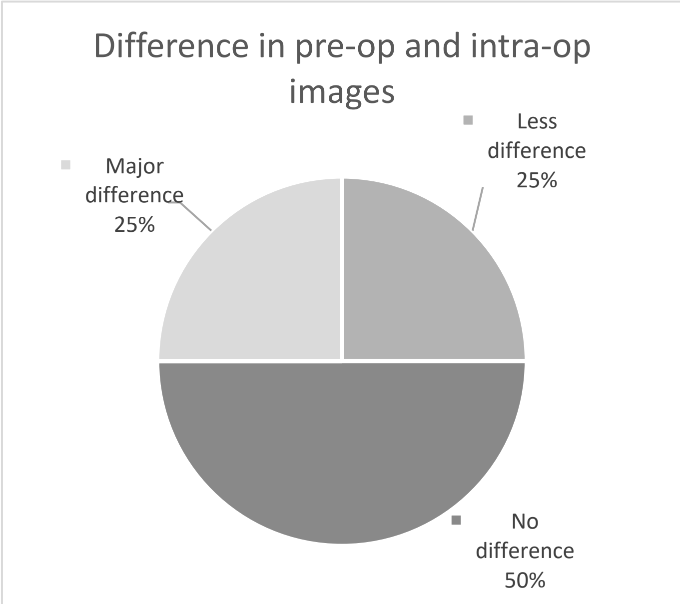
Combination of echocardiography, coronary angiography, CT scans, MRI (C1 C2 C3 C4)

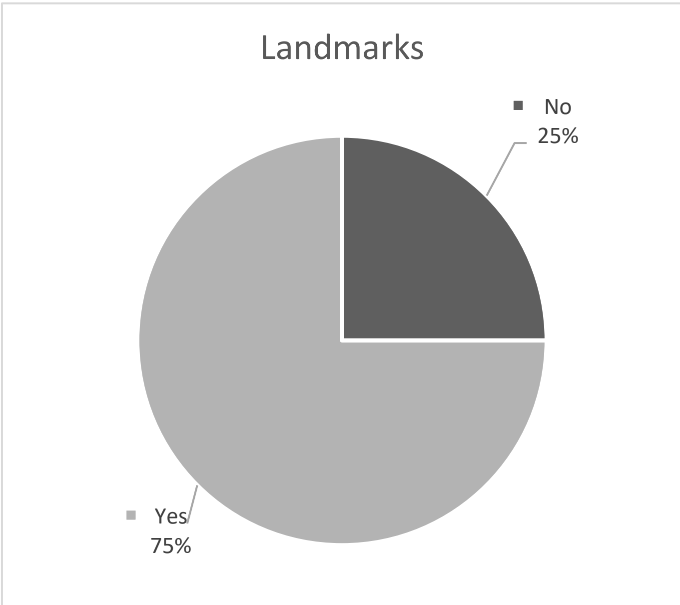
When would you need to super-impose such images on the vision of the laparoscope (e.g. to guide/help you identify structures in the abdomen)?

	Interviewee description	
C1	Mitral valve, coronary artery, et cetera, could be superimposed	
C2	It is not very helpful for cardiac surgeries. Anatomy is very clear. However, it may be helpful for some cases e.g. if it is difficult to see the coronary artery due to cardiac scars. In valve surgery, it is very difficult to see circumflex coronary artery.	
C3	Only when **C3** in trouble e.g. if **C3** needs to recall the angiogram.	
C4	Great idea. The angiogram to superimpose on heart to identify LAD is a great idea. It will help to remove falsefully grafting the wrong artery.	

How different is the operating field from the pre-op images (e.g. in terms of tissue deformation)?

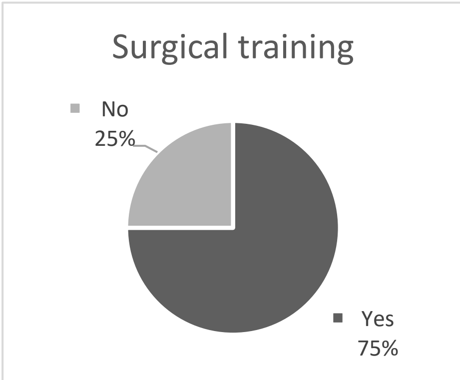
	Interviewee description
C1	• There is a less difference than the pre-operative images. • Yes, there are enough landmarks.
C2	• Yes, there is no much difference
	• Yes, there are enough landmarks
C3	• Landmarks can be easily taken in valve surgery. With beating heart surgery, it is difficult to define the landmarks. • Pre-operative and intra-operative images may be different, for example in the cases of degenerative mitral valve and endocarditis.
C4	• If you are not on CPBG and on beating heart surgery, it is not different. • There are some landmarks e.g. appendages, great vessels and the apex


Difference in pre-op and intra-op images
Less difference 25%
Major difference 25%
No difference 50%


Landmarks
No 25%
Yes 75%

General questions

How do you expect a system like SMARTsurg will improve in new surgeons' training?

	Interviewee description	
C1	• Robotic assisted beating coronary artery surgery could be helpful. Otherwise, it is not possible to improve the current surgical training. • RAMIS with trainees only be helpful if the training will be performed with the animals e.g. on the pig.	
C2	• Yes, a lot	
C3	• Virtual reality and robotic endoscopy is the ideal way of training the surgeons without going to do surgeries on humans. Current cardiac surgery training takes around 7 to 8 years, the surgeons still need to learn and nobody is allowed to operate on patients until then, so the virtual environment is helpful. Then if you could replicate to real surgery, it would be helpful.	
C4	• Yes, **C4** think, definitely it would do. Basically, if the bed side surgeon has the smart glass, it is a good idea.	

Closing remarks

Any other concerns about the technology?

	Interviewee description	
C1	• It would be never preferred over the current surgical methods because the patient interest is first. If the system provides the tangible	-Patient safety

	benefits with higher efficacy, safety and less invasively, then it will be accepted. It could be only accepted after rigorous clinical trials with strict research structure.	
C2	• The concern is patient safety.	
C3	• Main concern is the patient safety because there are many risks to consider.	
C4	• I do not think there are any barriers.	

3.4 Elicited requirements and mapping to individual System Block components

In each table, the categories are grouped together with the topics and its number of frequencies i.e. a total number of related utterances during the interview e.g. Anatomical problems (7). Multiple utterances with a same surgeon was also considered for eliciting the requirement if the meaning of the utterances was different with respect to the requirements. Then each category was mapped to the corresponding requirements and System Blocks components. Table 12 and 13 represent the 'within-case' analysis of Orthopaedic use cases, table 14 and 15 represent the 'within-case' analysis of Urology use cases and table 16 and 17 represent the 'within-case' analysis of Cardiac surgery use cases.

a. Orthopaedics surgery – 'within-case' analysis

'open-ended' questions'

Table 12. 'Within-case' analysis of Orthopaedics use cases – Mapping with System Blocks components and elicited requirements – 'open-ended' questions (N=6)

Category	**System blocks components**	**Requirements**
Anatomical problems (7)	-SLAVE INSTRUMENT L&R	Smaller instruments needed (current instrument diameter around 4 mm) (Need to change the knee positions and camera ports repeatedly; tissue problems e.g. thin meniscus)

Small instruments (3)	-SLAVE INSTRUMENT L&R	The smaller instruments than the current instruments needed. (Current instrument, e.g. 4 mm; helpful for doing surgery through medical meniscus posterior horn for stitching of meniscus tear)
Haptic feeling (3)	-FORCE SENSOR CONTROLLER SKELETON -FORCE SENSOR CONTROLLER WRIST -FORCE TORQUE SENSORS WRIST L&R -FORCE TORQUE SENSORS SKELETON L&R -FORCE DISPLAY	Exaggerated haptic feeling needed. (to reduce iatrogenic complications;
Teleoperation (2)	-MASTER EXOSKELETON CONTROLLER -MASTER ARM CONTROLLER -SLAVE ARM CONTROLLER -MAIN CONTROLLER	Teleoperation is needed (e.g. for minimal meniscus resection; surgeons' posture is not good during these procedures)
Surgeon's position (2)	--	Ergonomic surgeon's position
Manipulation with left handed surgeon (2)	- SLAVE INSTRUMENT L&R	Modification to current instruments are needed for left-handed surgeons (e.g. especially for manipulating the tissue)
Meniscus damage measurement technique (1)	- SLAVE INSTRUMENT L&R	New meniscus damage measurement technique needed.
Image quality (1)	-CAMERA INTERFACE AND 3D RECONSTRUCTION	Better image quality needed.

Superimpose information (1)	-PREOPERATIVE IMAGES -3D RECONSTRUCTION	Superimposed information needed (to cut the meniscus minimally)
Complex surgery (1)	--	--
Inexperienced assistants (1)	--	--
Instrumentation (1)	- SLAVE INSTRUMENT L&R	A new needle holder for suturing is needed in meniscus repair.
Small articulated instruments (1)_	- SLAVE INSTRUMENT L&R	Small articulated instruments needed. (to di the stitching on meniscus tear)

‘Close-ended’ questions’

Table 13. ‘Within-case’ analysis of Orthopaedics use cases – Mapping with System Blocks components and elicited requirements – ‘close-ended’ questions (N=6)

	System blocks components	**Requirements**
Three-fingered instrument	SLAVE INSTRUMENT L&R	Yes, it is needed (e.g. to stabilise the meniscus in meniscus repair; to easily view knee compartments; to cut free cartilage pieces; to repair tendon and nerves)
Instrument tip swapping	SLAVE INSTRUMENT L&R	Yes, it is needed.
Master interface	MASTER EXOSKELETON L&R	Hand exoskeleton
Extended visual feedback	-PREOPERATIVE IMAGES -3D RECONSTRUCTION -REGISTERED RECONSTRUCTION	Yes, it is needed. (e.g. to put the suture through the meniscus and

	-ACTIVE CONSTRAINTS CONSTRUCTION	to feel the correct length; to see popliteal artery; more narrow or flexible camera is useful)
Immersive environment and team communication	-SURGEON'S SMART GLASSES	Smart glasses
Physiological data	-SURGEON'S SMART GLASSES	No
Camera control	-SLAVE CAMERA HOLDER CONTROLLER	Something else (e.g. Joystick or exoskeleton or hand control)
Active constraints	-ACTIVE CONSTRAINTS ENFORCEMENT -ACTIVE CONSTRAINTS UPDATE -ACTIVE CONSTRAINTS CONSTRUCTION -CAMERA INTERFACE AND 3D RECONSTRUCTION	No, it is not needed Possible use if implemented: (e.g. to prevent injury to rim of the meniscus, to remove only the damaged meniscus or meniscus flaps)
Haptics	-FORCE TORQUE SENSORS WRIST L&R -FORCE TORQUE SENSORS SKELETON L&R -FORCE DISPLAY	Yes, it is needed.
Magnified force response	-FORCE SENSOR CONTROLLER SKELETON -FORCE SENSOR CONTROLLER WRIST	Yes, it is needed.
Alternative sensation	FORCE DISPLAY	Yes, the visual cues
Superimposed preoperative images	-PREOPERATIVE IMAGES -3D RECONSTRUCTION -CAMERA INTERFACE AND 3D RECONSTRUCTION	Yes, it is needed. However, different pre-operative and intra-operative images but enough landmarks e.g.

		Trochlea, medial and lateral condyle of femur and tibia)

b. Urology – 'within-case' analysis

'open-ended' questions'

Table 14. 'Within-case' analysis of Urology use cases – Mapping with System Blocks components and elicited requirements – 'open-ended' questions (N=17)

Category	System blocks components	Requirements
Haptic feeling (17)	-FORCE SENSOR CONTROLLER SKELETON -FORCE SENSOR CONTROLLER WRIST -FORCE TORQUE SENSORS WRIST L&R -FORCE TORQUE SENSORS SKELETON L&R -FORCE DISPLAY	Yes, it is needed. (e.g. to feel the planes between prostate and rectum, feeling of pushing and pulling tissues, thread tension for suturing)
Image quality (12)	-STEREO VIDEO MASTER SIDE -STEREO ENDOSCOPIC CAMERA -CAMERA INTERFACE AND 3D RECONSTRUCTION	Better image quality needed. ("Ultra-HD" 4K; more illumination; camera gets dirty with da Vinci Xi system; poor vision with magnification)
Instrumentation (10)	-SLAVE INSTRUMENT L&R	New instruments or modification to existing instruments needed. (e.g. thin instruments to aid minimally invasiveness and small needle drivers; bigger instruments to handle bowel (large jaws and more force); New instruments for tissue retraction; Bigger forceps and trocars to take the specimen out; easier system to put clips e.g. Hem-o-lok clips; disposable instruments)

Surgeon's position (10)	--	Ergonomic surgeon's position
Anatomical problems (9)	-SLAVE INSTRUMENTS L&R -CAMERA INTERFACE AND 3D RECONSTRUCTION	Flexible camera and articulated instruments (e.g. small and close structures in pelvis; anatomical area such as ridges of pubic bone; complex cases such as previous multiple pelvic or abdominal procedures or pelvic adhesions; peculiar shape of pubic bones)
Field of view (6)	-CAMERA INTERFACE AND 3D RECONSTRUCTION	Better field of view in operating area (Less than 5 cm^2 to 25 cm^2)
Articulated instruments (6)	-SLAVE INSTRUMENT L&R	Articulated instruments needed. (e.g. with at least two articulations; to make small movements in pelvis in radical prostatectomy)
Clutching mechanism (4)	-MASTER EXOSKELETON L&R	New clutching mechanism needed (e,g, frequent clutching is required to handle the workspace limitation; limited workspace)
Surgical approach/surgical complexity (4)	-PROTOCOL EXTRACTION AND VERIFICATION	Easier understanding of surgical workflow steps needed (It is difficult to handle complex surgical cases and follow the open surgery approaches to junior surgeons)
Cognitive load (3)	-PROTOCOL EXTRACTION AND VERIFICATION	Definitive guide for surgical steps needed.

		(e.g. thinking and defining approach and steps for junior surgeons – surgical resilience)
Flexible camera (3)	-CAMERA INTERFACE & 3D RECONSTRUCTION -SLAVE INSTRUMENT L&R	Flexible camera needed. (e.g. to look around corners; examples – automatic flexible cystectomy, flexible sigmoidoscopy, colonoscopy)
Superimposed information (2)	PREOPERATIVE IMAGES -3D RECONSTRUCTION	Superimposed information is needed. (e.g. to know relative position of organs, tumour and ureter; for tissue biopsy)
Image type (2)	-STEREO VIDEO MASTER SIDE -STEREO ENDOSCOPIC CAMERA	3D images needed.
Magnified vision (1)	-STEREO ENDOSCOPIC CAMERA	Good and clear magnified vision is needed.
Surgeon's wellbeing (1)	--	--
Latency (1)	-CONFIGURATION AND PARAMETER SERVER	Better response of the system needed in terms of communication of information.
Grasping mechanism (1)	-SLAVE INSTRUMENT L&R	More force during grasping is needed.
Camera length (1)	-CAMERA INTERFACE & 3D RECONSTRUCTION -SLAVE INSTRUMENT L&R	Short camera length is needed (to remove clashing of instruments with assistants; current size – 30 cm)

‘Close-ended’ questions’

Table 15. ‘Within-case’ analysis of Urology use cases – Mapping with System Blocks components and elicited requirements – ‘close-ended’ questions (N=17)

Categories	System blocks components	Requirements
Three-fingered instrument	SLAVE INSTRUMENT L&R	No, it is not needed. (would like to try first if implemented; wrist articulation is missing; could not provide same articulation as da Vinci single port; don’t needed for these use cases)
Instrument tip swapping	SLAVE INSTRUMENT L&R	Yes, it is needed.
Master interface	MASTER EXOSKELETON L&R	Hand exoskeleton.
Extended Visual Feedback	-PREOPERATIVE IMAGES -3D RECONSTRUCTION -REGISTERED RECONSTRUCTION -ACTIVE CONSTRAINTS CONSTRUCTION	Yes, it is needed. (e.g. in radical prostatectomy or trans-corporeal reconstruction; to see big vessels, renal arteries behind fat; lymphnodes near vena cava or aorta)
Immersive environment and team communication	-VR GLASSES -ASSISTANT SMART GLASSES A	Immersive stereo viewer for surgeons Smart glasses for assistants
Physiological data	-SURGEON’S SMART GLASSES -VR GLASSES	No, it is not needed. (some surgeons would like to see the blood loss and intraabdominal pressure)
Camera control	-SLAVE CAMERA HOLDER CONTROLLER	Pedals or head movements
Active constraints	-ACTIVE CONSTRAINTS ENFORCEMENT	Yes, it is needed.

