State-of-the-art in Operational execution deliverable D2.1

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1 Introduction

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This deliverable describes the state-of-the art in operational execution at the time of the start of the project – beginning of 2009. Operational execution is separated into 3 parts:

- **Interventional planning –** Review and explore pre-operative patient images. Use this to evaluate the different therapy strategies available at evidence based medicine. Decide on the therapeutic approach and appropriate tools and imaging-modalities.
- **Patient registration –** During intervention pre-operative images and real-time images need to be compared to be able to measure progress of the operation, and to support navigation.
- **Navigation and real-time Intra-Operative update** – During intervention it is necessary to bring instruments near the place where the treatment has to be executed. Navigation helps to reach that place. Intra operative update tracks the procedure according to the plan

In all three areas, the state-of-the art still indicates a low level of workflow support. The project aims to make a large improvement step for them. Interventional planning is mainly performed by "manually" browsing through the pre-operative images, and selecting those that gives the best view on the problem at hand. Experience of the medical specialist determines the procedures to be executed. Patient registration is mainly performed by displaying two images next to each other. In certain situations, software supported registration is used, showing the differences explicitly. This only occurs on a small scale, and only upon request. Navigation and intra-operative update is not supported electronically. Navigation is based on eye-hand coordination of the surgeon; inter-operative update is done remotely following the check-list. Especially during patient registration and navigation and real-time update, it will be crucial for the surgeon to be able to ask a second opinion from a colleague. The state-of-the-art is that the colleague has to go to the operating theatre, disinfect himself, and enters the room. Mobile solutions may offer help here. We have added a section on the state of the art in mobile solutions.

This document extensively describes the state-of-the-art in the following cases:

- Image Guided Therapy, especially for Prostate Cancer, Bronchoscopy and electrophysiology – section 2
- Decision support in interventional planning – sections 3 and 4
- Mobile solutions – section 5
- Literature review – section 6

In section 7 a summary is given.

2 Image Guided Therapy

Frenk Sloff, Peter Eshuis – Philips Healthcare, Tom Sutedja – VUMC

2.1 *Image Guided Brachy Therapy (IGBrachy) for Prostate Cancer*

In this section the state-of-the-art for TRansrectal UltraSound (TRUS) guided transperinial injection of 60-120 radioactive seeds is discussed.

Figure 1 provides an overview of the treatment modalities an urologist can offer for prostate cancer cure. In about 50% of the cases, LDR (Low Dose Rate) Image Guided seed implant, also known as brachytherapy, is performed by the urologist[1]. LDR Brachytherapy works very well for low risk patients, i.e. those who have low PSA- and Gleason-scores and of which the cancer stage is less or equal than T2a. Note that approximately 70% of European urologists offer at least 4 treatment modalities.

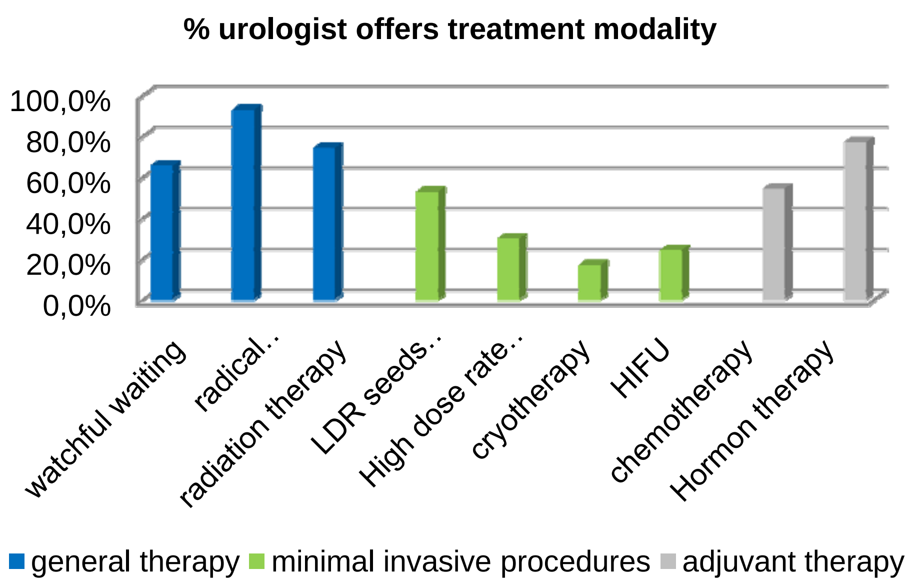


Figure 1 – Treatment options for prostate cancer

The goals for IGBT are:

- Use an Ultrasound volume scan to determine the position and boundary of the prostate.
- Interface to planning tool to retrieve seed placement plan.
- 'Accurate' implant radioactive seeds so that the tumour is covered.

In Figure 2, a common workflow for IGBT is depicted:

1. Patient selection
   The urinary function is assessed, the stage of cancer is determined and the patient history is assembled.

[1] *Data is from Survey European Urologist April 08 issue.*

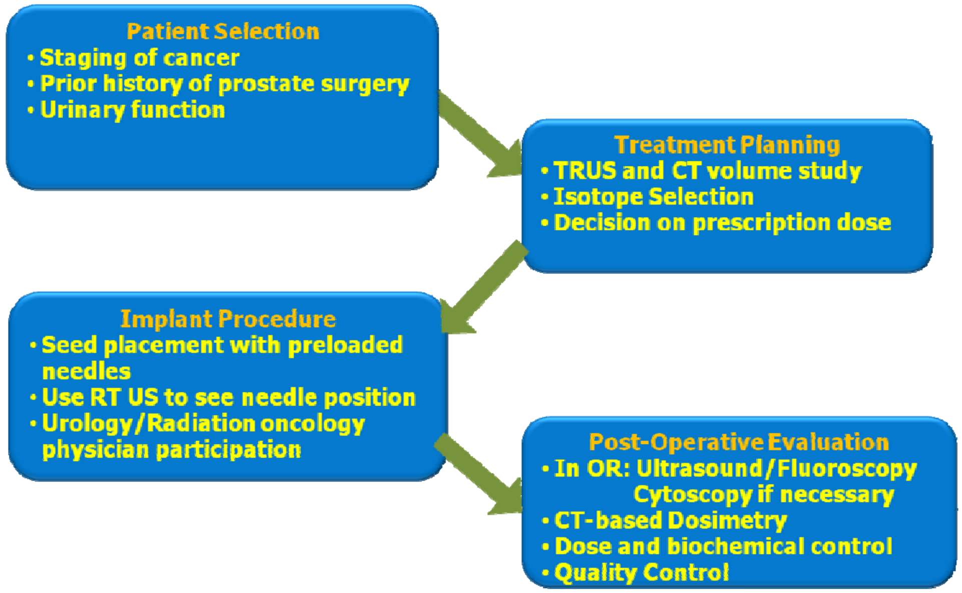


Figure 2 – IGBrachy common workflow

2. <u>Treatment planning</u>
   One week before the actual procedure, a TRUS is performed to determine the prostate boundary. This is done by performing a sweep of 10 seconds after which some 200 frames are reconstructed into an Ultrasound volume. The boundary of the prostate is automatically segmented by processing software and fed into a planning software package. This package will compute positions of the seeds to be placed, so that they will cover the tumour optimally. In some cases a CT volume scan is performed to determine needle access / bone interference. Also the type of isotope is selected.
3. <u>Implant procedure</u>
   The TRUS of a week ago (and potentially the 3D CT volume scan) is loaded in the visualisation software. Between 60 to 120 radioactive seeds are implanted in the prostate using hollow needles filled with the radioactive seeds.
4. <u>Post-operative evaluation</u>
   After seed placement, XRay fluoroscopy is used to check if any seeds have ended up in the urinary bladder. The seeds are removed from the bladder by performing a cytoscopic procedure.