	-ACTIVE CONSTRAINTS UPDATE -ACTIVE CONSTRAINTS CONSTRUCTION -CAMERA INTERFACE AND 3D RECONSTRUCTION	(e.g. not to damage nerves, small or big vessels e.g. aorta, vena cava and anonymous vascularisation e.g. extra renal artery; lymphadenectomy during prostatectomy; useful for training)
Haptics	-FORCE TORQUE SENSORS WRIST L&R -FORCE TORQUE SENSORS SKELETON L&R -FORCE DISPLAY	Yes, it is needed.
Magnified force response	-FORCE SENSOR CONTROLLER SKELETON -FORCE SENSOR CONTROLLER WRIST	No, it is not needed. (Realistic feedback is desired)
Alternative sensation	FORCE DISPLAY	Visual cues
Superimposed preoperative images	-PREOPERATIVE IMAGES -3D RECONSTRUCTION -CAMERA INTERFACE AND 3D RECONSTRUCTION	Yes, it is needed.

c. Cardiac surgeries – 'within-case' analysis

'Open-ended' questions'

Table 16. 'Within-case' analysis of Cardiac surgery use cases – Mapping with System Blocks components and elicited requirements – 'open-ended' questions (N=4)

Category	System blocks components	Requirements
Image quality (7)	-STEREO VIDEO MASTER SIDE -STEREO ENDOSCOPIC CAMERA -CAMERA INTERFACE AND 3D RECONSTRUCTION	Good vision - at least at the level of conventional loupes is needed; Magnification (2.5x to 3.5x); better field of view for operating area (from 1.5 mm^2 to 5 cm^2)
Haptic feeling (5)	-FORCE SENSOR CONTROLLER SKELETON -FORCE SENSOR CONTROLLER WRIST -FORCE TORQUE SENSORS WRIST L&R -FORCE TORQUE SENSORS SKELETON L&R -FORCE DISPLAY	Haptics
Anatomical problems (4)	-SLAVE INSTRUMENTS L&R -CAMERA INTERFACE AND 3D RECONSTRUCTION -CLIP ON ATTACHMENT L&R	Articulated instruments or flexible camera (Difficult to reach or visualise some anatomical structures e.g. the operation access is anterior and mitral valve is on the posterior side; ventricles behind the mitral valve; cross clamping of aorta)
Teleoperated camera (3)	-SLAVE ARM CAMERA HOLDER -SLAVE CAMERA HOLDER CONTROLLER	Teleoperated vision system (to remove camera handling by assistants)

Articulated/flexible instruments (2)	-SLAVE INSTRUMENT L&R -CLIP ON ATTACHMENT L&R	More flexible instruments and camera system (concept like flexible bronchoscope needed)
Surgeon's position and hand position (3)	-MASTER ARM L&R	Ergonomic surgeon's position
Superimposed information (2)	-PREOPERATIVE IMAGES -3D RECONSTRUCTION -SURGEON'S SMART GLASSES -ASSISTANT'S SMART GLASSES -VR GLASSES -STEREO VIDEO MASTER SIDE -2D MONITOR (ASSISTANT) -SURFACE DEFORMATION FIELD	Information on physiological data and medical imaging needed
Instrument jaw grip (2)	-SLAVE INSTRUMENT L&R -MASTER ARM L&R -CLIP ON ATTACHMENT L&R	Instruments, which could provide pencil grip, are needed
Flexible camera (2)	-CAMERA INTERFACE & 3D RECONSTRUCTION -SLAVE INSTRUMENT L&R -CLIP ON ATTACHMENT L&R	Flexible camera needed
Image type (1)	-STEREO VIDEO MASTER SIDE -STEREO ENDOSCOPIC CAMERA -VR GLASSES	3D vision (Magified high definition 3D)
Camera size (1)	-CAMERA INTERFACE AND 3D RECONSTRUCTION	Small camera system needed (due to smaller access)
Instrument size (1)	-SLAVE INSTRUMENT L&R -CLIP ON ATTACHMENT L&R	At least the size of current instruments (8/9 mm in diameter)
Interface size (1)	-MASTER EXOSKELETON L&R	Small interface needed (35-40 cm^2)

Master controller design (1)	-MASTER EXOSKELETON L&R -MASTER ARM L&R	Better wrist movements and higher angulation

‘Close-ended’ questions’

Table 17. ‘Within-case’ analysis of Cardiac surgery use cases – Mapping with System Blocks components and elicited requirements – ‘close-ended questions’ (N=4)

Category	System blocks components	Requirements
Three-fingered instrument	-SLAVE INSTRUMENT L&R -CLIP ON ATTACHMENT L&R	Yes, it is needed. (e.g. for cutting the sutures) (we will record the fine motion initially and see how we can design the master and slave. This is more challenging than laparoscopy) (willingness to try on a prototype) (removing the fingers from the end effector saves the space but replicating the castroviejo motion would be difficult. We are not going to solve this problem now)
Instrument tip swapping	-SLAVE INSTRUMENT L&R -CLIP ON ATTACHMENT L&R	Yes, it is needed.
Master interface	-MASTER EXOSKELETON L&R	Hand exoskeleton (wrist motion of the exoskeleton (for the three fingers))
Extended Visual Feedback	-PREOPERATIVE IMAGES -3D RECONSTRUCTION -REGISTERED RECONSTRUCTION -ACTIVE CONSTRAINTS CONSTRUCTION	Yes, it is needed.
Immersive environment and team communication	-VR GLASSES -ASSISTANT SMART GLASSES A	Immersive stereo viewer Smart glasses (only for the surgical training)

Physiological data	-SURGEON'S SMART GLASSES -ALTERNATIVE DISPLAY TO SMART GLASSES	Yes, it is needed to see
Camera control	-SLAVE CAMERA HOLDER CONTROLLER	Voice control (Big field voice control, focused field with another finer control) (willingness to try on a prototype)
Active constraints	-ACTIVE CONSTRAINTS ENFORCEMENT -ACTIVE CONSTRAINTS UPDATE -ACTIVE CONSTRAINTS CONSTRUCTION -CAMERA INTERFACE AND 3D RECONSTRUCTION	Yes, it is needed (It could be very useful because there are so many critical structures in the heart e.g. vessels, nerves. For example, active constraints could prevent burning of left internal mammary artery while using the cautery)
Haptics	-FORCE TORQUE SENSORS WRIST L&R -FORCE TORQUE SENSORS SKELETON L&R -FORCE DISPLAY	Yes, it is needed
Magnified force response	-FORCE SENSOR CONTROLLER SKELETON -FORCE SENSOR CONTROLLER WRIST	For clinical purposes, it should not be magnified, but kept into physiological ranges
Alternative sensation	-FORCE DISPLAY	No, it is not needed. (Natural response is desired)
Superimposed preoperative images	-PREOPERATIVE IMAGES -3D RECONSTRUCTION -SURGEON'S SMART GLASSES -ASSISTANT'S SMART GLASSES	Yes, it is needed.

	-VR GLASSES -STEREO VIDEO MASTER SIDE -2D MONITOR (ASSISTANT) -SURFACE DEFORMATION FIELD	

3.3.2 Across case analysis

After ‘within-case’ analysis, we have done ‘across-case’ analysis, as shown in Table 18, where we have grouped together common requirements across the cases. As shown in table 18, each cell represented with the elicited requirement with its need in three specialities, i.e. U – Urology, O – Orthopaedics and C – Cardiac surgery, along with its priorities. After that, a total score of each elicited requirement is calculated.

Table 18. ‘Across-case’ analysis

<table>
<tr><th>Requirements</th><th>U</th><th>O</th><th>C</th><th>Total score</th></tr>
<tr><td>1. Superimposed preoperative images
<table>
<tr><td>U</td><td>Superimposed preoperative information is needed.</td></tr>
<tr><td>O</td><td>Superimposed preoperative information needed

(to cut the meniscus minimally)

Yes, it is needed.
However, pre-operative and intra-operative images are very different.
There are enough landmarks (e.g. trochlea, medial and lateral condyle of femur and tibia).</td></tr>
<tr><td>C</td><td>Information on physiological data and medical imaging needed</td></tr>
</table></td><td>5</td><td>5</td><td>5</td><td>15</td></tr>
</table>

2. Articulated instruments **U** — (e.g. small and close structures in pelvis; anatomical area such as ridges of pubic bone; complex cases such as previous multiple pelvic or abdominal procedures or pelvic adhesions; peculiar shape of pubic bones) (e.g. with at least two articulations; to make small movements in pelvis during radical prostatectomy) **O** — Small articulated instruments needed. **C** — (Difficult to reach or visualise some anatomical structures e.g. the operation access is anterior and mitral valve is on the posterior side; ventricles behind the mitral valve; cross clamping of aorta)	5	5	5	15
3. Active constraints **U** — Yes, it is needed. (e.g. not to damage nerves, small or big vessels e.g. aorta, vena cava and supplementary vascularisation e.g. extra renal artery; lymphadenectomy during prostatectomy; useful for training) **O** — No, it is not needed Possible use if implemented: (e.g. to prevent injury to rim of the meniscus, to remove only the damaged meniscus or meniscus flaps) **C** — Yes, it is needed (It could be very useful because there are so many critical structures in the heart e.g. vessels, nerves. For example, active constraints could prevent burning of left internal mammary artery while using the cautery)	5	5	5	15

4. Master interface **U** – Hand exoskeleton **O** – Hand exoskeleton **C** – Hand exoskeleton (wrist motion of the exoskeleton (for three fingers)	4	5	5	14
5. Image quality **U** – ("Ultra-HD" 4K; more illumination; camera gets dirty with da Vinci Xi system; poor vision with magnification) **O** – Better image quality needed. **C** – Good vision - at least at the level of conventional loupes is needed; Magnification (2.5x to 3.5x); better field of view (from 1.5 mm^2 to 5 cm^2)	3	5	5	13
6. Smart glasses For assistants, surgical training (**U**; **O**; **C**)	3	5	5	13
7. Three-fingered instrument **U** – No, it is not needed. (would like to try first if implemented; wrist articulation is missing; could not provide same articulation as da Vinci single port; it does not needed for these use cases) **O** – Yes, it is needed	4	4	5	13

	(e.g. to stabilise the meniscus in meniscus repair; to easily view knee compartments; to cut free cartilage pieces; to repair tendon and nerves)				
C	Yes, it is needed. (e.g. for cutting the sutures) (we will record the fine motion initially and see how we can design the master and slave. This is more challenging than laparoscopy) (willingness to try on a prototype) (removing the fingers from the end effector saves the space but replicating the castro-viejo motion would be difficult. We are not going to solve this problem now)				
8.	***Haptics***	3	3	5	11
U	Yes, it is needed. (e.g. to feel the planes between prostate and rectum, feeling of pushing and pulling tissues, thread tension for suturing)				
O	Yes, it is needed.				
C	Yes, it is needed.				
9.	***Flexible camera***	5	--	5	10
U	(e.g. to look around corners; examples – automatic flexible cystectomy, flexible sigmoidoscopy, colonoscopy)				
O	--				

C	(Difficult to reach or visualise some anatomical structures e.g. the operation access is anterior and mitral valve is on the posterior side; ventricles behind the mitral valve; cross clamping of aorta) (like bronchoscope)				
10. 3D images (U; C)		5	--	5	10
11. Alternative haptic sensation		5	3	1	9
U	Visual cues				
O	Yes, the visual cues				
C	No, it is not needed. (Natural response is desired)				
12. Extended visual feedback		5	1	3	9
U	Yes, it is needed. (e.g. in radical prostatectomy or trans-corporeal reconstruction; to see big vessels, renal arteries behind fat; lymph nodes near vena cava or aorta)				
O	Yes, it is needed. (e.g. to put the suture through the meniscus and to feel the correct length; to see popliteal artery; more narrow or flexible camera is useful)				
C	Yes, it is needed.				

13. Needle holder (SLAVE SIDE) **U**: New instruments or modification to existing instruments needed. Small needle drivers **O**: A new needle holder for suturing is needed in meniscus repair. **C**: --	3	5	--	8
14. Immersive stereo viewer **U**: The immersion idea is correct whilst being mindful of the need to interact with your team medium **O**: -- **C**: Yes	3	--	5	8
15. Instrumentation **U**: New instruments or modification to existing instruments needed. (e.g. thin instruments to aid minimally invasiveness and small needle drivers; bigger instruments to handle bowel (large jaws and more force); new instruments for tissue retraction; bigger forceps and trocars to take the specimen out; easier system to put clips e.g. Hem-o-lok clips; disposable instruments) **O**: A new needle holder for suturing is needed in meniscus repair. **C**: --	3	5	--	8

16. Camera control **U** Head movements **O** Something else (e.g. joystick or exoskeleton or hand control) **C** Voice control (Big field voice control, focused field with another finer control) (willingness to try on a prototype)	1	3	4	8
17. Physiological data **U** No **O** No **C** Yes, it is needed to see	1	1	5	7
18. Small instruments **U** -- **O** (current instruments' diameter is around 4 mm) (Need to change the knee positions and camera ports repeatedly; tissue problems e.g. thin meniscus) (Current instrument, e.g. 4 mm; helpful for doing surgery through medial meniscus posterior horn for stitching of meniscus tear) **C** --	--	5	--	5

19. Teleoperation **U** -- **O** Teleoperation is needed. (e.g. for minimal meniscus resection; surgeons' posture is not good during these procedures) **C** --	--	5	--	5
20. Teleoperated vision system **U** -- **O** -- **C** (to remove camera handling by assistants)	--	--	5	5
21. Instrument jaw grip **U** -- **O** -- **C** Instruments, which could provide pencil grip, are needed	--	--	5	5
22. Camera size **U** -- **O** --	--	--	5	5

C Small camera system needed (due to smaller access)				
23. Magnified vision **U** Yes **O** -- **C** --	5	--	--	5
24. Magnified haptic feeling/force feeling **U** No, it is not needed. (Realistic feedback is desired) **O** Exaggerated haptic feeling needed. (to reduce iatrogenic complications) **C** For clinical purposes, it should not be magnified, but kept into physiological ranges	3	1	1	5
25. Master interface size **U** -- **O** -- **C** Small interface needed (35-40 cm^2)	--	--	3	3
26. Surgeon's position	1	1	1	3

Ergonomic surgeon's position (**U**; **O**; **C**)				
27. Instrument tip swapping (**U**; **O**; **C**)	1	1	1	3
28. Manipulation with left handed surgeon **U**: -- **O**: Modification to current instruments are needed for left-handed surgeons. (e.g. especially for manipulating the tissues) **C**: --	--	1	--	1
29. Field of view **U**: Wider field of view may be helpful. Size of the operative area (Less than 5 cm^2 to 25 cm^2) (e.g. to see the assistants' instruments; remove the need of changing the ports) **O**: -- **C**: --	1	--	--	1
30. Clutching mechanism **U**: New clutching mechanism needed (e.g. frequent clutching is required to handle the workspace limitation; limited workspace) **O**: --	1	--	--	1

C --				
31. Easier understanding of surgical workflow steps **U** (It is difficult to handle complex surgical cases and follow the open surgery approaches by the junior surgeons) (e.g. thinking and defining approach and steps for junior surgeons – surgical resilience) **O** -- **C** --	1	--	--	1
32. Grasping mechanism **U** More force, during grasping the tissue, is needed. **O** -- **C** --	1	--	--	1
33. Camera length **U** Short camera length is needed (to remove clashing of instruments with assistants; current size – approximately 30 cm) **O** -- **C** --	1	--	--	1

3.5 Results

We have conducted the total of 27 interviews, where the breakdown of specialties and surgeon's skill levels are explained in Table 19. As seen from the Table 19, we interviewed 17 Urologists, 6 Orthopaedic surgeons and 4 Cardiac surgeons. While the total number of junior and mid-career (intermediate) surgeons were 10 and 7 respectively, the number of senior surgeons across all the specialties were 10.

Interviews	UWE	POLIMI	
Orthopaedic surgeons	0	6 (1 senior; 3 mid-career; 2 junior)	
Urologists	7 (4 senior; 3 junior)	10 (3 senior; 3 mid-career; 4 junior)	
Cardiac surgeons	0	4 (2 senior; 1 mid-career; 1 junior)	
Total senior			10
Total intermediate			7
Total Junior			10

Table 19. Interview participant's information

The 'within-case' analysis has identified 13, 18 and 14 different categories of elicited requirements for Orthopaedics, Urology and Cardiac surgery use cases respectively. For Orthopaedics surgery, the category ('anatomical problem') were discussed, i.e. 7 times, more than any other categories. The haptic feeling, i.e. 17 times, and Image quality, i.e. 7 times, categories were discussed more than any other use cases' categories for Urology and Cardiac surgery use cases respectively. For all the use cases, we elicited requirements with 12 'close-ended' questions too. For the elicitation of these requirements, we used deductive reasoning because we have the specific requirements for different system components. Moreover, it is clear that generalization of the requirements to the higher granularity level e.g. overall system is not required as far as requirements for the system components are satisfied.

A total of 33 user requirements have been elicited, out of which 4 requirements (e.g. superimposed preoperative images, articulated instruments, active constraints and hand exoskeleton as master system) are the mandatory requirements, i.e. priority score >=14, which are summarized in this section. As shown in Fig 3, the total of 14 common requirements are elicited between all the specialties, and 5 requirements between the two specialties (e.g. 3 common requirements between Cardiac and Urology use cases and 2 common requirements between Cardiac and Orthopaedics use cases). There are 13 requirements (i.e. 4 for Cardiac, 6 for Urology and 3 for Orthopaedics), which are the use case specific requirements.

As shown in Table 18, we elicited mandatory requirements for each use case based on the priority assigned during the 'across' case analysis. For example, from No.1 "Superimposed preoperative images' to No.8 'Haptics' are mandatory requirements for Orthopaedic use cases, and from No. 1 'Superimposed preoperative images' to No. 10 "3D images" are the mandatory requirements for Urology and Cardiology use cases.

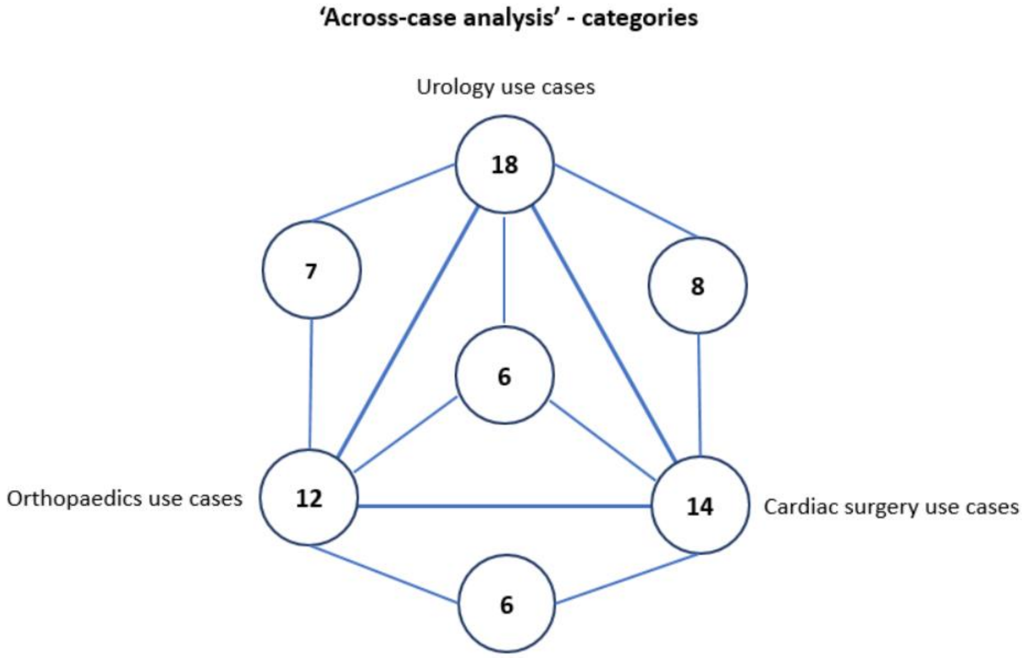
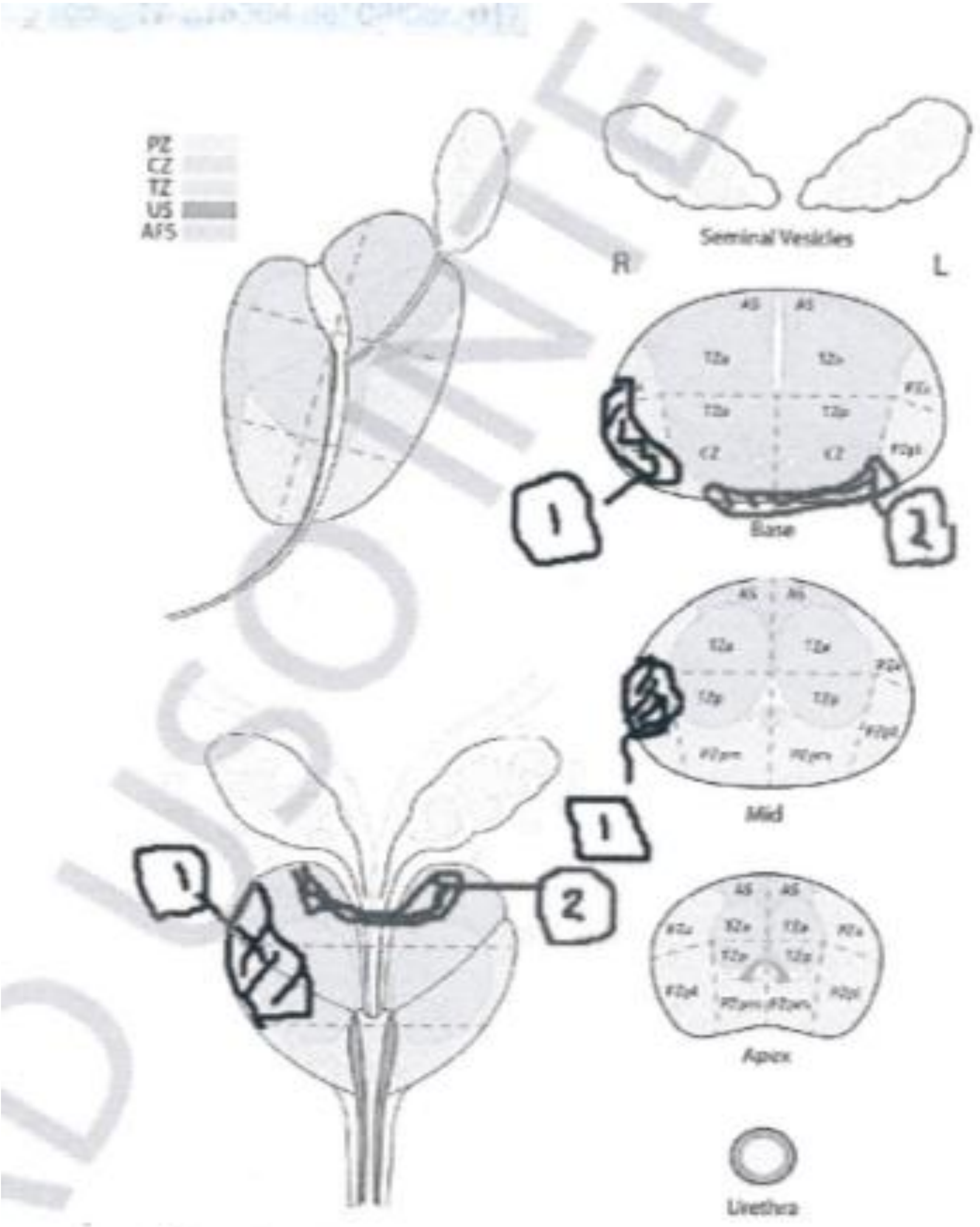


Figure 3. Common number of categories across different specialty

Superimposed preoperative images

Orthopaedic surgeons use X-Ray and MRI as preoperative images. They were not sure if it is possible to superimpose preoperative images because preoperative and intraoperative images are different especially for the orientation of images. The preoperative images are being taken in the supine position, while the knee joint is flexed during the surgery. However, there are few landmarks that could be useful for image registration e.g. medial and lateral femur condyle, anterior cruciate ligament, trochlea, and medial compartment of tibia. Urologists use CT, ultrasonography, and MRI as preoperative images. The preoperative and intraoperative images are always little different for Urology use cases. There is no much difference in the parenchymal organs, e.g. kidney, but images could change for other organs e.g. peritoneum, so the image registration could be difficult. However, superimposed images could be helpful for relative positions of the organs e.g. where the tumour or ureter is. Urologists suggested landmarks that could be useful for registration e.g. vessels like aorta, organs like spleen, lower and upper poles of the kidney during partial nephrectomy, nerves, seminal vesicles, pubic bone and apex of the prostate during the radical prostatectomy, and middle lobe of the prostate and pubic symphysis during cystectomy. Urologists suggested superimposed images are useful in specific surgical steps of these use cases for example, during the nerve sparing in radical prostatectomy or to identify the tumour during partial nephrectomy because these



Pictures from: http://www.acr.org/Quality-Safety/Resources/PIRADS/

PROSTATA: 45 x 30 x 37 mm **Volume:** 25,97 mm 3

Lesion	Size	Site	Level	Dist. Apex	T2W	DWI	DCE	ADC	SD	Contact with Capsule	Position	ECE	PI-RADS
1	9 mm	PZ - dx	Cranial;Intermediate	10 mm	4	4	0	1012	45	YES	laterale dx	2	4
2	20 mm	PZ - dx;sn	Cranial	20 mm	4	3	0	1084	73	YES	posteriore;postero-laterale dx;postero-laterale sn	2	3

Figure 4. The prostate lesion (image courtesy of European Institute of Oncology, Italy)

anatomical regions are visible on MRI. They suggested that superimposing preoperative images could also be useful to identify the enlarged lymph nodes in unusual locations. However, the surgeons need ‘on and off’ functionality for it. The surgeons also provided a prostatectomy example as shown in the Fig. 4. The base is clearly visible which provides the precise coordinates. One lesion is 10 mm and another one is 20 mm from the apex. Since the apex does not move, it is possible to determine the site of lesions for the fusion. Cardiac surgeons use combination of echocardiography, coronary angiography, CT scans or MRI as the preoperative images. They suggested that it is possible to superimpose preoperative images because there is not much difference between preoperative and intraoperative images for these two use cases. However, for the beating heart surgery, it is hard to define the landmarks. Otherwise, there are enough landmarks available for example, appendages, great vessels e.g. aorta and the apex of heart. Surgeons also suggested to superimpose the CT information on the smart glasses or conventional loupes, which they called the ‘smart loupes’.

Articulated instruments

Due to the small area and complex anatomy, Orthopaedic surgeons need articulated instruments to do the stitching on the meniscus tear as well as to see the damaged structures in 3D. For Urological use cases, articulated instruments may be helpful especially for radical prostatectomy. There are very small and close structures in pelvis e.g. ridges of pubic bone, in complex cases where there is adhesion in pelvis or abdomen, movement of instruments in the pelvis with peculiar shape of the pubic bone and to do surgery in the narrow area between the prostate and rectum. Surgeons need articulated instruments also to remove the need of changing ports repeatedly. The current cardiac surgery instruments do not provide 360° rotational movements. During cardiac surgery, it is difficult to access some anatomical structures e.g. the access to heart is provided from the anterior side, while the mitral valve is on the posterior side. Articulated instruments could also be helpful to access the ventricles behind the mitral valve. It could be also helpful for cross clamping of the aorta during retrograde cardioplegia.

Active constraints

Orthopaedic surgeons initially stated that they do not need active constraints. However, after further discussions it emerged that active constraints are highly needed and could be useful to prevent injury to rim of the meniscus. Moreover, it could be used to minimise cutting of the meniscus during surgery. For example, as shown in Fig. 5, “Parrot beak tear” and “Flap tear” are, special cases, where the active constraints could help to just remove the flaps. Moreover, in the case like “Bucket Handle Tear”, active constraints could be helpful to constraint the instruments movement in the red zone of meniscus where success of the repair is very high. So, in this case, active constraints could be helpful to prevent doing the surgery in red-white and white zone. It could also be helpful to prevent injury to peroneal nerve during the cauterisation for meniscectomy.

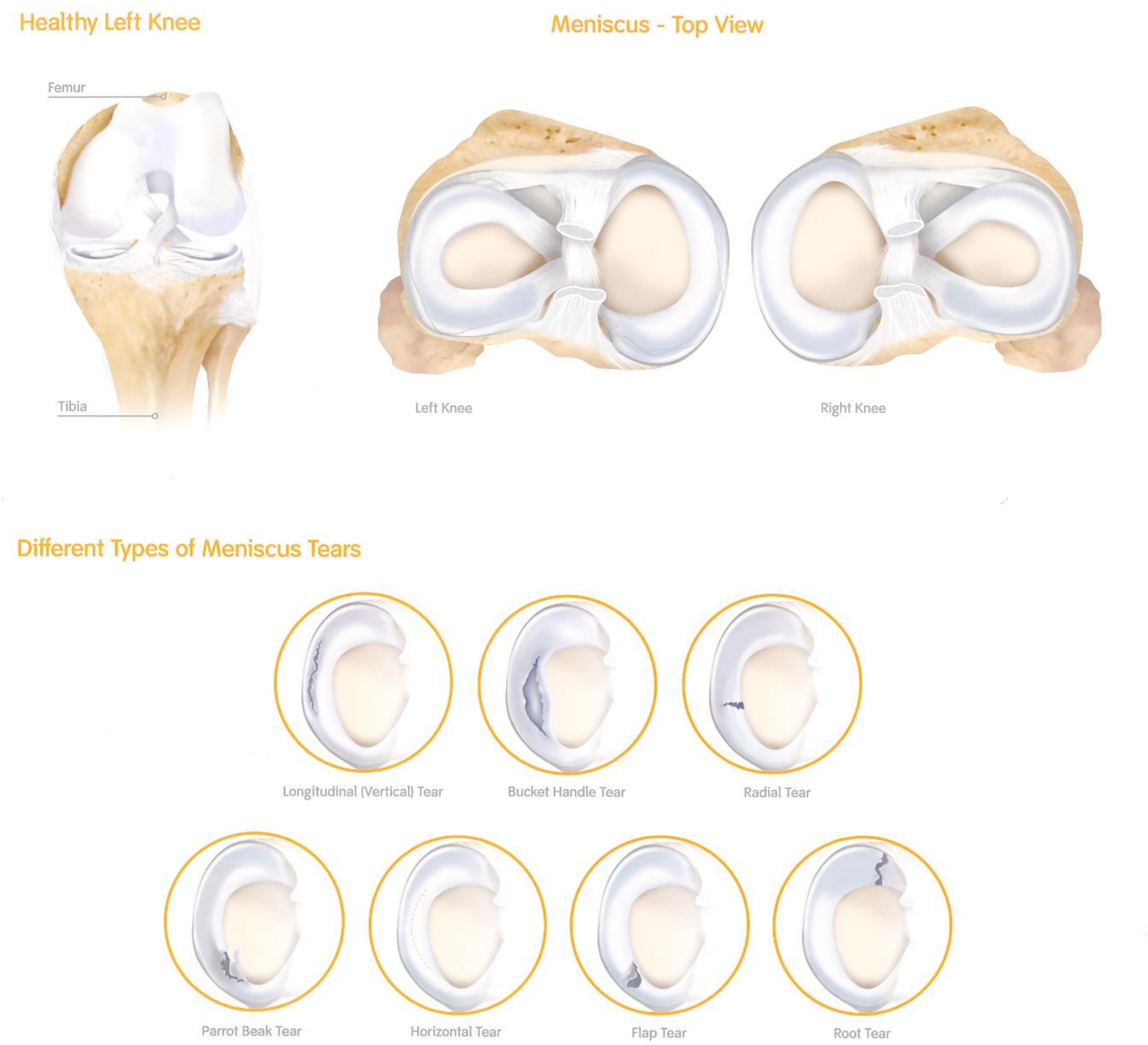


Figure 5. Different type of meniscus tear (Image courtesy of TheMIS Orthopaedics centre, Greece)

Active constraint is useful for radical prostatectomy during the lymphadenectomy to prevent injuries to arteries, veins and nerves or to prevent injury to accessory vessels coming from the pelvic wall side. It could be also useful during the nerve sparing in radical prostatectomy. In kidney surgery, it could be helpful to prevent injury to vena cava and aorta. However, many urologists believe that active constraints should only be implemented for the surgical training and junior surgeons. They also need the overriding functionality. They think, it is a distraction, confusing and may increase the surgery time. For cardiac surgery use cases, active constraints would be very helpful because there are many vital structures, e.g. vessels, nerves and so on, involved in the surgery. During harvesting the left internal mammary artery, the surgeons have to be cautious not to get too close to the left internal mammary artery while cauterising, where active constraints could be helpful.

Master system – Hand exoskeleton

With respect to hand exoskeleton, surgeons need them for both hands. The hand exoskeleton should be light weight and adjustable. It should also be small along with the master interface. There should be less wires and other things on exoskeleton. Surgeons also need the haptic feedback on hand exoskeleton.

3.6 Concerns with respect to the development of a robotic system

The concerns with respect to the robotic system are the cost, maintenance e.g. instruments need frequent replacements. The surgeons also concern about the tele-surgical implementation, distance from the patient's bed, and patient's safety. With regards to the technical functionalities, the concerns are synchronised movement of the surgical table and the slave system, robust surgical planning, reduction in system's size, improvement in the clutching mechanism and the range of instruments movements in the complex anatomical regions. The overhead design for the slave arm looks ok to surgeons and they think, it is similar to the da Vinci Xi system but the place for the anesthetic machine and the team should be comfortable. The surgeon thinks, it would be nice to feel as if your actual hand movements were controlling the instruments within the body rather than feeling of holding something which then in turn moves instruments in the body. Pedal command board to control system's functionality is fine and needed.

4. Application scenarios

Introduction

The application scenarios are explained based on priority of the requirements for each surgical use case i.e.

Orthopaedics

- Robot-assisted Partial Lateral Meniscectomy (RaPLM)
- Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)

Urology

- Robot-assisted Partial Nephrectomy (RAPN)
- Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
- Robot-assisted Radical Prostatectomy (RARP)

Cardiology

- Robot-assisted Coronary Artery Bypass Grafting (CABG)
- Robot-assisted Mitral Valve surgery (MV surgery)

Elicited possible application scenarios are shown in table 20, 21 and 22. In each table, on the left side there are the requirements, elicited with ‘across-case’ analysis, in the sequence of priority. Each possible scenario for individual use case is briefly mentioned in the “Description” cell. The phases and steps were also elicited where the scenario, explained in “Description” cell, would be implemented. For example, in table 20, first cell, explain that the preoperative images could be superimposed to see the damaged meniscus to cut the meniscus as minimum as possible. And this scenario should be implemented for the phase 4 and steps 4.1 and 4.2 of RaPLM. Further to that we asked feedback for each use case scenario from expert clinical partners. To describe the full surgical scenario for a surgical single use case, we considered the requirements until the priority of 10, and higher. We also mapped system Blocks components with surgical phases of each use case, shown below the elicited requirements in the table 20, 21 and 22. Each selected scenario is highlighted with the green colour.