Note that only procedures 3 and 4 are performed in the operating room.

In Figure 3, the actual procedure of placing the seeds is depicted. The patient is (partially) sedated and positioned on his back with legs astride. A matrix with approximately 15 x 15 holes is mounted perpendicular to the patient axis and is used to fix the needle insertion direction during implantation. A transrectal ultrasound probe is inserted to monitor the actual position of the needle so that the seeds can be deposited at the right spot. The matrix and the ultrasound probe are rigidly mounted onto a stepper which can move along the patient axis.

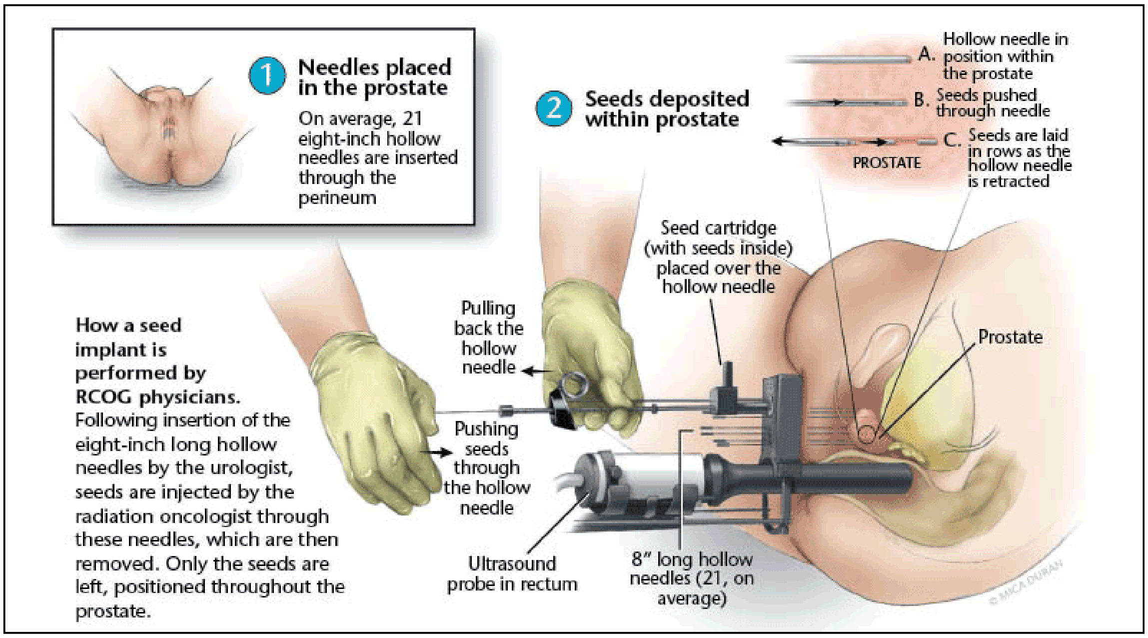


Figure 3 – IGBT intra-procedure details

With the current procedure, some clinical problems occur.

1. The procedure still consists of two separate steps, i.e. a planning step one week prior to the procedure and the actual seed placement. This can be more efficiently combined into one step.
2. Seed displacement (can be up to 0.5 [cm]):
   - The current procedure is very skill-dependent and has a long learning curve. Therefore the procedure suffers from variable outcomes.
   - The procedure suffers from inaccurate placement due to prostate motion and deformation (prostate swells up).
3. Seed migration:
   Seeds may migrate outside the prostate to e.g. the urinary bladder.

Accurate placement of the seeds is extremely important. Firstly, the set of seeds should have an associated irradiated region that must cover the tumour completely. Secondly, misplaced seeds will cause lead to significant side effects:

- Urinary incontinence
- Impotence
- Radiation damage to other organs

In other words accurate placement will minimize side effects for the patient.

The requirements for the newly to be engineered IGBT application will have to address the clinical problems mentioned in item 1 and 2 above. Seed migration cannot be prevented, although accurate seed placement will help to prevent it.

2.2 Image Guided Bronchoscopy (IGBronch)

In this section the state-of-the-art for Interventional Pulmonology for lung cancer diagnosis is discussed. Nevertheless, the various procedures can also be applied for diagnostic purposes in other diseases than lung cancer but this is beyond the scope of current project. This description mainly focuses on the central airways (Figure 6 – central green circle) and perihilar region (beyond or distal to the central airways but within the blue circle. The parenchymal region in the peripheral are more difficult to be viewed using current bronchoscope based on its diameter, such that beyond subsegmental bronchi direct viewing is impossible, unless assisted by additional imaging tool such as fluoroscopy, or catheter based thin optics with proper spatial algorithm that can accurately direct the catheter towards the target region.

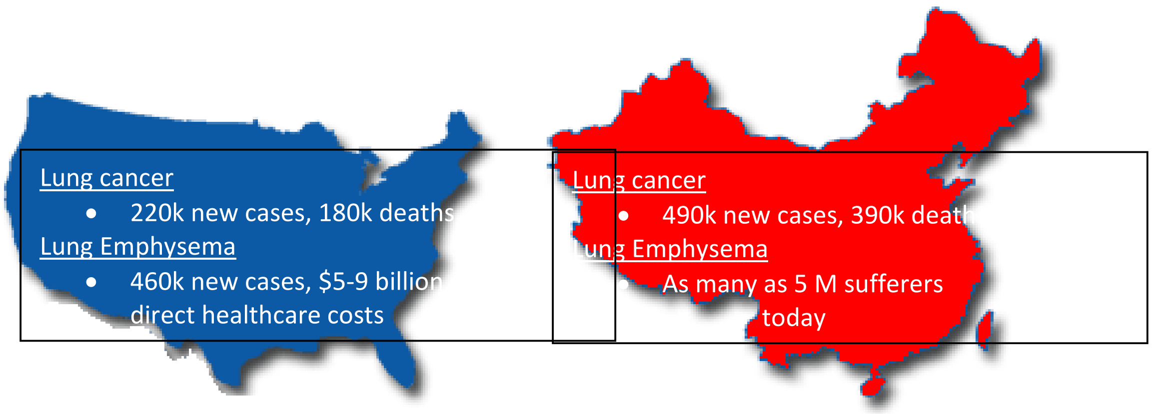


Figure 4 – New cases Lung Cancer and COPD in US and China per year[2]

Worldwide, Lung Cancer account for 1.10873 new cases globally in 2007, and its mortality is 80%[3]. Every year there are numerous people in China and the US who are diagnosed with lung cancer or lung emphysema (See Figure 4).