Table 20. Elicited application scenarios for Orthopaedics use cases

Requirements	Scenarios
1. Superimposed preoperative images -PREOPERATIVE IMAGES -3D RECONSTRUCTION -SURGEON'S SMART GLASSES -ASSISTANT'S SMART GLASSES -VR GLASSES -STEREO VIDEO MASTER -2D MONITOR (ASSISTANT) -SURFACE DEFORMATION FIELD	**Robot-assisted Partial Lateral Meniscectomy (RaPLM)** **Scenario – RaPLM1** Phase: 4. Partial meniscectomy Step: 4.1 Insert the punch; 4.2 Fine the details Description: Preoperative images could be superimposed to see the damaged meniscus to cut it minimally **Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)** **Scenario – RaLMR1** Phase: 4 Meniscal repair Step: 4.1 Meniscal repair; a. All inside technique OR; b. Inside-out technique OR; c. Outside-in technique Description: Preoperative images could be superimposed to see the meniscus tear before suturing
2. Articulated instruments -SLAVE INSTRUMENT L&R -CLIP ON ATTACHMENT L&R	**Robot-assisted Partial Lateral Meniscectomy (RaPLM)** **Scenario – RaPLM2** Phase: All the phases except 6. Closure phase Step: All the steps except the steps of 6. Closure phase Description: It is needed in all the phases

<table>
<tr>
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<td>
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR2
<table>
<tr><td>Phase</td><td>All the phases except 6. Closure phase</td></tr>
<tr><td>Step</td><td>All the steps except the steps of 6. Closure phase</td></tr>
<tr><td>Description</td><td>It is needed in all the phases</td></tr>
</table>
</td>
</tr>
<tr>
<td>
3. Active constraints
-ACTIVE CONSTRAINTS ENFORCEMENT
-ACTIVE CONSTRAINTS UPDATE
-ACTIVE CONSTRAINTS CONSTRUCTION
-CAMERA INTERFACE AND 3D RECONSTRUCTION
</td>
<td>
Robot-assisted Partial Lateral Meniscectomy (RaPLM)
Scenario – RaPLM3
<table>
<tr><td>Phase</td><td>4 Partial Meniscectomy</td></tr>
<tr><td>Step</td><td>4.1 Insert the punch
4.2 Fine the details</td></tr>
<tr><td>Description</td><td>Active constraints is implemented to prevent the injury to meniscus rim and to cut the minimum meniscus e.g. meniscus flaps could be labelled for the active constraints.</td></tr>
</table>
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR3
<table>
<tr><td>Phase</td><td>4 Meniscal repair</td></tr>
<tr><td>Step</td><td>4.1 Meniscal repair
a. All inside technique OR
b. Inside-out technique OR
c. Outside-in technique</td></tr>
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<table>
<tr>
<td></td>
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<table>
<tr><td>Description</td><td>Active constraints could be used to do repair accurately in red zone, white zone and red-white zone.</td></tr>
</table>
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<tr>
<td>4. Master interface (Hand exoskeleton)

-MASTER EXOSKELETON L&R</td>
<td>
Robot-assisted Partial Lateral Meniscectomy (RaPLM)
Scenario – RaPLM4
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
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Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR4
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
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<tr>
<td>5. Image quality

-CAMERA INTERFACE AND 3D RECONSTRUCTION</td>
<td>
Robot-assisted Partial Lateral Meniscectomy (RaPLM)
Scenario – RaPLM5
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>

Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR5
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
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6. Smart glasses (for assistants)

-SURGEON'S SMART GLASSES
-ASSISTANT's SMART GLASSES

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Robot-assisted Partial Lateral Meniscectomy (RaPLM)

Scenario – RaPLM6

Phase	All phases
Step	All steps

Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)

Scenario – RaLMR6

Phase	All phases
Step	All steps

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7. Three-fingered instruments

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R

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Robot-assisted Partial Lateral Meniscectomy (RaPLM)

Scenario – RaPLM7

Phase	2 Knee joint overview
Step	2.1 Examine anterior-inferior compartment (infrapatellar plica, Anterior Cruciate Ligament, notch) 2.2 Examine medial compartment (medical meniscus, cartilage) 2.3 Examine lateral compartment (lateral meniscus, cartilage, popliteal tendon) 2.4 Examine superior compartment (Patella, trochlea, suprapatellar joint membrane)
Description	Three-fingered instrument is used to see the knee compartments

Scenario – RaPLM8

Phase	4 Partial meniscectomy
Step	4.1 Insert the punch 4.2 Fine the details

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<table>
<tr><td>Description</td><td>Three-fingered instrument could be used to cut the free cartilage pieces and to repair tendon and nerves.</td></tr>
</table>
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR7
<table>
<tr><td>Phase</td><td>4 Meniscal repair</td></tr>
<tr><td>Step</td><td>4.1 Meniscal repair
a. all inside technique OR
b. Inside-out technique OR
c. Outside – in technique</td></tr>
<tr><td>Description</td><td>Three-fingered instrument could be used to stabilise the meniscus during the repair</td></tr>
</table>
</td>
</tr>
<tr>
<td>
8. Haptics
-FORCE TORQUE SENSORS WRIST L&R
-FORCE TORQUE SENSORS SKELETON L&R
-FORCE DISPLAY
</td>
<td>
Robot-assisted Partial Lateral Meniscectomy (RaPLM)
Scenario – RaPLM9
<table>
<tr><td>Phase</td><td>3 Probing – Marking of damage - Evaluation</td></tr>
<tr><td>Step</td><td>3.3 Evaluate position of tear in the meniscus (blood supply: red zone, white zone, red-white zone)
3.4 Evaluate position of tear in the meniscus (anterior horn, body, posterior horn)</td></tr>
<tr><td>Description</td><td>Haptics could be used to evaluate the position of tear in the meniscus</td></tr>
</table>
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<table>
<tr>
<td></td>
<td>
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)

Scenario – RaLMR8
<table>
<tr><td>Phase</td><td>3 Probing – Marking of damage - Evaluation</td></tr>
<tr><td>Step</td><td>3.3 Evaluate position of tear in the meniscus (blood supply: red zone, white zone, red-white zone)
3.4 Evaluate position of tear in the meniscus (anterior horn, body, posterior horn)</td></tr>
<tr><td>Description</td><td>Haptics could be used to evaluate the position of tear in the meniscus</td></tr>
</table>
Scenario – RaLMR9
<table>
<tr><td>Phase</td><td>4 Meniscal repair</td></tr>
<tr><td>Step</td><td>4.1 Meniscal repair
a. all inside technique OR
b. Inside-out technique OR
c. Outside – in technique</td></tr>
<tr><td>Description</td><td>Haptics could be used during suturing the meniscus</td></tr>
</table>
</td>
</tr>
<tr>
<td>
9. Needle holder

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R
</td>
<td>
Robot-assisted Partial Lateral Meniscectomy (RaPLM)
<table>
<tr><td>Phase</td><td>--</td></tr>
<tr><td>Step</td><td>--</td></tr>
<tr><td>Description</td><td>No, it is not needed</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr>
<td></td>
<td>
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR10
<table>
<tr><td>Phase</td><td>4 Meniscal repair</td></tr>
<tr><td>Step</td><td>4.1 Meniscal repair
a. all inside technique OR
b. Inside-out technique OR
c. Outside – in technique</td></tr>
<tr><td>Description</td><td>A new needle holder to do the suturing during the meniscus repair</td></tr>
</table>
</td>
</tr>
<tr>
<td>
10. Alternative haptic sensation
-FORCE DISPLAY
</td>
<td>
Robot-assisted Partial Lateral Meniscectomy (RaPLM)
Scenario – RaPLM10
<table>
<tr><td>Phase</td><td>3 Probing – Marking of damage - Evaluation</td></tr>
<tr><td>Step</td><td>3.3 Evaluate position of tear in the meniscus (blood supply: red zone, white zone, red-white zone)
3.4 Evaluate position of tear in the meniscus (anterior horn, body, posterior horn)</td></tr>
<tr><td>Description</td><td>Haptics could be used to evaluate the position of tear in the meniscus</td></tr>
</table>
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR11
<table>
<tr><td>Phase</td><td>3 Probing – Marking of damage - Evaluation</td></tr>
<tr><td>Step</td><td>3.3 Evaluate position of tear in the meniscus (blood supply: red zone, white zone, red-white zone)</td></tr>
</table>
</td>
</tr>
</table>

			3.4 Evaluate position of tear in the meniscus (anterior horn, body, posterior horn)
	Description	Haptics could be used to evaluate the position of tear in the meniscus

Scenario – RaLMR12

Phase	4 Meniscal repair
Step	4.1 Meniscal repair a. all inside technique OR b. Inside-out technique OR c. Outside – in technique
Description	Haptics could be used during suturing the meniscus

11. Extended visual feedback

-PREOPERATIVE IMAGES
-3D RECONSTRUCTION
-REGISTERED RECONSTRUCTION
-ACTIVE CONSTRAINTS CONSTRUCTION

Robot-assisted Partial Lateral Meniscectomy (RaPLM)

Scenario – RaPLM11

Phase	All phases
Step	All steps

Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)

Scenario – RaLMR13

Phase	All phases
Step	All steps

12. Instrumentation

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R

Robot-assisted Partial Lateral Meniscectomy (RaPLM)

Phase	--
Step	--

<table>
<tr><td></td><td>Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR14<table><tr><td>Phase</td><td>4 Meniscal repair</td></tr><tr><td>Step</td><td>4.1 Meniscal repair
a. all inside technique OR
b. Inside-out technique OR
c. Outside – in technique</td></tr><tr><td>Description</td><td>A small needle holder for doing the suturing</td></tr></table></td></tr>
<tr><td>13. Camera control

-SLAVE CAMERA HOLDER CONTROLLER</td><td>Robot-assisted Partial Lateral Meniscectomy (RaPLM)
Scenario – RaPLM12<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR15<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table></td></tr>
<tr><td>14. Small instruments

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R</td><td>Robot-assisted Partial Lateral Meniscectomy (RaPLM)
Scenario – RaPLM13<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table></td></tr>
</table>

<table>
<tr><td></td><td>Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR16
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table></td></tr>
<tr><td>15. Teleoperation

-MASTER EXOSKELETON CONTROLLER
-MASTER ARM CONTROLLER
-SLAVE ARM CONTROLLER
-MAIN CONTROLLER</td><td>Robot-assisted Partial Lateral Meniscectomy (RaPLM)
Scenario – RaPLM14
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR17
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table></td></tr>
<tr><td>16. Physiological data

-SURGEON’S SMART GLASSES</td><td>Robot-assisted Partial Lateral Meniscectomy (RaPLM)
<table><tr><td>Phase</td><td>--</td></tr><tr><td>Step</td><td>--</td></tr></table>
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
<table><tr><td>Phase</td><td>--</td></tr><tr><td>Step</td><td>--</td></tr></table></td></tr>
</table>

<table>
<tr>
<td>

17. Magnified haptic feeling/force feeling

-FORCE SENSOR CONTROLLER SKELETON
-FORCE SENSOR CONTROLLER WRIST

</td>
<td>

Robot-assisted Partial Lateral Meniscectomy (RaPLM)

Scenario – RaPLM15

Phase	3 Probing – Marking of damage - Evaluation
Step	3.3 Evaluate position of tear in the meniscus (blood supply: red zone, white zone, red-white zone) 3.4 Evaluate position of tear in the meniscus (anterior horn, body, posterior horn)
Description	Haptics could be used to evaluate the position of tear in the meniscus

Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)

Scenario – RaLMR18

Phase	3 Probing – Marking of damage - Evaluation
Step	3.3 Evaluate position of tear in the meniscus (blood supply: red zone, white zone, red-white zone) 3.4 Evaluate position of tear in the meniscus (anterior horn, body, posterior horn)
Description	Haptics could be used to evaluate the position of tear in the meniscus

Scenario – RaLMR19

Phase	4 Meniscal repair
Step	4.1 Meniscal repair a. all inside technique OR b. Inside-out technique OR c. Outside – in technique
Description	Haptics could be used during suturing the meniscus

</td>
</tr>
</table>

<table>
<tr><td>18. Surgeon's position</td><td>Robot-assisted Partial Lateral Meniscectomy (RaPLM)
Scenario – RaPLM16<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR20<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table></td></tr>
<tr><td>19. Manipulation with left-handed surgeon

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R</td><td>Robot-assisted Partial Lateral Meniscectomy (RaPLM)
Scenario – RaPLM17<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr><tr><td>Description</td><td>Modification to current instruments</td></tr></table>
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR)
Scenario – RaLMR21<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr><tr><td>Description</td><td>Modification to current instruments</td></tr></table></td></tr>
<tr><td>20. Instrument's tip swapping

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R</td><td>Robot-assisted Partial Lateral Meniscectomy (RaPLM)
Scenario – RaPLM18<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table></td></tr>
</table>

	Robot-assisted Repair of Partial Lateral Meniscus Tear (RaLMR) **Scenario – RaLMR22** Phase: All phases Step: All steps

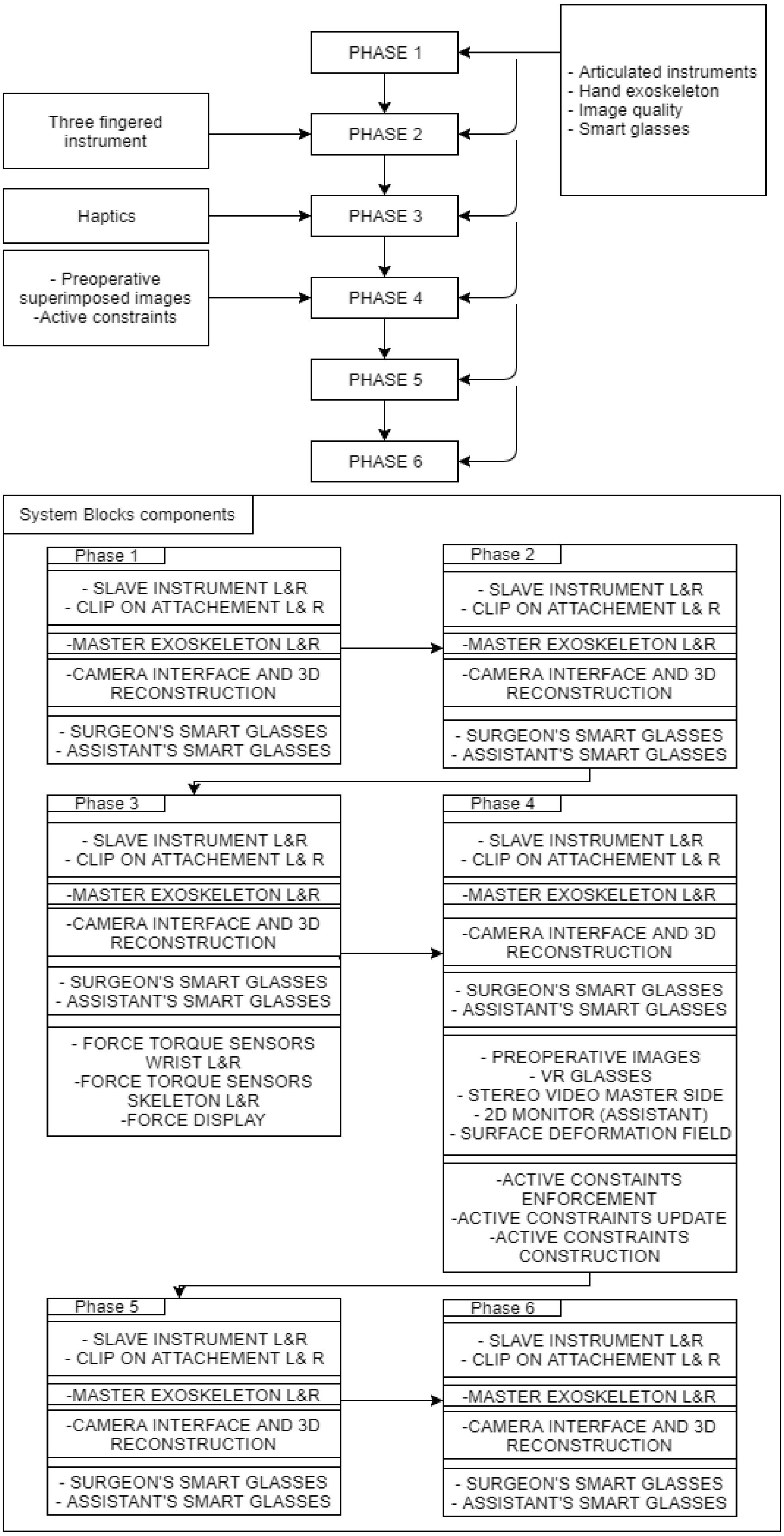

Figure 6. Application scenario for Robot-assisted Partial Lateral Meniscectomy

Table 21. Elicited application scenarios for Urology use cases

<table>
<tr><th>Requirements</th><th>Scenarios</th></tr>
<tr><td>1. Superimposed preoperative images

-PREOPERATIVE IMAGES
-3D RECONSTRUCTION
-SURGEON'S SMART GLASSES
-ASSISTANT'S SMART GLASSES
-VR GLASSES
-STEREO VIDEO MASTER
-2D MONITOR (ASSISTANT)
-SURFACE DEFORMATION FIELD</td><td>Robot-assisted partial nephrectomy (RAPN)

Scenario-RAPN1
<table>
<tr><td>Phase</td><td>4. Tumor preparation</td></tr>
<tr><td>Step</td><td>4.1 Dissect adipose capsule
4.2 Use ultrasound if endophytic neoplasia</td></tr>
<tr><td>Description</td><td>The preoperative images are superimposed at the beginning during the dissection of the adipose capsule to see the exophytic tumour if there is a lot of fat. If there is a endophytic tumour then images are also superimposed during the dissection and confirmation is done via ultrasound machine.</td></tr>
</table>
Scenario-RAPN2
<table>
<tr><td>Phase</td><td>5. Tumor excision</td></tr>
<tr><td>Step</td><td>5.1 Sharply incise the renal capsule</td></tr>
<tr><td></td><td>5.2 Expose the pedicles and clamp the renal artery</td></tr>
<tr><td>Description</td><td>The preoperative images are superimposed to see the renal artery while incising the renal capsule before clamping the artery.</td></tr>
</table>

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC1
<table>
<tr><td>Phase</td><td>2. Lymphadenectomy</td></tr>
<tr><td>Step</td><td>2.1 Start dissection at external iliac vessels and continue up to aortic bifurcation</td></tr>
</table>
</td></tr>
</table>

	2.2 Clear triangle of Marcille and the area along the internal iliac vessels including the presacral area from the lymphatic tissue
Description	Preoperative images are superimposed to see aortic bifurcation before starting the dissection at external iliac vessels. Then internal iliac vessels are identified to clear triangle of Marcille and the area along the internal iliac vessels.

Scenario-RARC2

Phase	3. Passage of the ureter beneath the sigmoid
Step	3.1 the left ureter is tunnelled under the sigmoid mesentery
Description	Preoperative images are superimposed to see the sigmoid mesentery before making the tunnel for left ureter.

Scenario-RARC3

Phase	4 Control/division of bladder pedicles
Step	4.3 Develop the surgical plane between the Denonvilliers' fascia and rectum 4.4 Mobilise bladder 4.5 Divide the vans deferens
Description	Preoperative images are superimposed to see the rectum to develop the surgical plane between the Denonvilliers' fascia and rectum. Moreover, before dividing the vans deferens, it is also visualised.

Scenario-RARC4

Phase	6 Control/Division of dorsal vein complex
Step	6.3 Maximum sparing of the urethra
Description	Preoperative images are superimposed to visualise the prostatic urethra to facilitate maximum sparing.

Robot-assisted radical prostatectomy (RARP)

Scenario-RARP1

Phase	3 Anterior bladder neck dissection
Step	3.1 Retract the bladder backwards 3.2 Incise the anterior bladder neck 3.3 Dissect the prostatic urethra bluntly and divide
Description	Preoperative images could be used to visualise the pubic symphysis to know good location for anterior bladder neck incision and not to damage the vasculature.

Scenario-RARP2

Phase	5. Seminal vesicles dissection
Step	5.3 Dissect the seminal vesicles and divide small vessels 5.4 Divide the vas deferens
Description	Preoperative images could be used to visualise neurovascular triangle that could prevent injury to neurovascular structure

Scenario-RARP3

Phase	7 Nerve sparing left
Step	7.2 Incise fascia around the prostate and divide the small vessels 7.3 Dissect the plane bluntly 7.4 Divide the pedicle
Description	Preoperative images could be used to superimpose the neurovascular bundle.

Scenario-RARP4

Phase	8 Nerve sparing right
Step	8.2 Incise fascia around the prostate and divide the small vessels 8.3 Dissect the plane bluntly 8.4 Divide the pedicle

<table>
<tr><td></td><td>
<table><tr><td>Description</td><td>Preoperative images could be used to superimpose the neurovascular bundle.</td></tr></table>
</td></tr>
<tr><td>2. Articulated instruments

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R</td><td>
Robot-assisted partial nephrectomy (RAPN)
<table><tr><td>Phase</td><td>--</td></tr><tr><td>Step</td><td>--</td></tr><tr><td>Description</td><td>It is not needed</td></tr></table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
<table><tr><td>Phase</td><td>--</td></tr><tr><td>Step</td><td>--</td></tr><tr><td>Description</td><td>It is not needed</td></tr></table>
Robot-assisted radical prostatectomy (RARP)
Scenario-RARP5
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr><tr><td>Description</td><td>Especially during posterior bladder neck dissection, Nerve sparing left and right, Apex dissection and urethrovesical anastomosis</td></tr></table>
</td></tr>
<tr><td>3. Active constraints

-ACTIVE CONSTRAINTS ENFORCEMENT
-ACTIVE CONSTRAINTS UPDATE
-ACTIVE CONSTRAINTS CONSTRUCTION</td><td>
Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN3
<table><tr><td>Phase</td><td>1. Kidney preparation</td></tr><tr><td>Step</td><td>1.3 Isolate ureter and gonadic veins
1.4 Dissect ureter and gonadic veins</td></tr></table>
</td></tr>
</table>

<table>
<tr>
<td>-CAMERA INTERFACE AND 3D RECONSTRUCTION</td>
<td>
<table>
<tr><td></td><td>1.6 Push away liver/spleen from kidney</td></tr>
<tr><td>Description</td><td>During these steps, active constraints could be used to prevent injuries to aorta and vena cava as well as vascular structures to liver and spleen.</td></tr>
</table>
Scenario-RAPN4
<table>
<tr><td>Phase</td><td>2. Upper pole preparation</td></tr>
<tr><td>Step</td><td>2.1 Mobilise the kidney
2.2 Retract liver and spleen</td></tr>
<tr><td>Description</td><td>During these steps, active constraints could be used to prevent injuries to aorta and vena cava as well as vascular structures to liver and spleen.</td></tr>
</table>
Scenario-RAPN5
<table>
<tr><td>Phase</td><td>5. Tumor excision</td></tr>
<tr><td>Step</td><td>5.2 Expose the pedicles and clamp the renal artery</td></tr>
<tr><td>Description</td><td>After the preoperative images is superimposed, the active constraints could be used to prevent injuries to the renal arteries.</td></tr>
</table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC5
<table>
<tr><td>Phase</td><td>2. Lymphadenectomy</td></tr>
<tr><td>Step</td><td>2.1 Start dissection at external iliac vessels and continue up to aortic bifurcation
2.2 Clear triangle of Marcille and the area along the internal iliac vessels including the presacral area from the lymphatic tissue</td></tr>
<tr><td>Description</td><td>The active constraints is used to prevent injury to aorta and internal iliac vessels.</td></tr>
</table>
</td>
</tr>
</table>

Scenario-RARC6

Phase	5. Nerve spare
Step	5.1 Do interfacial release of the neurovascular bundle
Description	It is used to prevent the injury to nerves

Scenario-RARC7

Phase	7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis (Orthotopic neobladder, intracorporeal technique)
Step	7.6 Close posterior part of the studer reservoir and part of anterior part
Description	While closing the posterior part of the studer reservoir, it is advised not to go very near to entero-urethral anastomosis.

Robot-assisted radical prostatectomy (RARP)

Scenario-RARP6

Phase	14. Lymph node dissection
Step	14.1 Dissect the lymphatic tissue bluntly 14.2 Divide the main lymphatic trunks 14.3 Remove the lymph nodes
Description	Active constraints could be used to prevent injury to the common iliac vessels, internal and external iliac vessels, and genitofemoral nerve

<table>
<tr>
<td>4. Master interface (Hand exoskeleton)

-MASTER EXOSKELETON L&R</td>
<td>
Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN6
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC8
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted radical prostatectomy (RARP)
Scenario-RARP7
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
</td>
</tr>
<tr>
<td>5. Image quality

-STEREO VIDEO MASTER SIDE
-STEREO ENDOSCOPIC CAMERA
-CAMERA INTERFACE AND 3D RECONSTRUCTION</td>
<td>
Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN7
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC9
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted radical prostatectomy (RARP)
Scenario-RARP8
<table><tr><td>Phase</td><td>All phases</td></tr></table>
</td>
</tr>
</table>

<table>
<tr><td></td><td>
<table><tr><td>Step</td><td>All steps</td></tr></table>
</td></tr>
<tr><td>6. Smart glasses (for assistants)

-ASSISTANT SMART GLASSES A</td><td>
Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN8
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC10
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted radical prostatectomy (RARP)
Scenario-RARP9
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
</td></tr>
<tr><td>7. Three-fingered instrument

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R</td><td>
Robot-assisted partial nephrectomy (RAPN)
<table><tr><td>Phase</td><td>--</td></tr><tr><td>Step</td><td>--</td></tr><tr><td>Description</td><td>It is not needed</td></tr></table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
<table><tr><td>Phase</td><td>--</td></tr><tr><td>Step</td><td>--</td></tr><tr><td>Description</td><td>It is not needed</td></tr></table>
</td></tr>
</table>

<table>
<tr><td></td><td>

Robot-assisted radical prostatectomy (RARP)

Phase	--
Step	--
Description	It is not needed

It is not needed; however, the surgeons show the willingness to try the instrument. The scenarios will be decided at the later stage.

</td></tr>
<tr><td>

8. Haptics

-FORCE TORQUE SENSORS WRIST L&R
-FORCE TORQUE SENSORS SKELETON L&R
-FORCE DISPLAY

</td><td>

Robot-assisted partial nephrectomy (RAPN)

Scenario-RAPN9

Phase	1. Kidney preparation
Step	1.6 Push away liver/spleen from kidney
Description	Haptic feeling while pushing away liver/spleen from kidney

Scenario-RAPN10

Phase	2. Upper pole preparation
Step	2.2 Retract liver and spleen
Description	Haptic feeling while retracting liver and spleen

Scenario-RAPN11

Phase	6. Renal breach closure
Step	6.1 Perform medullary suturing and apply the clips 6.3 Perform cortical suturing 6.4 Re-approximate the cortical parenchyma 6.7 Reconstruct Gerota's fascia

</td></tr>
</table>

Description	Haptic feeling while suturing and thread tensioning while performing medullary and cortical suturing

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)

Scenario-RARC11

Phase	5. Nerve spare
Step	5.1 Do interfacial release of the neurovascular bundle
Description	Haptic feedback is provided during the interfacial release of the neurovascular bundles in order to maximize the nerve sparing

Scenario-RARC12

Phase	6. Control/division of dorsal vein complex
Step	6.3 Maximum sparing of the urethra
Description	Haptic feedback is provided for maximum sparing of the urethra during division of dorsal vein complex

Scenario-RARC13

Phase	7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis (Orthotopic neobladder, intracorporeal technique)
Step	7.3 Bowel continuity re-established with stapled trouser anastomosis 7.4 Complete urethra-enteric anastomosis for neobladder 7.6 Close posterior part of the studer reservoir and part of anterior part 7.10 Perform Bricker uretero-ileal anastomosis to afferent limb of neobladder or ileal conduit

Phase	7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis (ileal conduit, intracorporeal technique)
Step	7.10 Close the remaining reservoir and check the leakage
Description	Haptic feedback for suturing and thread tensioning during urethra-enteric anastomosis and uretero-ileal anastomosis and closing the studer remaining reservoir

Robot-assisted radical prostatectomy (RARP)

Scenario-RARP10

Phase	1 Bladder takedown
Step	1.2 Grasp the urachus and incise the peritoneum
Description	Feeling for grasping the urachus

Scenario-RARP11

Phase	2 Endoscopic fascia incision
Step	2.1 Retract the prostate and incise the endopelvic fascia
Description	Haptic feeling during retracting the prostate

Scenario-RARP12

Phase	3 Anterior bladder neck dissection
Step	3.1 Retract the bladder backwards 3.4 identify the catheter and grasp
Description	Haptic feeling during retracting the bladder backwards

Scenario-RARP13

Phase	5 Posterior bladder neck dissection
Step	5.1 Hold the vas deferens upwards
Description	Haptic feeling during holding the vas deferens

Scenario-RARP14

Phase	6 Posterior plane dissection
Step	6.1 Hold the left seminal vesicle upwards and laterally 6.2 Retract the Denonvilliers' fascia
Description	Haptic feeling for holding the left seminal vesicles upwards and laterally and to retract the Denonvillers' fascia

Scenario-RARP15

Phase	6 Posterior plane dissection
Step	6.1 Hold the left seminal vesicle upwards and laterally 6.2 Retract the Denonvilliers' fascia
Description	Haptic feeling for holding the left seminal vesicles upwards and laterally and to retract the Denonvillers' fascia

Scenario-RARP16

Phase	7 Nerve sparing left
Step	7.1 Hold the left seminal vesicle backwards and medially
Description	Haptic feeling for holding the left seminal vesicle backwards and medially

Scenario-RARP17

Phase	8 Nerve sparing right
Step	8.1 Grasp the bladder and retract the right seminal vesicle
Description	Haptic feeling for grasping the bladder and retracting the right seminal vesicle

Scenario-RARP18

Phase	9 Dorsal vein complex dissection
Step	9.6 Retract the prostate backwards
Description	Haptic feeling during retracting the prostate backwards

<table>
<tr><td></td><td>

Scenario-RARP19

Phase	13 Bladder neck dissection
Step	13.2 Perform bilateral plication over the lateral aspect of the bladder 13.3 Suturing to match the bladder neck size to the membranous urethra
Description	Suturing to match the bladder neck size to the membranous urethra

Scenario-RARP20

Phase	15 Posterior reconstruction
Step	15.1 Approximate the free edge of the remaining Denonvilliers' fascia 15.2 Approximate the posterior lip of the bladder neck and vesicoprostatic muscle
Description	Haptic feeling during the stitching for the approximation of the remaining Denonvilliers' fascia and posterior lip of the bladder neck

Scenario-RARP21

Phase	16 Urethrovesical anastomosis
Step	16.1 Start the anastomosis at 5 o'clock on the bladder neck 16.2 Pass the needle at 5 o'clock in the urethra and then at 6 o'clock in the bladder neck 16.3 Suturing the tissue
Description	Haptic feeling during the suturing for urethrovesical anastomosis

</td></tr>
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9. Flexible camera

-CAMERA INTERFACE & 3D RECONSTRUCTION
-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R

</td><td>

Robot-assisted partial nephrectomy (RAPN)

Phase	--
Step	--
Description	It is not needed

</td></tr>
</table>

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)

Phase	--
Step	--
Description	It is not needed

Robot-assisted radical prostatectomy (RARP)

Scenario-RARP22

Phase	Nerve sparing left
Step	7.1 Hold the seminal vesicle backwards and medially 7.2 Incise fascia around the prostate and divide the small vessels 7.3 Dissect the plane bluntly 7.4 Divide the pedicle
Description	Flexible camera could be used to divide the small vessels and pedicle

Scenario-RARP23

Phase	Nerve sparing right
Step	7.1 Grasp the bladder and retract the right seminal vesicle 7.2 Incise fascia around the prostate and divide the small vessels 7.3 Dissect the plane bluntly 7.4 Divide the pedicle
Description	Flexible camera could be used to divide the small vessels and pedicle

<table>
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10. 3D images

-STEREO VIDEO MASTER SIDE
-STEREO ENDOSCOPIC CAMERA
-VR GLASSES

</td><td>

Robot-assisted partial nephrectomy (RAPN)

Scenario-RAPN12

Phase	All phases
Step	All steps

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)

Scenario-RARC14

Phase	All phases
Step	All steps

Robot-assisted radical prostatectomy (RARP)

Scenario-RARP24

Phase	All phases
Step	All steps

</td></tr>
<tr><td>

11. Needle holders

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R

</td><td>

Robot-assisted partial nephrectomy (RAPN)

Scenario-RAPN13

Phase	6. Renal breach closure
Step	6.1 Perform medullary suturing and apply the clips 6.3 Perform cortical suturing 6.4 Re-approximate the cortical parenchyma 6.7 Reconstruct Gerota's fascia
Description	Small needle holder to do suturing during medullary and cortical suturing

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)

Scenario-RARC15

</td></tr>
</table>

Phase	5. Nerve spare
Step	5.1 Do interfacial release of the neurovascular bundle
Description	Small needle holder to do suturing for nerve spring during the interfacial release of the neurovascular bundle.

Scenario-RARC16

Phase	6. Control/division of dorsal vein complex
Step	6.3 Maximum sparing of the urethra
Description	Small needle holder to do maximum sparing of the urethra

Scenario-RARC17

Phase	7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis (Orthotopic neobladder, intracorporeal technique)
Step	7.3 Bowel continuity re-established with stapled trouser anastomosis 7.4 Complete urethra-enteric anastomosis for neobladder 7.6 Close posterior part of the studer reservoir and part of anterior part 7.10 Perform Bricker uretero-ileal anastomosis to afferent limb of neobladder or ileal conduit
Phase	7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis (ileal conduit, intracorporeal technique)
Step	7.10 Close the remaining reservoir and check the leakage
Description	Small needle holder to do urethra-enteric anastomosis and uretero-ileal anastomosis

Robot-assisted radical prostatectomy (RARP)

Scenario-RARP25

Phase	13 Bladder neck dissection
Step	13.2 Perform bilateral plication over the lateral aspect of the bladder 13.3 Suturing to match the bladder neck size to the membranous urethra
Description	Suturing to match the bladder neck size to the membranous urethra

Scenario-RARP26

Phase	15 Posterior reconstruction
Step	15.1 Approximate the free edge of the remaining Denonvilliers' fascia 15.2 Approximate the posterior lip of the bladder neck and vesicoprostatic muscle
Description	Haptic feeling during the stitching for the approximation of the remaining Denonvilliers' fascia and posterior lip of the bladder neck

Scenario-RARP27

Phase	16 Urethrovesical anastomosis
Step	16.1 Start the anastomosis at 5 o'clock on the bladder neck 16.2 Pass the needle at 5 o'clock in the urethra and then at 6 o'clock in the bladder neck 16.3 Suturing the tissue
Description	Haptic feeling during the suturing for urethrovesical anastomosis

12. Alternative haptic sensation (visual cues)

-FORCE DISPLAY

Robot-assisted partial nephrectomy (RAPN)

Scenario-RAPN14

Phase	1. Kidney preparation
Step	1.6 Push away liver/spleen from kidney
Description	Haptic feeling while pushing away liver/spleen from kidney

Scenario-RAPN15

Phase	2. Upper pole preparation
Step	2.2 Retract liver and spleen
Description	Haptic feeling while retracting liver and spleen

Scenario-RAPN16

Phase	6. Renal breach closure
Step	6.1 Perform medullary suturing and apply the clips 6.3 Perform cortical suturing 6.4 Re-approximate the cortical parenchyma 6.7 Reconstruct Gerota's fascia
Description	Haptic feeling while suturing and thread tensioning while performing medullary and cortical suturing

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)

Scenario-RARC18

Phase	5. Nerve spare
Step	5.1 Do interfacial release of the neurovascular bundle
Description	Haptic feedback is provided during the interfacial release of the neurovascular bundles in order to maximize the nerve sparing

Scenario-RARC19

Phase	6. Control/division of dorsal vein complex
Step	6.3 Maximum sparing of the urethra

Description	Haptic feedback is provided for maximum sparing of the urethra during division of dorsal vein complex

Scenario-RARC20

Phase	7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis (Orthotopic neobladder, intracorporeal technique)
Step	7.3 Bowel continuity re-established with stapled trouser anastomosis 7.4 Complete urethra-enteric anastomosis for neobladder 7.6 Close posterior part of the studer reservoir and part of anterior part 7.10 Perform Bricker uretero-ileal anastomosis to afferent limb of neobladder or ileal conduit
Phase	7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis (ileal conduit, intracorporeal technique)
Step	7.10 Close the remaining reservoir and check the leakage
Description	Haptic feedback for suturing and thread tensioning during urethra-enteric anastomosis and uretero-ileal anastomosis and closing the studer remaining reservoir

Robot-assisted radical prostatectomy (RARP)

Scenario-RARP28

Phase	1 Bladder takedown
Step	1.2 Grasp the urachus and incise the peritoneum
Description	Feeling for grasping the urachus

Scenario-RARP29

Phase	2 Endoscopic fascia incision

Step	2.1 Retract the prostate and incise the endopelvic fascia
Description	Haptic feeling during retracting the prostate

Scenario-RARP30

Phase	3 Anterior bladder neck dissection
Step	3.1 Retract the bladder backwards 3.4 identify the catheter and grasp
Description	Haptic feeling during retracting the bladder backwards

Scenario-RARP31

Phase	5 Posterior bladder neck dissection
Step	5.1 Hold the vas deferens upwards
Description	Haptic feeling during holding the vas deferens