The goals for image guided bronchoscopy

- Insertion of steerable flexible of a bundled flexible optical fibers e.g. bronchoscope to navigate and examine the airways targeting the region of interest. The region of interest(s) are chosen based on images from routine non-invasive imaging i.e. Chest x-rays or currently routinely and widely used computed tomography scans of the thorax.
- The use of the bronchoscope and optical fibers help visualizing centrally located tumours which is important in terms of describing the exact location, disease extension e.g. in using additional imaging techniques such as autofluorescence. Image assisted and guided precision biopsy are required to ensure collecting representative specimens of histological diagnosis as this is still the gold standard for diagnosing lung cancer

In more peripherally located region of interest, the dimension of the bronchoscope limits its reach, assisted navigation and steering by way of thinner catheter optic (optic bundles), thinner bronchoscope or the alternative steerable catheter guided maneuver using fluoroscopy is a more proper way in trying to collect samples for e.g. histology.

Adjacent to the tracheobronchial tree - thus outside the tracheobronchial tubes and its bifurcation - lymph nodes are located. In lung cancer, spread to the regional lymph nodes are prognostically the most important determinant of survival. Definite proof or exclusion of lymph node involvement prior

[2] *Sources:*

- *Cancer Research UK, CancerStats, Nov 2004, National Heart, Lung and Blood Institute*
- *MedTech "Emphysema Devices Search for Breathing Room"*
- *WHO World Cancer Report*
- *WHO Quick COPD Facts*

[3] *http://www.cancer.org/acs/groups/content/@nho/documents/document/globalfactsandfigures2007rev2p.pdf*

to any therapeutic decision is an absolute requirement of state of the art staging. Again, the advances of navigational imaging may better improve lymph node staging than pure blind puncturing i.e. transbronchial needle aspiration for acquiring cytological/histological diagnosis
It estimated that approximately 3 millions pulmonology procedures are executed worldwide per year and these minimally invasive interventional procedures are expected to increase due to current availability of smart catheters and the development of virtual navigation based on the non-invasive CT spatial data. These are great potentials to increase cost-effectiveness of diagnostic, staging and treatment interventions, with obvious lower morbidity and mortality, apart from the feasibility in using day care facility for the execution of the procedure exploiting the readily available standard optical systems used in a multidisciplinary setting. Endoscopy units are not exclusively a unique environment for use by the interventional pulmonologists only.

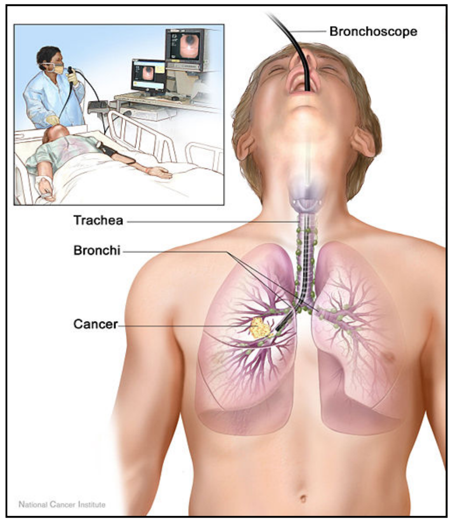


Figure 5 – Bronchoscopy procedure

A case example is depicted in Figure 6: taking biopsies.

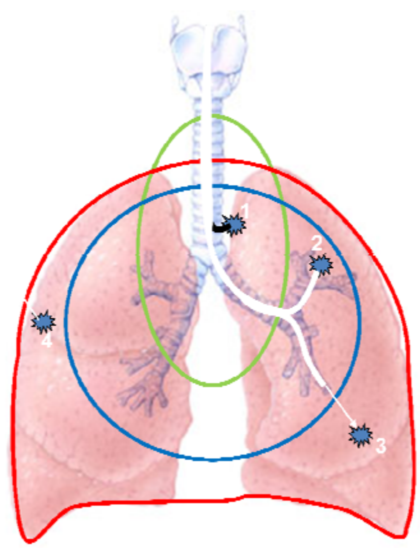


Figure 6 – Interventional pulmonology: Central airways region, perihilar region and peripheral parenchymal region.

Figure 6 shows (1) an example of using needle transbronchially through the left tracheal wall to collect sample from a potentially metastasized cancerous lymph node (“4 Left region”); While 2,3 and

4 are increasingly more difficult tumor locations for acquiring representative samples as the bronchial tubes' sizes becoming smaller and smaller towards the parenchymal regions, limiting the physical reach of bronchoscopic instruments and together with finite view beyond the distal tip, this will require assisted imaging and precise navigation.

1. Mediastinal lymph nodes are relatively easy located outside the tracheobronchial tubes, and they can be "blindly" puncture inc case of massive size lymph nodes of 2 cm and larger. By ultrasound or image guided assistance e.g. virtual bronchsocopy, more properly puncturing for acquiring representative specimens for proof or exclusion of malignant involvement prior to decision of any therapeutic strategy are required. (**green** area in Figure 6).
2. Sub-segmental lesions are harder to reach as they lie further away. Assisted navigation through the airway paths (**blue** area in Figure 6) is required, currently under fluoroscopy but can exploit the spatial algorithm data based on the standard routine computed tomography scan imaging.
3. Peripheral lesions are more difficult to be reached because the diameter of the bronchoscope prevents further advancement and that target lesion – based on CT information – is not in the vicinity of the larger airway (**red** area inFigure 6). In this case percutaneous or transthoracic approach to acquire tissue for histological diagnosis can be performed, with the risk of pneumothorax.

In Figure 7, a common workflow for IGBronch is depicted:

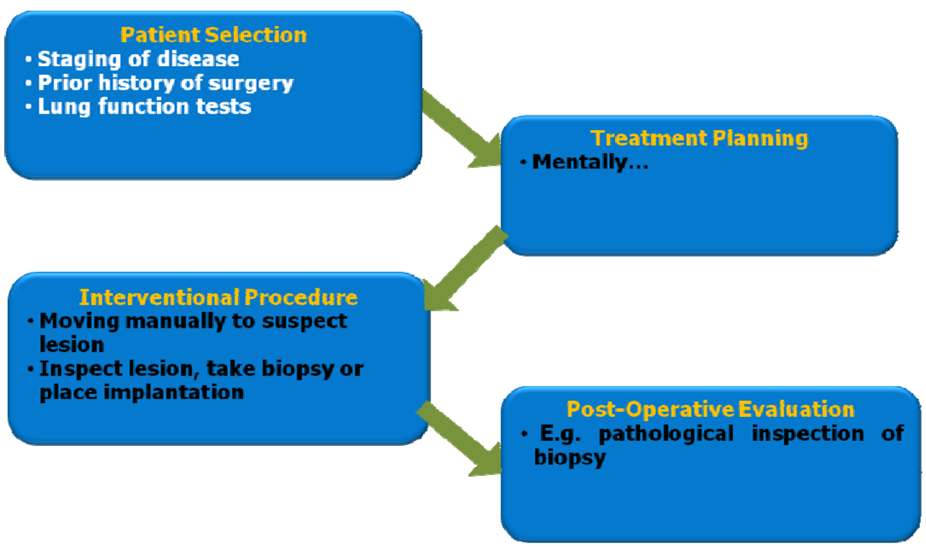


Figure 7 – IGBronch common workflow

1. <u>Patient selection</u>
   Patient history assembled, the radiological imaging (chest x-rays / CT scan /PET scan) and lung function is assessed, Radiology imaging of the stage of cancer is determined based on the clinical TN(M) criteria. Mutidisciplinary discussion and planning with the Nuclear medicine specialist and radiologist of all potential constructed images for mapping the region of interest
2. <u>Treatment planning</u>
   Planning to target the lesion for acquiring samples for histology (or cytology). Depending on the differential diagnosis, the requirements for samples apart from histology and cytology, protocol compliance with the cyto/histopathologist. Rapid on site cyto-pathologist may be required
3. <u>Interventional procedure</u>
   A:_The bronchoscope is advanced and manouvered manually transorally or transnasally to the region of interest (with or without "navigational assistance": see three regions of interest),

biopsy specimen is taken using paired biopsy forceps advanced thru the working channel of the bronchoscope