Scenario-RARP32

Phase	6 Posterior plane dissection
Step	6.1 Hold the left seminal vesicle upwards and laterally 6.2 Retract the Denonvilliers' fascia
Description	Haptic feeling for holding the left seminal vesicles upwards and laterally and to retract the Denonvillers' fascia

Scenario-RARP33

Phase	6 Posterior plane dissection
Step	6.1 Hold the left seminal vesicle upwards and laterally 6.2 Retract the Denonvilliers' fascia
Description	Haptic feeling for holding the left seminal vesicles upwards and laterally and to retract the Denonvillers' fascia

Scenario-RARP34

Phase	7 Nerve sparing left

Step	7.1 Hold the left seminal vesicle backwards and medially
Description	Haptic feeling for holding the left seminal vesicle backwards and medially

Scenario-RARP35

Phase	8 Nerve sparing right
Step	8.1 Grasp the bladder and retract the right seminal vesicle
Description	Haptic feeling for grasping the bladder and retracting the right seminal vesicle

Scenario-RARP36

Phase	9 Dorsal vein complex dissection
Step	9.6 Retract the prostate backwards
Description	Haptic feeling during retracting the prostate backwards

Scenario-RARP37

Phase	13 Bladder neck dissection
Step	13.2 Perform bilateral plication over the lateral aspect of the bladder 13.3 Suturing to match the bladder neck size to the membranous urethra
Description	Suturing to match the bladder neck size to the membranous urethra

Scenario-RARP38

Phase	15 Posterior reconstruction
Step	15.1 Approximate the free edge of the remaining Denonvilliers' fascia 15.2 Approximate the posterior lip of the bladder neck and vesicoprostatic muscle
Description	Haptic feeling during the stitching for the approximation of the remaining Denonvilliers' fascia and posterior lip of the bladder neck

Scenario-RARP39

<table>
<tr>
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<table>
<tr><td>Phase</td><td>16 Urethrovesical anastomosis</td></tr>
<tr><td>Step</td><td>16.1 Start the anastomosis at 5 o'clock on the bladder neck
16.2 Pass the needle at 5 o'clock in the urethra and then at 6 o'clock in the bladder neck
16.3 Suturing the tissue</td></tr>
<tr><td>Description</td><td>Haptic feeling during the suturing for urethrovesical anastomosis</td></tr>
</table>
</td>
</tr>
<tr>
<td>13. Extended visual feedback

-PREOPERATIVE IMAGES
-3D RECONSTRUCTION
-REGISTERED RECONSTRUCTION
-ACTIVE CONSTRAINTS CONSTRUCTION</td>
<td>
Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN17
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
Special scenario:
<table>
<tr><td>Phase</td><td>1. Kidney preparation</td></tr>
<tr><td>Step</td><td>1.2 Expose adipose tissue of the kidney
1.3 Isolate ureter and gonadic veins
1.4 Dissect ureter and gonadic veins</td></tr>
<tr><td>Description</td><td>Extended visual feedback could be useful to see the ureter, gonadic veins</td></tr>
</table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC21
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
Robot-assisted radical prostatectomy (RARP)
Scenario-RARP40
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
</td>
</tr>
</table>

14. Immersive stereo viewer

-VR GLASSES

Robot-assisted partial nephrectomy (RAPN)

Scenario-RAPN18

Phase	All phases
Step	All steps

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)

Scenario-RARC22

Phase	All phases
Step	All steps

Robot-assisted radical prostatectomy (RARP)

Scenario-RARP41

Phase	All phases
Step	All steps

15. Instrumentation

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R

Robot-assisted partial nephrectomy (RAPN)

Scenario-RAPN19

Phase	1 Kidney preparation
Step	1.1 Dissect parietal peritoneum 1.2 Expose adipose tissue of the kidney 1.3 Isolate ureter and gonadic veins 1.4 Dissect ureter and gonadic veins 1.5 Push away liver/spleen from kidney
Description	Thin instruments to dissect the parietal peritoneum, ureter and gonadic veins and exposing the adipose tissue. New instruments for push away liver/spleen from kidney

Scenario-RAPN20

Phase	2. Upper pole preparation
Step	2.1 Mobilize the kidney 2.2 Retract liver and spleen

Description	New instruments to retract liver and spleen

Scenario-RAPN21

Phase	6. Renal breach closure
Step	6.1 Perform medullary suturing and apply the clips 6.3 Perform cortical suturing 6.4 Re-approximate the cortical parenchyma 6.7 Reconstruct Gerota's fascia
Description	Small needle holders to do medullary and cortical suturing

Scenario-RAPN22

Phase	7. Closure
Step	7.2 Remove trocar 7.3 Extract the specimen
Description	Bigger trocar and forceps to take the specimen out

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)

Scenario-RARC23

Phase	1 Ureteric dissection and division
Step	1.1 Identify and divide the ureter
Description	Easier system to put Hem-o-lok clips

Scenario-RARC24

Phase	2. Lymphadenectomy
Step	2.1 Start dissection at external iliac vessels and continue up to aortic bifurcation 2.2 Clear triangle of Marcille and the area along the internal iliac vessels including the presacral area from the lymphatic tissue
Description	Easier system to put Hem-o-lok clips

Scenario-RARC25

Phase	4. Control/division of bladder pedicle
Step	4.5 Divide the vas deferens 4.6 Divide lateral pedicles
Description	Easier system to put Hem-o-lok clips

Phase	5. Nerve sparing
Step	5.1 Divide seminal vesicles 5.2 Divide the neurovascular bundles
Description	Easier system to put Hem-o-lok clips

Scenario-RARC26

Phase	6. Control/division of dorsal vein complex
Step	6.1 Divide the dorsal vein complex 6.3 Maximum sparing of the urethra
Description	Small needle holder to do the maximum sparing of the urethra

Scenario-RARC27

Phase	7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis (Orthotopic neobladder, intracorporeal technique)
Step	7.4 Complete urethra-enteric anastomosis for neobladder 7.6 Close the posterior part of the studer reservoir and part of anterior part 7.10 Perform Bricker uretero-ileal anastomosis to afferent limb of neobladder or ileal conduit
Description	Small needle holder for urethra-enteric anastomosis and uretero-ileal anastomosis

Scenario-RARC28

Phase	7. Bowel stapling, isolation of required bowel segment and uretero-ileal

	anastomosis (ileal conduit, intracorporeal technique)
Step	7.7 Suture posterior walls of ureters 7.9 Suture ureters to the afferent limbs of the studer pouch 7.10 Suture stents and fix the skin
Description	Small needle holder for urethra-enteric anastomosis and uretero-ileal anastomosis

Robot-assisted radical prostatectomy (RARP)

Scenario-RARP42

Phase	5 Seminal vesicles dissection
Step	5.3 Dissect the seminal vesicles and divide small vessels 5.4 Divide the vas deferens
Description	Easier system to put Hem-o-lok clips

Scenario-RARP43

Phase	7. Nerve sparing left
Step	7.1 Incise fascia around the prostate and divide small vessels 7.4 Divide the pedicle
Description	Easier system to put Hem-o-lok clips

Scenario-RARP44

Phase	8 Nerve sparing right
Step	7.1 Incise fascia around the prostate and divide small vessels 7.4 Divide the pedicle
Description	Easier system to put Hem-o-lok clips

Scenario-RARP45

Phase	11 Prostate extraction
Step	11.1 Put the prostate in an endobag

	11.2 Extract the endobag
Description	Bigger forceps and trocars to take the specimen out

Scenario-RARP46

Phase	13 Bladder neck dissection
Step	13.2 Perform bilateral plication over the lateral aspect of the bladder 13.3 Suturing to match the bladder neck size to the membranous urethra
Description	Small needle drivers for suturing

Scenario-RARP48

Phase	15 Posterior reconstruction
Step	15.1 Approximate the free edge of the remaining Denonvilliers' fascia 15.2 Approximate the posterior lip of the bladder neck and vesicoprostatic muscle
Description	Small needle driver for suturing

Scenario-RARP49

Phase	16 Urethrovesical anastomosis
Step	16.1 Start the anastomosis at 5 o'clock on the bladder neck 16.2 Pass the needle at 5 o'clock in the urethra and then at 6 o'clock in the bladder neck 16.3 Suturing the tissue
Description	Small needle driver for suturing

Scenario-RARP50

Phase	14 Lymph node dissection
Step	14.2 Divide the main lymphatic trunks
Description	Easier system to put Hem-o-lok clips

<table>
<tr>
<td>16. Camera control (Head movements)

-SLAVE CAMERA HOLDER CONTROLLER</td>
<td>Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN23
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC29
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted radical prostatectomy (RARP)
Scenario-RARP51
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
</td>
</tr>
<tr>
<td>17. Physiological data

-SURGEON'S SMART GLASSES
-VR GLASSES</td>
<td>Robot-assisted partial nephrectomy (RAPN)
<table><tr><td>Phase</td><td>--</td></tr><tr><td>Step</td><td>--</td></tr><tr><td>Description</td><td>It is not needed</td></tr></table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
<table><tr><td>Phase</td><td>--</td></tr><tr><td>Step</td><td>--</td></tr><tr><td>Description</td><td>It is not needed</td></tr></table>
Robot-assisted radical prostatectomy (RARP)
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<tr><td></td><td>
<table>
<tr><td>Phase</td><td>--</td></tr>
<tr><td>Step</td><td>--</td></tr>
<tr><td>Description</td><td>It is not needed</td></tr>
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</td></tr>
<tr><td>18. Magnified vision

-STEREO ENDOSCOPIC CAMERA</td><td>
Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN24
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
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Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC30
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
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Robot-assisted radical prostatectomy (RARP)
Scenario-RARP52
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
</td></tr>
<tr><td>19. Magnified haptic feeling/force feeling

-FORCE SENSOR CONTROLLER SKELETON
-FORCE SENSOR CONTROLLER WRIST</td><td>
Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN25
<table>
<tr><td>Phase</td><td>1. Kidney preparation</td></tr>
<tr><td>Step</td><td>1.6 Push away liver/spleen from kidney</td></tr>
<tr><td>Description</td><td>Haptic feeling while pushing away liver/spleen from kidney</td></tr>
</table>
Scenario-RAPN26
<table>
<tr><td>Phase</td><td>2. Upper pole preparation</td></tr>
<tr><td>Step</td><td>2.2 Retract liver and spleen</td></tr>
</table>
</td></tr>
</table>

Description	Haptic feeling while retracting liver and spleen

Scenario-RAPN27

Phase	6. Renal breach closure
Step	6.1 Perform medullary suturing and apply the clips 6.3 Perform cortical suturing 6.4 Re-approximate the cortical parenchyma 6.7 Reconstruct Gerota's fascia
Description	Haptic feeling while suturing and thread tensioning while performing medullary and cortical suturing

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)

Scenario-RARC31

Phase	5. Nerve spare
Step	5.1 Do interfacial release of the neurovascular bundle
Description	Haptic feedback is provided during the interfacial release of the neurovascular bundles in order to maximize the nerve sparing

Scenario-RARC32

Phase	6. Control/division of dorsal vein complex
Step	6.3 Maximum sparing of the urethra
Description	Haptic feedback is provided for maximum sparing of the urethra during division of dorsal vein complex

Scenario-RARC33

Phase	7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis (Orthotopic neobladder, intracorporeal technique)
Step	7.3 Bowel continuity re-established with stapled trouser anastomosis 7.4 Complete urethra-enteric anastomosis for neobladder 7.6 Close posterior part of the studer reservoir and part of anterior part 7.10 Perform Bricker uretero-ileal anastomosis to afferent limb of neobladder or ileal conduit
Phase	7. Bowel stapling, isolation of required bowel segment and uretero-ileal anastomosis (ileal conduit, intracorporeal technique)
Step	7.10 Close the remaining reservoir and check the leakage
Description	Haptic feedback for suturing and thread tensioning during urethra-enteric anastomosis and uretero-ileal anastomosis and closing the studer remaining reservoir

Robot-assisted radical prostatectomy (RARP)

Scenario-RARP53

Phase	1 Bladder takedown
Step	1.2 Grasp the urachus and incise the peritoneum
Description	Feeling for grasping the urachus

Phase	2 Endoscopic fascia incision
Step	2.1 Retract the prostate and incise the endopelvic fascia
Description	Haptic feeling during retracting the prostate

Scenario-RARP54

Phase	3 Anterior bladder neck dissection
Step	3.1 Retract the bladder backwards 3.4 identify the catheter and grasp
Description	Haptic feeling during retracting the bladder backwards

Scenario-RARP55

Phase	5 Posterior bladder neck dissection
Step	5.1 Hold the vas deferens upwards
Description	Haptic feeling during holding the vas deferens

Scenario-RARP56

Phase	6 Posterior plane dissection
Step	6.1 Hold the left seminal vesicle upwards and laterally 6.2 Retract the Denonvilliers' fascia
Description	Haptic feeling for holding the left seminal vesicles upwards and laterally and to retract the Denonvillers' fascia

Scenario-RARP57

Phase	6 Posterior plane dissection
Step	6.1 Hold the left seminal vesicle upwards and laterally 6.2 Retract the Denonvilliers' fascia
Description	Haptic feeling for holding the left seminal vesicles upwards and laterally and to retract the Denonvillers' fascia

Scenario-RARP58

Phase	7 Nerve sparing left
Step	7.1 Hold the left seminal vesicle backwards and medially
Description	Haptic feeling for holding the left seminal vesicle backwards and medially

Scenario-RARP59

Phase	8 Nerve sparing right
Step	8.1 Grasp the bladder and retract the right seminal vesicle
Description	Haptic feeling for grasping the bladder and retracting the right seminal vesicle

Scenario-RARP60

Phase	9 Dorsal vein complex dissection
Step	9.6 Retract the prostate backwards
Description	Haptic feeling during retracting the prostate backwards

Scenario-RARP61

Phase	13 Bladder neck dissection
Step	13.2 Perform bilateral plication over the lateral aspect of the bladder 13.3 Suturing to match the bladder neck size to the membranous urethra
Description	Suturing to match the bladder neck size to the membranous urethra

Scenario-RARP62

Phase	13 Bladder neck dissection
Step	13.2 Perform bilateral plication over the lateral aspect of the bladder 13.3 Suturing to match the bladder neck size to the membranous urethra
Description	Suturing to match the bladder neck size to the membranous urethra

Scenario-RARP63

Phase	15 Posterior reconstruction
Step	15.1 Approximate the free edge of the remaining Denonvilliers' fascia 15.2 Approximate the posterior lip of the bladder neck and vesicoprostatic muscle
Description	Haptic feeling during the stitching for the approximation of the remaining

<table>
<tr>
<td></td>
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<table>
<tr><td></td><td>Denonvilliers’ fascia and posterior lip of the bladder neck</td></tr>
</table>
Scenario-RARP64
<table>
<tr><td>Phase</td><td>16 Urethrovesical anastomosis</td></tr>
<tr><td>Step</td><td>16.1 Start the anastomosis at 5 o’clock on the bladder neck
16.2 Pass the needle at 5 o’clock in the urethra and then at 6 o’clock in the bladder neck
16.3 Suturing the tissue</td></tr>
<tr><td>Description</td><td>Haptic feeling during the suturing for urethrovesical anastomosis</td></tr>
</table>
</td>
</tr>
<tr>
<td>20. Surgeon’s position</td>
<td>
Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN28
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC34
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
Robot-assisted radical prostatectomy (RARP)
Scenario-RARP65
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr>
<td>21. Instrument tip swapping

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R</td>
<td>Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN29
Phase: All phases
Step: All steps

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC35
Phase: All phases
Step: All steps

Robot-assisted radical prostatectomy (RARP)
Scenario-RARP66
Phase: All phases
Step: All steps</td>
</tr>
<tr>
<td>22. Field of view

-CAMERA INTERFACE AND 3D RECONSTRUCTION</td>
<td>Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN30
Phase: All phases
Step: All steps

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC36
Phase: All phases
Step: All steps

Robot-assisted radical prostatectomy (RARP)
Scenario-RARP67
Phase: All phases</td>
</tr>
</table>

<table>
<tr><td></td><td>
<table><tr><td>Step</td><td>All steps</td></tr></table>
</td></tr>
<tr><td>23. Clutching mechanism

-MASTER EXOSKELETON L&R</td><td>
Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN31
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC37
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted radical prostatectomy (RARP)
Scenario-RARP68
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
</td></tr>
<tr><td>24. Easier understanding of surgical workflow steps

-PROTOCOL EXTRACTION AND VERIFICATION
-USER INTENTION/PROFILE</td><td>
Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN32
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC39
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted radical prostatectomy (RARP)
</td></tr>
</table>

<table>
<tr><td></td><td>Scenario-RARP69

Phase	All phases
Step	All steps

</td></tr>
<tr><td>25. Grasping mechanism

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R</td><td>Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN33

Phase	1 Kidney preparation
Step	1.5 Cut the ligaments between kidney and spleen/liver 1.6 Push away liver/spleen from kidney
Description	To grasp the ligaments between kidney and spleen or liver and to push away liver/spleen from kidney

Scenario-RAPN34

Phase	2. Upper pole preparation
Step	2.1 Mobile the kidney 2.2 Retract liver and spleen
Description	To mobile the kidney and to retract the liver and spleen

</td></tr>
<tr><td>26. Camera length

-CAMERA INTERFACE & 3D RECONSTRUCTION
-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R</td><td>Robot-assisted partial nephrectomy (RAPN)
Scenario-RAPN35