B: In case of transbronchial needle puncture for lymph node staging, specially designed needle can be passed down the working channel and target region outside the tracheobrohchial tree is punctured blindly or with assisted imaging such as real time ultrasound and/or assisted navigation by virtual bronchsocopy (currently not real time, based on the 2D CT reconstructed spatial data)

4. Post-operative evaluation

   The collected or additional tissue specimens are collected in special tissue jars (various liquid medium depending on the microscopical and biological diagnostics to be performed) and send to the pathologist. Rapid on site cytologist can only tell the likelihood samples are representative specimens, but cannot always ascertain the diagnosis.

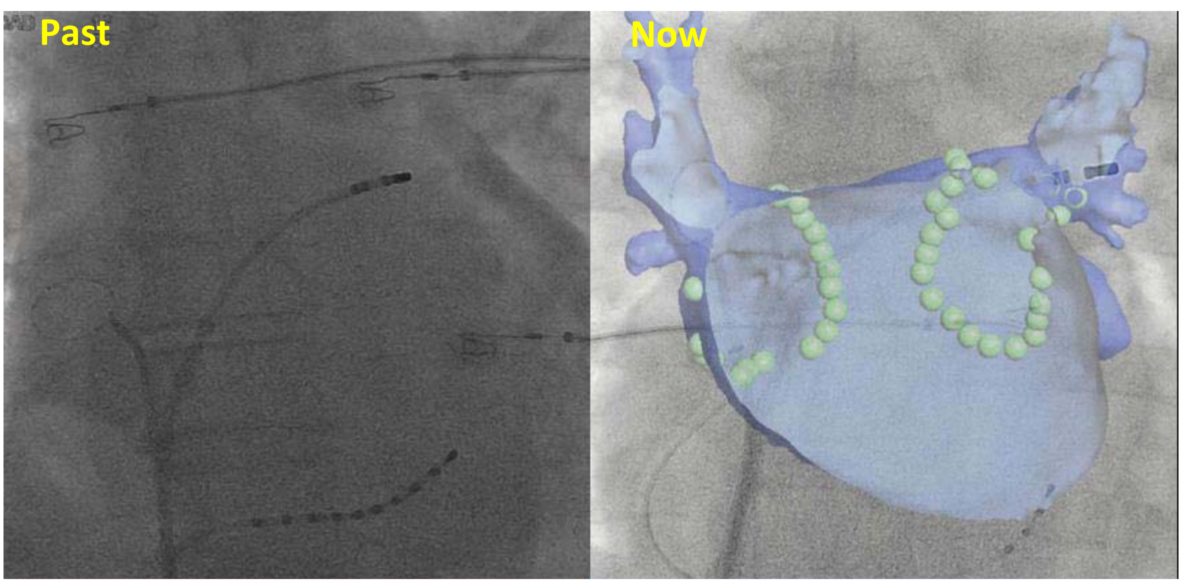
Note that steps 2, 3 and 4 are performed in the operating room.

The problem with current procedures is that they have low diagnostic yield, e.g. 30-70% for lymph nodes:

- It is difficult to plan and navigate, so the mental localization for the physician is challenging.
- One can't see targets outside the airways.
- There is poor soft tissue characterization for peripheral lesions.
- It is difficult to manipulate endo-bronchial instruments.

The requirements for the newly to be engineered IGBronch application will have to address the clinical problems mentioned above.

2.3 Electrophysiology



Traditional fluoroscopy image

3D image of left atrium overlaid with the EP navigator on fluoroscopy image (green spheres mark the catheter positions for ablation)

Figure 8 – navigating for Electrophysiology

2.3.1 Traditional

The electrophysiologist performs ablation therapy with a catheter, which locally burns heart tissue on or around the location of the origin of the heart rhythm disorder. Hereby a little scar is created stopping the heart rhythm disorder. This picture shows a typical fluoroscopy image used for many years during such an ablation procedure. The image shows the position of the EP catheters in the left atrium of the heart. The three hooks correspond to the ECG electrodes attached to the skin of the patient. The big catheter (top right) is the ablation catheter. The round “lasso” catheter (middle left) is used to measure the ECG signal in one of the pulmonary veins that enter the atrium. The lower catheter is also performing ECG measurements. The treatment takes a lot of time (easily exceeding 3-4 hours), because accurate navigation of the devices in the fluoroscopy image is not easy.

2.3.2 EP navigator

With the EP (electrophysiology) navigator the physician has a tool available in the operating room for catheter navigation. This tool provides additional spatial information next to the fluoroscopy images. Here the 3D shape of the left atrium is created based on a CT scan. This volumetric representation is registered to the fluoroscopy images to always have a match. In such a data fused image it is directly clear where all the instruments are with respect to the left atrium: the ablation catheter in the upper left pulmonary vein and the lasso catheter in the upper right pulmonary vein. This information is very useful and valuable for the physician, enabling him/her to perform the ablation procedure faster and more accurate than with the fluoroscopy image only. Besides, the 3D model provides the opportunity to record the ablation points (green spheres), such that the physician does not need to rely on his mindmap only.

3 Decision support in interventional treatment

Huub Rutten, Elsemiek ten Pas – Sopheon

In 2009, the year that the Edafmis project started, the Agency for Healthcare Research and Quality of the U.S. Department of Health and Human Services published a report entitled: *Clinical Decision Support Systems: State of the Art* (ww.ahrq.gov). Clinical decision support systems (CDSS) are defined as “typically designed to integrate a medical knowledge base, patient data and an inference engine to generate case specific advice.” We summarize some findings we consider to be relevant for Edafmis, related to the target area of care, standardisation and knowledge maintenance.

- Existing decision support systems are often limited to diagnosis, and when they support treatment it is to warn clinicians about potential problems with drug dosage and/or drug interaction. No system has been designed yet for real-time interventions that make use of highly sophisticated intra-operative imaging and monitoring data.
- Existing decision support systems are not linked to a hospital’s protocol or guideline management system and medical procedures appear to have a relatively low degree of standardization, therefore it requires substantial time investments of an organisation to adapt a DSS to their own needs.
- Existing decision support systems also require substantial investments to be kept up-to-date. No systems or initiatives are being reported where the updating of protocols or guidelines is supported by ‘new evidence feeds’ received from a medical knowledge base.

A lot of research is being done in the field of so-called Computer Interpretable Guidelines (CIGs). Various research groups engage in the development of formal languages, methods and tools in order to improve the quality of care. (see also Edafmis deliverable D1.1). These projects also aim to provide clinicians with a form of automated decision support, however:

- The software tools generally still have research status, there are few commercial products. To the best of our knowledge the currently available systems are not scalable to thousands of protocols.
- The focus is on the formalization of knowledge, not on the real-time integration of intra-operative data such as images and vital signs.

As to practice, in the intervention room clinicians currently have in the best case seamless access to the relevant protocols which are state-of-the-art, complete and compliant with guideline quality standards. Whether the protocols are available on paper or displayed in electronic format, they constitute a stand-alone source of information. It is up to the clinician to apply the rules laid down in the protocols to real-time patient data and images during the intervention.

4 Decision support in interventional planning

Jan-Marc Verlinden - ZorgGemak

This section discusses how decision support is offered to medical professionals using EGADSS, the ***E****vidence-based* ***G****uidelines* ***A****nd* ***D****ecision* ***S****upport* ***S****ystem*.

EGADSS is an open source tool that was designed to work in conjunction with primary care Electronic Medical Record (EMR) systems to provide patient specific point of care reminders. It is also envisaged to inform patients directly through Patient Health Record (PHR) systems. We expect the system to be of use in interventions in a clinical setting as well.
EGADSS is designed as a standalone system that serves requests from existing Electronic Medical Records to provide patient specific clinical guidance based on its internal collection of guidelines. Centralising the guideline management under a single tool permits easier maintenance of the content. EGADSS has adopted the Arden Syntax language to encode the clinical practice guidelines. The service of EGADSS uses the Clinical Document Architecture (CDA) standard to communicate with EMR, PHR, or Electronic Health Record (EHR) systems. Using this XML-format enables EGADSS easy interoperability with many of the existing healthcare information systems.
The Guideline Reasoning Engine is one of the EGADSS core components. It operates on decision algorithms, medical knowledge, and specific patient data in order to generate recommendations and guidance for the clinician. The engine is based on the well-proven CLIPS-engine developed by NASA.

The main shortcoming of EGADSS in the settings of an intervention is that it only supports a static view of Decision Support for the provider. It does not support longitudinal guidelines; rather single clinical decisions can be made. Some workflow must therefore be introduced when applied to interventional *treatment*. For interventional *planning*, however, this shortcoming is irrelevant.

Another consequence of the fact that EGADSS itself does not have any detailed internal representation of time but only responds to the patient summary that is sent from the clinical information system is that the clinical information system must send a continuous stream of snapshots with patient data. The decision support recommendations from EGADSS may change over time, since during the series of queries the static views of the patient can change.

Finally, EGADSS is not able to combine various data streams. For example, it is not possible to draw a meaningful conclusion of a temperature value measured at 8:30am combined with a blood pressure value taken at 9:15am.

5 State-of-the art for mobile solutions

In this chapter we would like to give state-of-art of mobile applications in healthcare sector with a focus on operational execution: First, we start with explaining the general state-of-art of mobile applications in the market. In the second part we give mobile applications in health care sector which are actually in the market.

6.1 State-of-art for mobile applications

There are a lot of mobile platforms used in the market today – some are Open Source, some are not. The most important native platforms are (alphabetically):

- **Android**: Open Source OS (based on Linux),
- **Bada**: Mobile platform from Samsung running on Linux or RealTime OS,
- **BlackBerry**: J2ME compatible but extensions allow a tighter integration,
- **MeeGo**: Intel and Nokia powered Open Source OS (based on Linux),
- **iOS** (OS X / iPhone): Requires Apple Developer Account,
- **Symbian**: Open Source OS ,
- **webOS**: Widget style programming, OS (based on Linux):
- **Windows Mobile**: .NET CF or Windows Mobile API, most devices ship with J2ME compatible JVM
- **Windows Phone**: New Windows based OS targeted at consumers

All these platforms allow us to create native applications for them without establishing a business relationship with the respective vendor. Most mass market phones are, however, equipped with embedded operating systems that do not offer you the opportunity to create native applications. Examples include but are not limited to **Nokia Series 40**, **Samsung SGH** and **Sony Ericsson Java Platform** phones.

Native Applications: The main benefits for programming native applications include better integration of the application with the platform's features and often better performance. Typical drawbacks are the effort required and the complexity of supporting several native platforms (or limiting your app to only one platform). Some examples of native application environments:

- **J2ME / Java ME**
- **Flash Lite and Alternative Flash-compatible Platforms** Flash is supported or installed on these devices:
  - **Feature phones**

    Many feature phones from Nokia, Samsung, Sony and a host of others have included support for Flash Lite. The Flash Lite player is compatible with Flash 3, 6 or 8 depending when the device was manufactured. These are perfect for simple Flash games (e.g., puzzle and card games).
  - **Smartphones**

    Some smartphones have a Flash engine or player pre-installed. This is a critical factor in developing Flash applications for these devices, and all applications must comply with the device manufacturer's license terms and API specifications.

    - Full Flash support has been announced for Android-based devices, and RIM's Blackberry. Developers should clearly understand the restrictions of each platform and also understand that there are a number of Alternative Flash-compatible products that can enable Flash to operate on a number of these devices.

- Binary Runtime Environment for Wireless (BREW)
- Widgets:
    - Web Runtime Widgets on Symbian
    - Skylight
    - W3C / Vodafone Widgets
    - Samsung
    - PhoneGap
    - Sony Ericsson WebSDK
    - Blackberry

Widely used mobile applications on different platforms:

- **Android Applications:** The Android platform is fairly recent, created by Google and the Open Handset Alliance in late 2007, Android is an operating system and an application framework with complete tooling support and a variety of preinstalled applications. In 2010, Google announced that every day 160,000 Android devices are shipped to end users. Since the platform is supported by many hardware manufacturers, it is the fastest growing smartphone operating system. Additionally, Android is planned to be used for tablets, media players, set-top boxes, desktop phones and car entertainment systems.

- **iPhone and iPad Applications:** The iPhone is a highly interesting and very popular development platform for many reasons, a commonly named one being the App Store. When it was introduced in July 2008, the App Store took off like no other marketplace did before. Now there are far more than 200,000 applications in the App Store, and the number is growing daily.
  Since the iPad, which went on sale in April 2010 uses the same operating system and APIs as the iPhone, skills acquired in iPhone development can be used in iPad development. A single binary can even contain different versions for both platforms with large parts of the code being shared.

- **Symbian Applications:** The Symbian platform is an open-source software platform for mobile devices. It consists of an operating system (formerly known as Symbian OS), middleware and user interface layers (formerly known as S60) and, since 2009, has been stewarded by the Symbian Foundation.
  Close to 350 million Symbian devices (operating on 250 networks across the world) have shipped since the first Symbian OS-based device was launched in 2000.

- **J2ME / Java ME Applications:** The capabilities of the Java platform are constantly evolving thanks to the Java Community Process that standardizes new APIs (like the Advanced Multimedia API) and even whole platforms (like the Mobile Service Architecture).
  Right now J2ME development seems to be a bit unfashionable compared to iPhone or Android development, but J2ME development is still the best way to reach around 80% of mobile phone users worldwide.