Phase	All phases
Step	All steps

Robot-assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)
Scenario-RARC40

Phase	All phases
Step	All steps

Robot-assisted radical prostatectomy (RARP)
Scenario-RARP70

Phase	All phases

</td></tr>
</table>

	Step	All steps

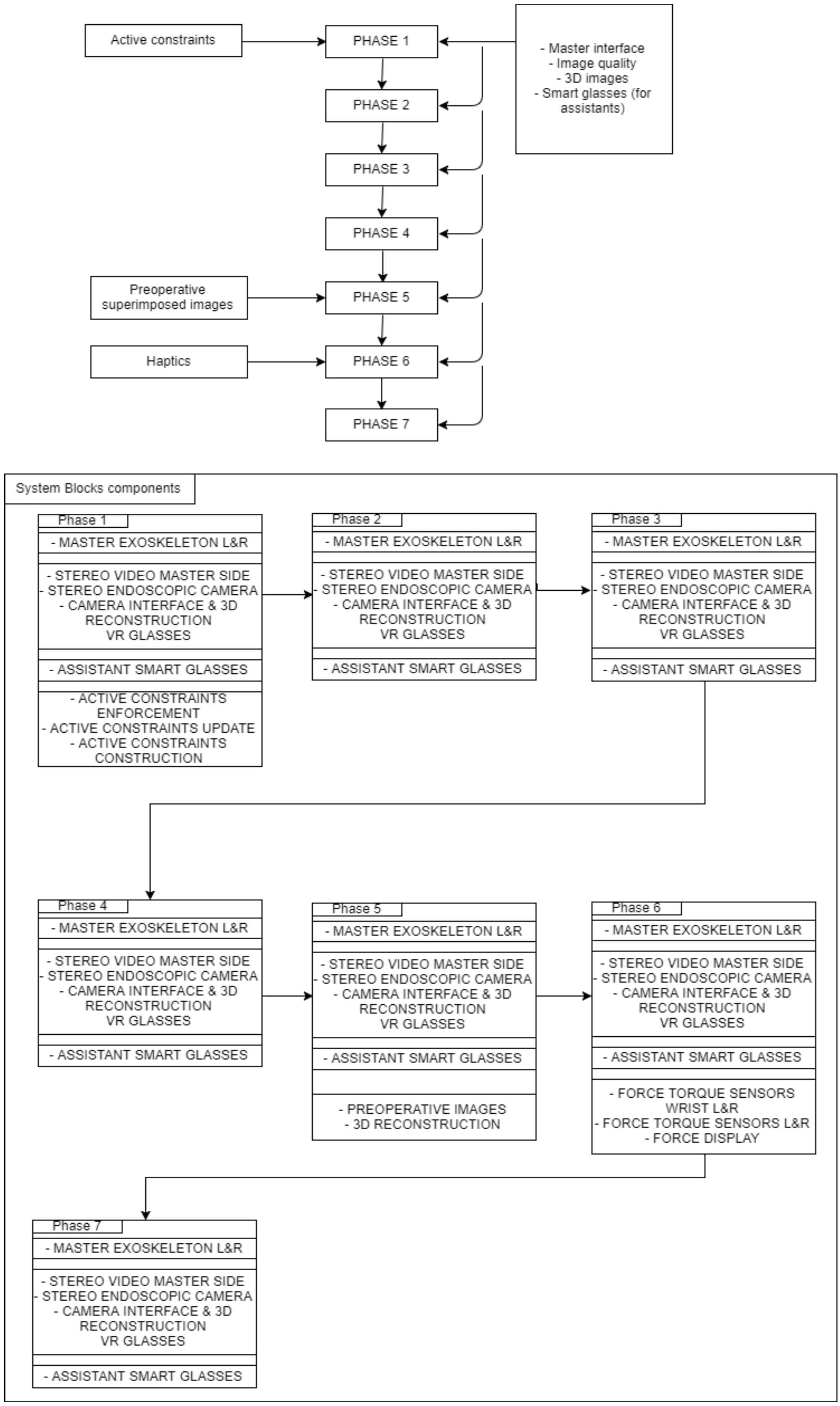

Figure 7. Application scenario for Robot-assisted Partial Nephrectomy

Table 22. Application scenarios – cardiac surgery use cases

<table>
<tr>
<td>1. Superimposed preoperative images

-PREOPERATIVE IMAGES
-3D RECONSTRUCTION
-SURGEON'S SMART GLASSES
-ASSISTANT'S SMART GLASSES
-VR GLASSES
-STEREO VIDEO MASTER SIDE
-2D MONITOR (ASSISTANT)
-SURFACE DEFORMATION FIELD</td>
<td>Robot-assisted coronary artery bypass grafting (CABG)

Scenario – CABG1
<table>
<tr><td>Phase</td><td>1 LIMA (Left Internal Mammary Artery) takedown</td></tr>
<tr><td>Step</td><td>1.1 Collapse the left lung
1.2 Expose the thoracic fascia
1.3 Develop the incision in parallel to the LIMA
1.4 Cauterise sternal branches
1.5 Detach full LIMA pedicle
1.6 Incise pericardial sacs</td></tr>
<tr><td>Description</td><td>During the LIMA takedown, preoperative images could be used to identify LIMA and thymus gland</td></tr>
</table>

Robot-assisted Mitral Valve surgery (MV surgery)
Scenario - MV1
<table>
<tr><td>Phase</td><td>2 MV repair/replacement via a small right thoracotomy</td></tr>
<tr><td>Step</td><td>2.1 Resect the prolapsing scallop inclusive of the ruptured/elongated corda
2.2 Suture the residual gap within the leaflet
2.3 Insert and tie artificial corda
2.4 Remodelling annuloplasty</td></tr>
<tr><td>Description</td><td>Preoperative images could be superimposed to see the mitral valve damage and back of the mitral valve</td></tr>
</table>
</td>
</tr>
<tr>
<td>2. Articulated instruments</td>
<td>Robot-assisted coronary artery bypass grafting (CABG)</td>
</tr>
</table>

<table>
<tr>
<td>-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R</td>
<td>

Scenario – CABG2

<table>
<tr><td>Phase</td><td>1 LIMA (Left Internal Mammary Artery) takedown</td></tr>
<tr><td>Step</td><td>1.1 Collapse the left lung
1.2 Expose the thoracic fascia
1.3 Develop the incision in parallel to the LIMA
1.4 Cauterise sternal branches
1.5 Detach full LIMA pedicle
1.6 Incise pericardial sacs
1.7 Expose the ascending aorta and the LAD and the D1/D2 territory</td></tr>
<tr><td>Description</td><td>Articulated instruments are used to take down LIMA and to go posterior side of the heart e.g. to assess posterior branch of the coronary artery</td></tr>
</table>

Robot-assisted Mitral Valve surgery (MV surgery)

Scenario – MV2

<table>
<tr><td>Phase</td><td>2 MV repair/replacement via a small right thoracotomy</td></tr>
<tr><td>Step</td><td>2.1 Resect the prolapsing scallop inclusive of the ruptured/elongated corda
2.2 Suture the residual gap within the leaflet
2.3 Insert and tie artificial corda
2.4 Remodelling annuloplasty
2.5 If not repairable, undertake MV replacement
2.6 Excise the native valve and tie the artificial valve on the native annulus</td></tr>
<tr><td>Description</td><td>The operation access site is on the anterior side and the valve is on the posterior side. The articulated instruments could also be useful to access the ventricles behind the mitral valves.</td></tr>
</table>

</td>
</tr>
<tr>
<td>3. Active constraints</td>
<td>Robot-assisted coronary artery bypass grafting (CABG)</td>
</tr>
</table>

<table>
<tr><td>-ACTIVE CONSTRAINTS ENFORCEMENT
-ACTIVE CONSTRAINTS UPDATE
-ACTIVE CONSTRAINTS CONSTRUCTION
-CAMERA INTERFACE AND 3D RECONSTRUCTION</td><td>Scenario – CABG3
<table><tr><td>Phase</td><td>1 LIMA (Left Internal Mammary Artery) takedown</td></tr><tr><td>Step</td><td>1.3 Develop the incision in parallel to the LIMA
1.4 Cauterise sternal branches
1.5 Detach full LIMA pedicle</td></tr><tr><td>Description</td><td>Active constraints could be useful for preventing the burning of LIMA while cauterising the sternal branches or when using the diathermy</td></tr></table>
Robot-assisted Mitral Valve surgery (MV surgery)
<table><tr><td>Phase</td><td>--</td></tr><tr><td>Step</td><td>--</td></tr></table></td></tr>
<tr><td>4. Master interface (Hand exoskeleton)
-MASTER EXOSKELETON L&R</td><td>Robot-assisted coronary artery bypass grafting (CABG)
Scenario – CABG4
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV3
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table></td></tr>
<tr><td>5. Image quality
-STEREO VIDEO MASTER SIDE</td><td>Robot-assisted coronary artery bypass grafting (CABG)
Scenario – CABG5
<table><tr><td>Phase</td><td>All phases</td></tr></table></td></tr>
</table>

<table>
<tr>
<td>-STEREO ENDOSCOPIC CAMERA
-CAMERA INTERFACE AND 3D RECONSTRUCTION</td>
<td>
<table><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV4
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
</td>
</tr>
<tr>
<td>6. Smart glasses (for assistants)

-ASSISTANT SMART GLASSES</td>
<td>
Robot-assisted coronary artery bypass grafting (CABG)
Scenario – CABG6
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV5
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
</td>
</tr>
<tr>
<td>7. Three fingered instruments

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R</td>
<td>
Robot-assisted coronary artery bypass grafting (CABG)
Scenario – CABG7
<table>
<tr><td>Phase</td><td>2 LIMA-LAD (Left Anterior Descending Artery) anastomosis via left minithoracotomy</td></tr>
<tr><td>Step</td><td>2.3 Undertake LIMA-LAD anastomosis</td></tr>
<tr><td>Description</td><td>Three-fingered instruments could be used to cut the sutures.

(we will record the fine motion initially and see how we can design the master and slave. This is more challenging than laparoscopy) (willingness to try on a prototype) (removing the fingers from the end effector saves the space but</td></tr>
</table>
</td>
</tr>
</table>

	replicating the castro-viejo motion would be difficult. We are not going to solve this problem now)

Scenario – CABG8

Phase	2 LIMA-LAD (Left Anterior Descending Artery) anastomosis via closed chest robotics approach
Step	2.2 Block the coronary artery blood flow 2.3 Undertake LIMA-LAD anastomosis
Description	Three-fingered instruments could be used to cut the sutures. (we will record the fine motion initially and see how we can design the master and slave. This is more challenging than laparoscopy) (willingness to try on a prototype) (removing the fingers from the end effector saves the space but replicating the castro-viejo motion would be difficult. We are not going to solve this problem now)

Robot-assisted Mitral Valve surgery (MV surgery)

Scenario – MV6

Phase	2 MV repair/replacement via a small right thoracotomy
Step	2.1 Resect the prolapsing scallop inclusive of the ruptured/elongated corda 2.2 Suture the residual gap within the leaflet 2.3 Insert and tie artificial corda 2.4 Remodelling annuloplasty 2.5 If not repairable, undertake MV replacement 2.6 Excise the native valve and tie the artificial valve on the native annulus

Description	The three-fingered instrument is used to cut the sutures during MV repair. (We will record the fine motion initially and see how we can design the master and slave. This is more challenging than laparoscopy) (Willingness to try on a prototype)

8. Haptics

-FORCE TORQUE SENSORS WRIST L&R
-FORCE TORQUE SENSORS SKELETON L&R
-FORCE DISPLAY

Robot-assisted coronary artery bypass grafting (CABG)

Scenario – CABG9

Phase	1 LIMA (Left Internal Mammary Artery) takedown
Step	1.7 Identify segment of anastomosis
Description	Haptics could be useful to identify calcium deposits

Scenario – CABG10

Phase	2 LIMA-LAD (Left Anterior Descending Artery) anastomosis via left minithoracotomy
Step	2.3 Undertake LIMA-LAD anastomosis
Description	Haptic feeling during suturing LIMA and LAD for anastomosis

Scenario – CABG11

Phase	2 LIMA-LAD (Left Anterior Descending Artery) anastomosis via closed chest robotics approach
Step	2.2 Block the coronary artery blood flow 2.3 Undertake LIMA-LAD anastomosis
Description	Haptic feeling during suturing LIMA and LAD for anastomosis

Robot-assisted Mitral Valve surgery (MV surgery)

Scenario – MV7

	Phase: 1 Open Left Atrium and expose Mitral valve Step: 1.3 Left the interatrial septum Description: Haptic feeling could be useful while using the atrial retractor **Scenario – MV8** Phase: 2 MV repair/replacement via a small right thoracotomy Step: 2.2 Suture the residual gap within the leaflet 2.3 Insert and tie artificial corda 2.4 Remodelling annuloplasty 2.5 If not repairable, undertake MV replacement 2.6 Excise the native valve and tie the artificial valve on the native annulus 2.7 Close LA Description: Haptic feeling could be useful while suturing the tissues during MV repair
9. Flexible camera -CAMERA INTERFACE & 3D RECONSTRUCTION -SLAVE INSTRUMENT L&R -CLIP ON ATTACHMENT L&R	**Robot-assisted coronary artery bypass grafting (CABG)** **Scenario – CABG12** Phase: All phases Step: All steps **Robot-assisted Mitral Valve surgery (MV surgery)** **Scenario – MV9** Phase: All phases Step: All steps

<table>
<tr><td></td><td></td></tr>
<tr><td>10. 3D images

-STEREO VIDEO MASTER SIDE
-STEREO ENDOSCOPIC CAMERA
-VR GLASSES</td><td>Robot-assisted coronary artery bypass grafting (CABG)
Scenario – CABG13
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV10
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table></td></tr>
<tr><td>11. Alternative haptic sensation

-FORCE DISPLAY</td><td>Robot-assisted coronary artery bypass grafting (CABG)

Scenario – CABG14
<table><tr><td>Phase</td><td>1 LIMA (Left Internal Mammary Artery) takedown</td></tr><tr><td>Step</td><td>1.7 Identify segment of anastomosis</td></tr><tr><td>Description</td><td>Haptics i.e. natural response could be useful to identify calcium deposits</td></tr></table>
Scenario – CABG15
<table><tr><td>Phase</td><td>2 LIMA-LAD (Left Anterior Descending Artery) anastomosis via left minithoracotomy</td></tr><tr><td>Step</td><td>2.3 Undertake LIMA-LAD anastomosis</td></tr><tr><td>Description</td><td>Haptic feeling i.e. natural response during suturing LIMA and LAD for anastomosis</td></tr></table>
Scenario – CABG16</td></tr>
</table>

<table>
<tr>
<td></td>
<td>
<table>
<tr><td>Phase</td><td>2 LIMA-LAD (Left Anterior Descending Artery) anastomosis via closed chest robotics approach</td></tr>
<tr><td>Step</td><td>2.2 Block the coronary artery blood flow
2.3 Undertake LIMA-LAD anastomosis</td></tr>
<tr><td>Description</td><td>Haptic feeling i.e. natural response during suturing LIMA and LAD for anastomosis</td></tr>
</table>
Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV11
<table>
<tr><td>Phase</td><td>2 MV repair/replacement via a small right thoracotomy</td></tr>
<tr><td>Step</td><td>2.2 Suture the residual gap within the leaflet
2.3 Insert and tie artificial corda
2.4 Remodelling annuloplasty
2.5 If not repairable, undertake MV replacement
2.6 Excise the native valve and tie the artificial valve on the native annulus
2.7 Close LA</td></tr>
<tr><td>Description</td><td>Haptic feeling could be useful while suturing the tissues during MV repair</td></tr>
</table>
</td>
</tr>
<tr>
<td>12. Extended visual feedback

-PREOPERATIVE IMAGES
-3D RECONSTRUCTION
-REGISTERED RECONSTRUCTION
-ACTIVE CONSTRAINTS CONSTRUCTION</td>
<td>
Robot-assisted coronary artery bypass grafting (CABG)
Scenario – CABG17
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV12
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr>
<td>13. Immsersive stereo viewer

-VR GLASSES</td>
<td>Robot-assisted coronary artery bypass grafting (CABG)
Scenario – CABG18
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>
Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV13
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table></td>
</tr>
<tr>
<td>14. Camera control (Voice control)

-SLAVE CAMERA HOLDER CONTROLLER</td>
<td>Robot-assisted coronary artery bypass grafting (CABG)
Scenario – CABG19
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr><tr><td>Description</td><td>Voice control (big field voice control, focused field with another finer control) (willingness to try on prototype)</td></tr></table>
Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV14
<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr><tr><td>Description</td><td>Voice control (big field voice control, focused field with another finer control) (willingness to try on prototype)</td></tr></table></td>
</tr>
</table>

<table>
<tr>
<td>15. Teleoperated vision system

-SLAVE ARM CAMERA HOLDER
-SLAVE CAMERA HOLDER CONTROLLER</td>
<td>Robot-assisted coronary artery bypass grafting (CABG)
Scenario – CABG20
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV15
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
</td>
</tr>
<tr>
<td>16. Instrument jaw grip (SLAVE SIDE)

-SLAVE INSTRUMENT L&R
-MASTER ARM L&R
-CLIP ON ATTACHMENT L&R</td>
<td>Robot-assisted coronary artery bypass grafting (CABG)

Scenario – CABG21
<table>
<tr><td>Phase</td><td>2 LIMA-LAD (Left Anterior Descending Artery) anastomosis via left minithoracotomy</td></tr>
<tr><td>Step</td><td>2.3 Undertake LIMA-LAD anastomosis</td></tr>
<tr><td>Description</td><td>Principles of pencil grip could be useful in anastomosis</td></tr>
</table>
Scenario – CABG22
<table>
<tr><td>Phase</td><td>2 LIMA-LAD (Left Anterior Descending Artery) anastomosis via closed chest robotics approach</td></tr>
<tr><td>Step</td><td>2.2 Block the coronary artery blood flow
2.3 Undertake LIMA-LAD anastomosis</td></tr>
<tr><td>Description</td><td>Principles of pencil grip could be useful in anastomosis</td></tr>
</table>
Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV16
<table>
<tr><td>Phase</td><td>2 MV repair/replacement via a small right thoracotomy</td></tr>
<tr><td>Step</td><td>2.2 Suture the residual gap within the leaflet</td></tr>
</table>
</td>
</tr>
</table>