- **Qt Applications:** Pronounced cute — not que-tee — Qt is an application framework that is used to create desktop applications and even a whole desktop environment for Linux — the KDE Software Compilation. The reason many developers have used Qt on the desktop is because it frees them from having to consider the underlying platform — a single Qt codeline can be compiled to run on Microsoft Windows, Apple Mac, and Linux.

When Nokia bought Trolltech — the company behind Qt — it was with the goal of bringing this same ease of development for multiple platforms to Nokia's mobile devices. Today, Qt can be used to create applications for devices based on Symbian, Maemo and, in the near future, MeeGo, an open source platform initiated by Nokia and Intel.

- **Windows Phone 7 Series:** Microsoft is making a fresh start with its Windows Phone 7 Series. The former Windows Mobile operating system was declining in both user acceptance and market share, so the need for innovation was clearly felt. The new platform geared towards consumers rather than business users, it brings new user experience ideas and includes the Metro UI inspired by Microsoft's Zune music player.

- **Bada Applications:** Bada is a new mobile platform from Samsung, introduced in November 2009. Bada can run either on a Linux kernel, for high-end devices; or real-time OS kernels, for low-end devices. Samsung wants Bada to be the "Smartphone for everybody", and they aim to replace feature phones with Bada smartphones. Currently there are 3 devices available with Bada. Wave is a top level device, the other two focus on the mid level market. The Wave supports UMTS. The Bada UI is based on TouchWiz, as its already known from Samsung's Android Handhelds. Samsung plans to sell about 20 Million Bada phones a year.

6.2 State-of-art for mobile applications in healthcare sector

If we look at e-health trends in Europe, lead market initiatives' market classification will provide us a framework for future e-health application areas where clinical information system, secondary usage non-critical systems, telemedicine and integrated health clinical information network are defined as possible market areas.

When current e-health scenarios and technological trends are considered, there is an obvious opportunities in telemedicine domain where personalized health systems and services, disease management, remote patient monitoring, teleconsultation, telecare and telemedicine services are offered. One of the common aspects of all these services are they are provided personal information for patients. However, current scenarios and solutions fail to include the most personalized device, mobile/smart phones.

In current technology landscape, there are numerous devices which provide remote analysis and monitoring for managing health and wellness such as blood glucose monitors or EGC recorder. The main purpose of these devices is to collect personal health information over surrounding portable health devices. Standardization and interoperability studies have also been separately conducted by some organizations such as Continua Health Alliance (http://www.continuaalliance.org) whose ultimate aim is to ensure interoperability of personal health devices with connected health vision.

Medical Application Device Examples are; blood pressure monitors, precision weight scales, blood glucose monitors, ECG recorders, pulse oximeters, peak flow meters, pedometers, accelerometers, body scales (calculates weight, BMI, fat mass and lean mass).

Some examples of devices which can be connected to mobile phones or PCs via Bluetooth, Zigbee or WiFi (list is takes from Microsoft Vault's web site):

- **BloodPressure** from A&D Medical
- **Weight** from A&D Medical

- **BloodGlucose** from Bayer Diabetes Care
- **ECG** from DailyCare BioMedical
- **BloodPressure** from HoMedics
- **BloodGlucose** from LifeScan, Inc., a Johnson & Johnson Company
- **Condition Management** from MedApps
- **PeakFlow** from Microlife
- **BloodPressure** from Microlife
- **Gadget** from Microsoft HealthVault
- **BloodGlucose** from Nipro Diagnostics, Inc.
- **PulseOximeter** from Nonin
- **Pedometer** from Omron
- **BloodPressure** from Omron
- **HeartRate** from Polar
- **Weight** from Tanita
- **BloodPressure** from Walgreens
- **Weight** from Withings

There are hundreds of medical iPhone / iPad applications and on iTunes AppStore. Some selected mobile application examples which are in Edafmis project's scope:

- **Osirix For iPhone:** OsiriX is an image processing software dedicated to DICOM images (".dcm" / ".DCM" extension) produced by imaging equipment (MRI, CT, PET, PET-CT, SPECT-CT, Ultrasounds, ..). It is fully compliant with the DICOM standard for image communication and image file formats. OsiriX is able to receive images transferred by DICOM communication protocol from any PACS or imaging modality (C-STORE SCP/SCU, and Query/Retrieve : C-MOVE SCU/SCP, C-FIND SCU/SCP, C-GET SCU/SCP) .
- **iVCL or Vycaria For iPhone / iPad**: Vycaria provides Single Plane and Bi Plane C-arm Fluoroscopy Simulation Software for all Diagnostic Imaging staff. The VCL's are software applications that simulate X-Ray Fluoroscopy (Image Intensifier / C-Arm) equipment using a real-time interactive 3D Games engine (like the PlayStation or X Box).
- **The Oncologist:** The Oncologist is dedicated to helping oncology, hematology and radiation professionals stay on the cutting edge of new medical treatments and technologies, encouraging better cancer patient care and practice management. It offers the articles and case studies published in current print and online editions of the Journal over the last 12 months. This App also features video and audio podcasts featuring news and latest research advances in cancer control and care.
- **The OCT Browser:** This is a fully functional software and a part of the OCT Browser Software Suite, designed by physicians for physicians. Four example OCT images are bundled with this release. Two additional sample OCT files can be downloaded from our website for testing the file sharing (via iTunes) functionality.
- **ICD9 Consult Lite:** The 2009 ICD9-CM diagnosis codes are both searchable and browsable by their traditional categories. Search simultaneously by code, diagnosis, included diagnoses, and description, through the whole ICD9-CM or through just a category or selected nonspecific code. Images within the list indicate whether a code is specific or nonspecific. Tap to view the diagnosis and the full text of its standard ICD-9 long description and to add it to your Favorites list for immediate access later.

6 Literature review

Christoph Stettina – CETIM

6.1 Introduction

In this article we report on a structured literature review on ICT support in planning of image-guided medical interventions. Our goal is to evaluate, synthesize and present the findings and trends in the field of minimally invasive interventions. Technology has enormous impact on workflows and their flexibility in intervention rooms. However, despite improvements in medical support systems and in medical protocols the styles of collaborating do not match. The technical instruments and support systems are yet stand alone and not interoperable.

Minimally invasive and image-guided interventions make operations less risky minimizing side effects for patients, promising cost reductions and shorter operations. Their integration into medical workflows, however, requires special attention due to their requirements in pre-processing and integration of data from the pre-operative phase into the intervention room.

While the industry concentrates on the development of actual IGI techniques there is less research on the infrastructure supporting the treatments. We find it necessary to investigate what efforts are being undertaken to combine pre-, intra- and post-operative data in medical interventions. Here we provide the report of our investigation, aiming to provide information about a phenomenon across a wide range of settings.

6.2 Background

Clinical practice consists of a doctor's personal assessment of a patient in order to provide diagnosis and treatment. Simple diagnostics are possible without dissecting or conducting examinations inside the human body, the information available however, is sparse. Modern medical imaging offers precise anatomical representations, but the interpretation of the data acquired often remains a difficult task. In this section we give a brief background on ICT support in planning of image-guided medical interventions and how it is applied in the field.

Minimally invasive interventions consist of three distinctive phases: pre-, intra- and post-operative. In a first step the image-guided interventions are driven by 3-dimensional reconstruction of the patient’s anatomy. Medical imaging can provide valuable information for diagnosis and preoperative planning of surgical procedures. However, the information gathered for diagnosis cannot be easily transferred into the operating room.

While the original idea behind applying the structured literature review method originates from evidence based medicine, taking the ICT perspective we refer to the guideline as proposed by Kitchenham and Charters (2007).

6.3 Related Work

Before conducting the study we executed a database search looking for previous reviews on intervention support systems. None of the identified reviews directly addressed information technology in intervention planning for minimally invasive interventions. Many reviews we found discuss computerized clinical decision support systems (CCDSS), most aiming at the organizational level, discussing patient planning, scheduling of activities, primary care and electronic health records.

Troccaz, Lavallee and Cinquin (1996) describe their experiences in the field of Computer-augmented surgery with minimally invasive methods, helping the surgeon in planning and execution of operation strategies through quantitative use of multi-modal data.

Hunt et al. (1998) review the application of computer-based decision support systems in clinical settings and found clinical performance for drug dosing, preventive care, and other aspects of medical care, but not convincingly for diagnosis.

The review of Chaudhry et al. (2006) discusses the impact of health information technology on quality, efficiency, and costs of medical care. They found evidence for efficacy of health information technologies in improving quality and efficiency, however, not on how and at what costs other institutions can achieve similar benefits.

6.4 Objectives

Within the EDAFMIS project the authors investigate the introduction of medical intervention support systems in medical operating rooms. Within the scope of the project we want to study how to integrate ICT into medical workflows. In this review we want to investigate the current applied practices and research to establish a knowledge base in the medical field.

We want to find out how planning and preparation can help embedding ICT into medical workflows, thus we define our research questions as follows:

1. What are major planning concepts that have been investigated in ICT supported medical interventions?
2. What is the strength of the evidence in support of these findings?
3. What are the implications of these studies for the industry and research community?

6.5 Review Method

A well-defined methodology makes possibility of biased literature less likely although it does not protect publication bias in the primary studies. It can provide information about a phenomenon across a wide range of settings. For this review we followed the method of a systematic literature review (Kitchenham and Charters, 2007; CRD, 2009; Dybå and Dingsøyr , 2008) undertaking the review with a method placing demands on research questions, identification of studies, selection process and synthesis.

The SLR research method consists of three main stages: planning, execution, and reporting (Kitchenham and Charters, 2007). In the first phase we have defined our research questions, developed a review protocol, and defined the inclusion and exclusion criteria. In the second phase we retrieved the relevant studies according to the defined search strategy and data sources. We then conducted a quality assessment and categorized the studies. In the final phase we synthesised our findings.

The rest of this section describes the respective stages in more detail.

Protocol Development

The protocol we developed specifies the research question, search strategy, inclusion, exclusion, quality criteria and methods of synthesis.

Inclusion and Exclusion Criteria
Papers eligible for inclusion of the review were chosen according to their focus on planning of interventions in operating rooms supported by ICT. The review includes studies written in English and published up to 2010.

- Remove if focus clearly not on planning of medical interventions
- Remove if focus clearly not on ICT

Studies were excluded if the focus or main focus was not on information technology and if they were not directed towards interventions in operating rooms. At this stage papers discussing organizational planning in hospital settings, psychiatry, primary care, disease interventions and disaster alarm plans were excluded.

- Remove if focus on technical details

As the scope of our review is ICT supported planning, purely technical papers focusing on a single part of the process or technical descriptions were excluded. Visionary papers and descriptive studies not tested in practice were not included.

Data Sources and Search Strategy
Although there are many sources and collections of scientific literature, both electronic and paper based, we have limited our search to electronic collections, considering only peer-reviewed journals, conferences, and workshops. While there are also a lot of books, working papers, web pages, magazine articles, white papers their quality cannot be reliably determined due to the missing peer review.
Taking the ICT perspective we have executed our search with the ISI Web of Knowledge database containing a wide variety of computer science and management information systems journals.

We have constructed our search terms using the following steps as proposed by Brereton et al. (2007):

- Define the major terms
- Identify alternative spellings, synonyms or related terms for major terms.
- Check the keywords in any relevant papers we already had.
- Use the Boolean OR to incorporate alternative spellings, synonyms or related terms.
- Use the Boolean AND to link the major terms

The major terms are “medical planning” and “intervention” and “ICT”. The resulting search terms are:

- medical AND planning
- intervention OR operation
- ICT OR computer OR system OR IGI OR IGIT

All these terms were combined using the Boolean “AND” operator, that is:

(1) AND (2) AND (3)

Quality Assessment and Categorization
The 100 studies that remained after stage 3 we chose to categorize according to the project relevance and the scientific rigour.

We have sorted the papers dividing them into 3 distinctive categories as given by our research scope: (1) planning for image-guided minimally invasive procedures, (2) planning supported by simulation and for traditional surgery, and (3) intervention planning in a broader organizational scope. Only papers from the first category were selected.

Scope	Amount	Category
(1) Image Guided Interventions	10	Minimally Invasive Procedures
	7	Robot Assisted Surgery
(2) EDAFMIS – WP2 Scope	18	Planning through Simulation
	19	Computer Assisted Surgery
(3) EDAFMIS – Project Scope	5	Telemedicine
	15	Clinical Information System
	5	Workflows
	2	Education
	12	Imaging Techniques

As only peer-reviewed conference, workshop and journal articles published up to 2010 were selected for further evaluation, we settled on a classification dividing the papers into (1) empirical studies, (2) lessons learned, (3) technical design descriptions and (4) visionary papers.

Empirical studies were defined as those containing a description of research method and context. Lessons learned articles were those describing a development or application of a technical design or method and its first evaluation. Technical design papers were those purely discussing the technical implementation. Visionary papers were those containing predictions.

Visionary papers and purely technical descriptions were excluded.

6.6 Results

Minimally Invasive Procedures

Minimally invasive surgery (MIS), are performed through small incisions (0.5–1.5 cm) using video and digital imaging techniques.

The first minimally invasive procedure to be developed and widely accepted was laparoscopic cholecystectomy (gall bladder removal) (Song, 2010). Prior to 1990, laparoscopy essentially only found widespread application in gynecology (Litynski, 1999) mostly as diagnostic laparoscopy or short procedures. With the introduction of automatically advancing clips laparoscopic cholecystectomies became applicable to most general surgeons and opened the field for a widespread application. Today there are several procedures that can be executed using minimally invasive techniques for stent placement, low dose rate brachy-therapy, coronary catheterization or cardiac ablation.

In this section we present planning approaches for minimally invasive interventions. Although medical imaging provides precise 3-dimensional visualizations without the necessity to dissect, the interpretation of the data acquired, however, requires several steps for pre-processing.