	2.3 Insert and tie artificial corda 2.4 Remodelling annuloplasty 2.5 If not repairable, undertake MV replacement 2.6 Excise the native valve and tie the artificial valve on the native annulus 2.7 Close LA Description: Principles of pencil grip could be useful during the suturing.
17. Camera size -CAMERA INTERFACE AND 3D RECONSTRUCTION	**Robot-assisted coronary artery bypass grafting (CABG)** **Scenario – CABG23** Phase: All phases Step: All steps **Robot-assisted Mitral Valve surgery (MV surgery)** **Scenario – MV17** Phase: All phases Step: All steps
18. Physiological data -SURGEON'S SMART GLASSES -ALTERNATIVE DISPLAY TO SMART GLASSES	**Robot-assisted coronary artery bypass grafting (CABG)** **Scenario – CABG24** Phase: All phases Step: All steps Description: Information on vital signs i.e. heart rate, respiratory rate, blood pressure **Robot-assisted Mitral Valve surgery (MV surgery)** **Scenario – MV18** Phase: All phases Step: All steps

<table>
<tr><td></td><td>
<table><tr><td>Description</td><td>Information on vital signs i.e. heart rate, respiratory rate, blood pressure</td></tr></table>
</td></tr>
<tr><td>19. Magnified haptic feeling/force feeling

-FORCE SENSOR CONTROLLER SKELETON
-FORCE SENSOR CONTROLLER WRIST</td><td>
Robot-assisted coronary artery bypass grafting (CABG)

Scenario – CABG25
<table>
<tr><td>Phase</td><td>1 LIMA (Left Internal Mammary Artery) takedown</td></tr>
<tr><td>Step</td><td>1.7 Identify segment of anastomosis</td></tr>
<tr><td>Description</td><td>Haptics could be useful to identify calcium deposits</td></tr>
</table>

Scenario – CABG26
<table>
<tr><td>Phase</td><td>2 LIMA-LAD (Left Anterior Descending Artery) anastomosis via left minithoracotomy</td></tr>
<tr><td>Step</td><td>2.3 Undertake LIMA-LAD anastomosis</td></tr>
<tr><td>Description</td><td>Haptic feeling during suturing LIMA and LAD for anastomosis</td></tr>
</table>
Scenario – CABG27
<table>
<tr><td>Phase</td><td>2 LIMA-LAD (Left Anterior Descending Artery) anastomosis via closed chest robotics approach</td></tr>
<tr><td>Step</td><td>2.2 Block the coronary artery blood flow
2.3 Undertake LIMA-LAD anastomosis</td></tr>
<tr><td>Description</td><td>Haptic feeling during suturing LIMA and LAD for anastomosis</td></tr>
</table>
Robot-assisted Mitral Valve surgery (MV surgery)

Scenario – MV19
<table>
<tr><td>Phase</td><td>2 MV repair/replacement via a small right thoracotomy</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td></td><td><table><tr><td>Step</td><td>2.2 Suture the residual gap within the leaflet
2.3 Insert and tie artificial corda
2.4 Remodelling annuloplasty
2.5 If not repairable, undertake MV replacement
2.6 Excise the native valve and tie the artificial valve on the native annulus
2.7 Close LA</td></tr><tr><td>Description</td><td>Haptic feeling could be useful while suturing the tissues during MV repair</td></tr></table></td></tr>
<tr><td>20. Master interface size

-MASTER EXOSKELETON L&R</td><td>Robot-assisted coronary artery bypass grafting (CABG)
Scenario – CABG28<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV20<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table></td></tr>
<tr><td>21. Surgeon’s position</td><td>Scenario – CABG29
Robot-assisted coronary artery bypass grafting (CABG)<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table>Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV21<table><tr><td>Phase</td><td>All phases</td></tr><tr><td>Step</td><td>All steps</td></tr></table></td></tr>
</table>

<table>
<tr>
<td>22. Instrument tip swapping

-SLAVE INSTRUMENT L&R
-CLIP ON ATTACHMENT L&R</td>
<td>Robot-assisted coronary artery bypass grafting (CABG)
Scenario – CABG30
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
Robot-assisted Mitral Valve surgery (MV surgery)
Scenario – MV22
<table>
<tr><td>Phase</td><td>All phases</td></tr>
<tr><td>Step</td><td>All steps</td></tr>
</table>
</td>
</tr>
</table>

For example, Fig 6 represents the fully envisaged surgical scenario for RaPLM where, “articulated instruments”, “Hand exoskeleton”, “Image quality” and “Smart glasses” are useful for all the phases. “Three finger instrument”, “Haptics” and “Preoperative images and Active constraint” are useful in Phase 2, Phase 3 and Phase 4 respectively. We also mapped system Blocks components with surgical phases of each phases of RaPLM. Similar way, Fig 7 represents application scenario for RAPN and Fig 8 represents application scenario for CABG.

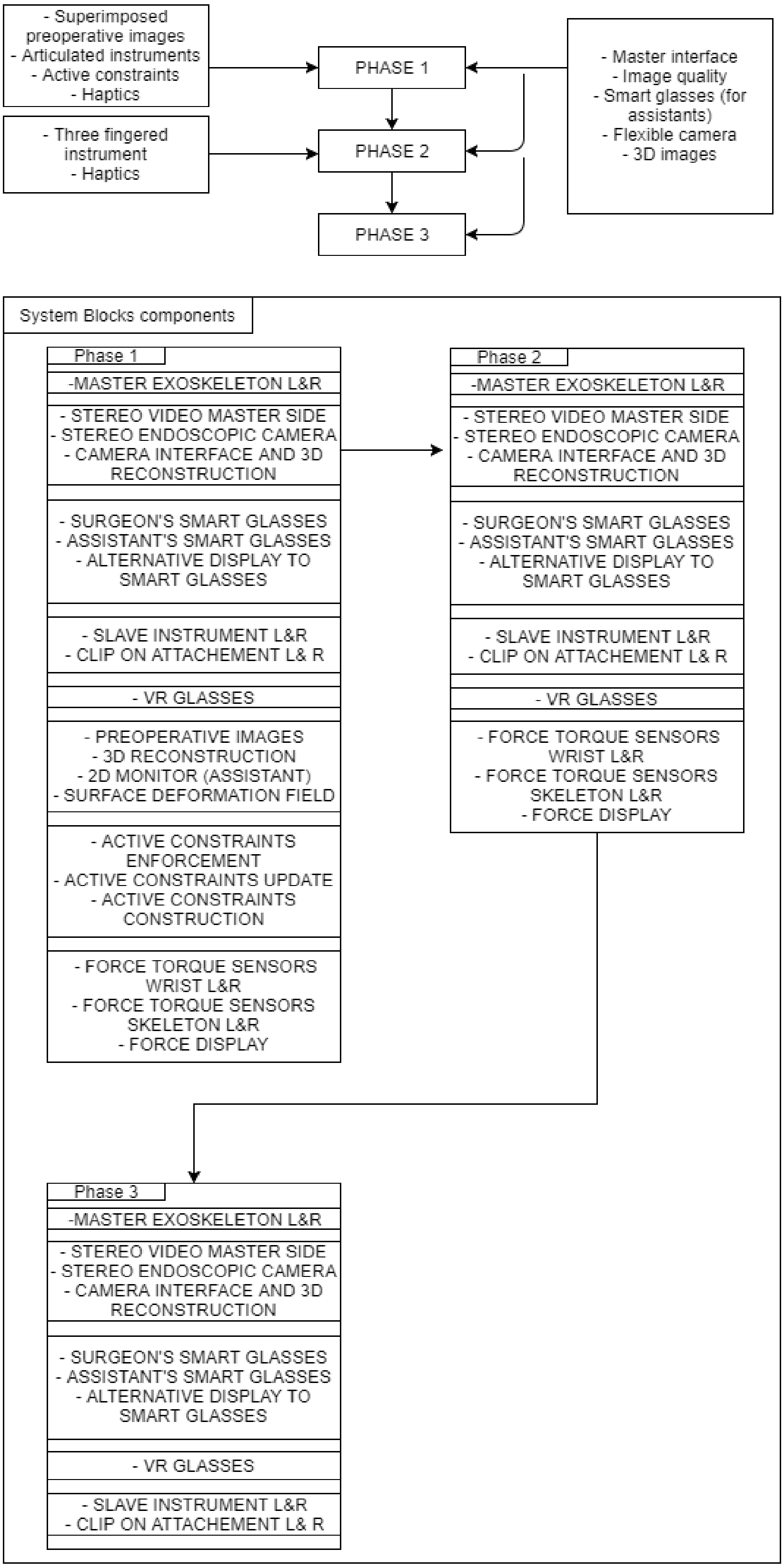

Figure 8. Application scenario for Robot-assisted Coronary Artery Bypass Grafting

The total number of elicited application scenarios and selected application scenarios are shown in Table 23, 24 and 25.

Orthopaedics use cases

Application scenarios	Total number	High/Medium High requirements (Total score above 10)
Robot-assisted Partial Lateral Meniscectomy (RaPLM)	18	9
Robot-assisted Repair of Partial Lateral Meniscus Tear (RaPLR)	22	9
Total – Orthopaedics	40	18

Table 23. Total elicited application scenarios for Orthopaedics surgery use cases

Urology use cases

Application scenarios	Total number	High/Medium High requirements (Total score above 10)
Robot-Assisted Partial Nephrectomy (RAPN)	34	12
Robot-Assisted cystectomy and intracorporeal reconstruction with ileal conduit or orthotopic neobladder (RARC)	40	17
Robot-Assisted radical prostatectomy (RARP)	70	27
Total – Urology	144	56

Table 24. Total elicited application scenarios for Urology use cases

Cardiac surgery use cases

Application scenarios	Total number	High/Medium High requirements (Total score above 8)
Robot-assisted coronary artery bypass grafting (CABG)	30	13
Robot-assisted Mitral Valve surgery (MV surgery)	22	10
Total – Cardiac surgery	52	23

Table 25. Total elicited application scenarios for Cardiac surgery use cases

5. APPENDICES

5.1 APPENDIX A – DETAILED USE CASES DESCRIPTION

http://smartsurg-project.eu/repository/WP2/Use_cases_full_descriptions.zip

5.2 APPENDIX B - INTERVIEW DOCUMENTS

1. USER INFORMATION FORM

User Information Form

Please fill your details below; they will be kept confidential and will only be used to derive statistical data.

Gender:______________________________

Age:_________________________________

Speciality:____

____

Surgical procedures that you commonly perform (please indicate if these are open, MIS*, or RAMIS**):

____

____

Do you consider yourself (as a surgeon, please circle):

Trainee junior intermediate senior

How many years have you been performing open surgery (please circle):

Less than 1 1-2 3-4 5-6 More than 7

How many years have you been performing minimally invasive surgery (manual-laparoscopy) (please circle):

Less than 1 1-2 3-4 5-6 More than 7

How many years have you been performing robot-assisted minimally invasive surgery (please circle):

Less than 1 1-2 3-4 5-6 More than 7

* MIS: Minimally Invasive Surgery
**RAMIS: Robot-Assisted MIS

2. THE QUESTIONNAIRE SET

User Requirements 'preparation' Questionnaire

GENERAL QUESTIONS – STATE OF THE ART:

- What are the barriers of current methods that you use (open surgery/manual MIS/RAMIS*) in terms of:
  - ✓ Vision?
  - ✓ Instruments (slave system: instruments and robotic arms)?
  - ✓ Interface (master system that the surgeon uses)?

- What affects your surgical resilience during long procedures?
- What is good about each scenario that you use (open surgery/ manual MIS/RAMIS)? What is bad?
- What feature(s) do you not have in manual MIS that you have in open surgery and that you wish you had?
- What feature(s) do you not have in RAMIS that you have in open surgery and that you wish you had?
- If you are a da Vinci user, is there anything specific that you cannot do using the Da Vinci surgical system? Please think of examples. What would enable you to tackle this challenge?
- How could each scenario be different? (extend it, change it)

More specifically:

What are the barriers of current methods that you use (open surgery/manual MIS/RAMIS*) in terms of:

Surgical Instruments

(Open/MIS/RAMIS – slave system: including robotic arm/instrument holder)

- Do you find the manipulation of tissues using MIS instruments restrictive as compared to your own hand?
- Is this the case for RAMIS instruments?
- What kind of grasps do you use during open/MIS/RAMIS?
- What would you change about current manual MIS/RAMIS instruments?
- What different grasping methods/grasping instruments would you welcome?
- Would a third finger be of use?
- Would you want the instrument to have tips that can be swapped over so that the same main instrument can perform as different tools if it has more than one digits?

Master system

Note: the master system is the device used to tele-operate the instruments.

How would you prefer to control the instruments? Using tele-operation? What kind of interface?
If you are a Da Vinci user, how would you change the master console and the interface with your hands?

Vision

- Do you use cameras/endoscopes/laparoscopes?
- Are they 2D/3D?
- What are the barriers in the laparoscope of the DaVinci/laparoscopy and how do you think they could be overcome?
- What are your requirements in terms of field of view?
- Do you need visual feedback in wider areas e.g. behind obstacles (other organs)?

- When operating, do you communicate efficiently with the rest of the surgical team?
- If you are a da Vinci user, do you feel immersed in the Da Vinci console?

*MIS: Minimally Invasive Surgery
RAMIS: Robot-Assisted MIS

- If yes, do you welcome this or would you prefer to also have greater awareness of your surrounding environment?
- In this respect, would you welcome such information displayed in your vision during surgery? If yes, what kind of information (e.g. physiological data)?

Camera control

In manual MIS, the surgeon communicates with the surgical assistant for positioning of the camera. Da Vinci has a clutch system for controlling the camera using the master handles.

- If you are a da Vinci user, how would you rate the Da Vinci's system in terms of efficiency and ergonomics?
- Is a teleoperated camera holder required?
- How would you prefer the camera was controlled (e.g. voice commands, eye gaze tracking, head movements, foot pedal, other)?
- Would you wish to move, extend or focus the field of view by moving your head around?

Active constraints/No-go zones

Note: 'Active constraint' is the process of labelling regions of the patient's body, e.g. a vessel or a nerve bundle, with one of the four possibilities: safe, close, boundary and forbidden. Surgeons label safe regions the regions that are appropriate for the robot to be and to operate in. One way to use them is to stop the instrument from entering forbidden zones by force resistance exerted by the master device. The other way is to highlight by augmented reality those zones and/or signal with alternative sensory channels as auditory or vibration.

- How could 'active constraints' help you during a surgical operation?
- Would you like knowing that the instrument would not enter or even touch the boundaries of forbidden regions and/or tissues labelled by you (the surgeon) in a preoperative and operative stage?
- Would you like the robot to keep the instrument at a certain angle, e.g. normal to the operating path, specified by you to help you guide it?

Haptics.

Note: Haptics is the tactile-kinaestetic feeling, which is presented in the interaction with the body through the instruments.

- How important is haptic feedback during surgery for you?
- What type of haptic feedback would be useful to you (e.g. force feedback of pulling/pushing tissue and surrounding structures or of the thread tension during suturing, force feedback during grasping, texture, temperature)?
- Would it be helpful to 'exaggerate' this feeling, i.e. scaled up from the measured exerted force on the tissue?
- Would alternative sensory information be useful as a replacement to haptic feedback or as complimentary to it (e.g. acoustic signals/visual cues/vibration proportional to the exerted force on the tissue or as alarm for over-the-threshold forces)?

Pre-op Images

- Do you use pre-operative images? If yes, what type and why?
- When would you need to super-impose such images on the vision of the laparoscope (e.g. to guide/help you identify structures in the abdomen)?
- How different is the operating field from the pre-op images (e.g. in terms of tissue deformation)?

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RAMIS: Robot-Assisted MIS

General questions

- What feature(s) do you not have in manual MIS that you have in open surgery and that you wish you had?
- What feature(s) do you not have in RAMIS that you have in open surgery and that you wish you had?
- If you are a da Vinci user, is there anything specific that you cannot do using the Da Vinci surgical system?
- Please think of examples. What would enable you to tackle this challenge?
- How do you expect a system like SMARTsurg will improve in new surgeons' training?

PERSONAL PERSPECTIVE ON A NOVEL SURGICAL SYSTEM

If you were asked to compile a surgical system together, which parts would you choose and why?

- What are your expectations for a new system (in terms of vision, haptics, instruments, interface)?

CLOSING REMARKS

- Any other concerns about the technology?
- Would you like to be kept informed on developments? If yes, e-*mail should be in consent form*

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RAMIS: Robot-Assisted MIS

5.3 APPENDIX C – LINKS TO THE TRANSCRIPTION VERBATIMS AND AUDIO RECORDINGS

http://smartsurg-project.eu/repository/WP2/Interviews.zip

5.4 APPENDIX D – SYSTEM BLOCKS COMPONENTS

http://smartsurg-project.eu/repository/WP2/SMARTsurg_Partner-Block_Definition_v6.zip

5.5 APPENDIX E - GRASPERS

 Retractor	 Bipolar forceps
 Maryland forceps	 PK dissecting forceps
 ProGrasp forceps	 Cadiere forceps

 DeBakey forceps	 Bowel grasper
 Kelly forcep	 Arthroscopic graspers
 Coronary forceps	 Arthroscopic cutter
 Castroviejo-type forcep	

Table 26. Graspers

5.6 APPENDIX F – ETHICAL COMMITTEE APPROVAL

POLITECNICO
MILANO 1863

Milan, on 10\04\2017

Opinion n. 5\2017

RESEARCH SERVICES
RESEARCH SUPPORT
SERVICES AND
DIDACTIC INNOVATION

OBJECT: Research Ethical Committee Opinion. Project: "*Smart weArable Robotic Teleoperated SURGery*". Scientific coordinator: Prof. Giancarlo Ferrigno.

The Research Ethical Committee,

- given the request for opinion of 03\04\2017;
- for what concern the project: "*Smart weArable Robotic Teleoperated SURGery";*
- examined all documents;
- with regard to the phase of the project concerning the collection of personal data (opinions of the surgeons),

issues the following opinion:

POSITIVE

The President
(Prof. Carlo Ghezzi)

Politecnico di Milano
Research Service
Piazza Leonardo da Vinci, 32
20133 Milan
Phone: +39 02 2399 4345
Fax +39 02 2399 2575
www.polimi.it

Figure 9. Ethical committee approval

6 REFERENCES

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