ID	Reference	Title	Intervention Type	Operative Support	Evidence Type	Year
009	Documet et al.	A multimedia electronic patient record system for image-assisted minimally invasive spinal surgery	Spinal	pre,intra, post	Lessons Learned	2009

037	Maier-Hein et al.	In vivo accuracy assessment of a needle-based navigation system for CT-guided radiofrequency ablation of the liver	Liver Ablation	Intra	Empirical	2008
043	Jantschke et al.	Preparation, assistance and imaging protocols for robotically assisted MR and CT-based procedures	Periradicular therapy	Pre, intra	Lessons Learned	2007
071	Bo et al.	Applications of pelvic 3D reconstruction and dimension measurement to colorectal cancer surgery	Colorectal Cancer	Pre, intra	Lessons Learned	2006
080	John et al.	Interrogation of patient data delivered to the operating theatre during hepato-pancreatic surgery using high-performance computing	Hepato-pancreatic surgery	Pre, intra	Lessons Learned	2004
094	Meinzer et al.	Medical imaging examples of clinical applications	Visceral & Cardiac surgery	Pre, intra	Lessons Learned	2002
107	Wagner et al.	Principles of computer-assisted arthroscopy of the temporomandibular joint with optoelectronic tracking technology	TMJ arthroscopy	intra	Empirical	2001
146	Troccaz et al.	Computer-augmented surgery	Multiple	Pre, intra	Lessons Learned	1996
154	Nolte et al.	Computer-aided fixation of spinal implants	Spinal implantation	Pre, intra	Empirical	1995

Documet et al. (2009) [009] discuss their approach in developing a multimedia ePR system for imaging-assisted minimally invasive spinal surgery. Their aim is the integration of Pre-, Intra-, and Post-Op surgical data from scattered data acquisition systems, real-time data collection during the surgery, and improving the efficiency of surgical workflow. Their approach includes digital images, clinical forms, waveforms, and textual data for planning the surgery, two real-time imaging techniques (digital fluoroscopic, DF). Within their lessons learned they describe 5 main issues: (1) Lack of standards from peripheral data and imaging devices used in the OR. (2) The clinical environment was different from the laboratory environment. (3) The clinical institution was not always in control of its computer and ICT (4) User acceptance (5) Graphical user interface challenging for new users.

Maier-Hein et al. (2008) [037] studied the accuracy of a system for computer-assisted needle placement. Two medical experts with experience in CT-guided interventions and two nonexperts used the navigation system to perform 32 needle insertions. They conclude that the system allows for accurate needle placement into hepatic tumors based on one planning CT and could thus enable considerable improvement to the clinical treatment standard for RFA procedures and other CT-guided interventions in the liver.

Jantschke et al. (2007) [043] describe the evaluation of a positioning system providing the correct insertion angle and depth during image-guided (MRT and CT) percutaneous interventions. The lessons learned present an intervention in CT and MRT from the point of view of a registered radiology technician.

Bo et al (2005) [071] measure and analyze large numbers of interrelated parameters in order to inprove diagnosis, operation planning and surgery from 3D surface reconstruction of the pelvis from CT images on a personal computer.

John et al. (2004) [080] research the success rate of hepato-pancreatic surgical resections that can be improved by replacing the light box with an interactive 3D representation of the medical data in the operating theatre. In the 16 patient cases studied the interrogation of the 3D images live in theatre and comparison with the surgeons' operative findings (including intraoperative ultrasound) led to the operation being abandoned in 25% of cases, adoption of an alternative surgical approach in 25% of cases, and helpful image guidance for successful resection in 50% of cases.

Meinzer et al. (2002) [094] present examples of clinical applications that are integrated into clinical routine and are based on medical imaging fundamentals. They discuss a procedure for achieving this with the liver surgery planning system developed in their department. As result the system was used by various surgeons in five liver surgeries.

Wagner et al. (2001) [107] evaluate the applicability, accuracy, and benefits of computer-assisted arthroscopy of the temporomandibular joint (TMJ) with optoelectronic tracking technology. In the first 10 cases of computer-assisted TMJ arthroscopy they found profit from improved precision in the handling of the arthroscope, with little immobility caused for either surgeon or patient.

Troccaz, Lavallee and Cinquin (1996) [146] describe their experiences in the field of Computer-augmented surgery with minimally invasive methods. They aim is to support the surgeon in planning and execution of operation strategies through quantitative use of multi-modal data.

Nolte et al. (1995) [154] describe a system for diagnosis as well as for preoperative planning of surgical procedures improved by interactive navigation by computer-aided fixation of spinal implants. Six patients have undergone posterior fixation of degenerative lumbar spinal segments. After the sixth patient, CT was introduced as a means of postoperative evaluation, the clinical results indicate improved surgical outcome.

Robot Assisted Surgery

Limitations imposed on the surgeon by controlling minimally invasive surgery (MIS) instruments led to the introduction of robots and robot assisted surgery to overcome these limitations in movement, vision and tactile sensing.

ID	Reference	Title	Intervention Type	Operative Support	Evidence Type	Year
006	Lee et al. (a)	From medical images to minimally invasive intervention: Computer assistance for robotic surgery	-	Intra	Lessons Learned	2010
012	Duan et al.	A medical robot for needle placement therapy in liver cancer	Liver ablation (MWA)	Intra	Lessons Learned	2010
015	Lee et al. (b)	In vivo and in situ image guidance and modelling in robotic assisted surgery	cardiothorac ic / gastro-intestinal	Pre, intra	Technical Descripti on	2009
035	Megali et al.	EndoCAS navigator platform a common platform for computer and robotic assistance in minimally invasive surgery	intra-abdominal	Pre, intra	Lessons Learned	2008
049	Bast et al.	Robot- and computer-assisted craniotomy: resection planning, implant modelling and robot safety	cranial tumour resection	Pre, intra	Lessons Learned	2006
052	Hayashibe et al.	Robotic surgery setup simulation with the integration of inverse-kinematics computation and medical imaging	-	Pre	Lessons Learned	2005
083	Kronreif et al.	Interactive localisator for percutaneous interventions	-	Pre, intra	Empirical	2003

103	Coste-Manière et al.	Optimized port placement for the totally endoscopic coronary artery bypass grafting using the da Vinci robotic system	endoscopic coronary artery bypass graft	Pre, intra	Lessons Learned	2001
106	Voss et al.	ICAPS An Integrative Computer-Assisted Planning System for pedicle screw insertion	Pedicle screw insertion	Pre, intra	Lessons Learned	2001

Lee et al. (2010a) [006] discuss developments in robotic assisted MIS frameworks. They identify multi-modal image-guided MIS systems as one of the challenges to be tackled for soft tissue interventions such as tumor excision or beating heart surgery.

Duan et al. [012] conducted detailed kinematic analysis of a needle placement robot with 5 degrees of freedom, a workstation for path-planning and image processing, a conventional 2D ultrasound device, and an electromagnetic (EM) tracking system. They evaluate the feasibility of the needle placement robot by experiment.

Lee et al. (2010b) [015] discuss image guidance and modelling in robotic assisted surgery. They discuss the data sources available pre-operatively, the difficulties and limitations as to the amount of intra-operative data that can be acquired.

Megali et al. (2008) [035] report on a developed platform for common computer assisted surgery and a intraoperative laparoscopic navigation. They report on positive application of minimally invasive navigation in early clinical trials for surgical treatment of intra-abdominal disease.

Bast et al. (2006) [049] discuss resection planning, implant modelling and robot safety designing a robot-guided intervention system for cranial tumour resection. Resection planning is performed preoperatively using three-dimensional (3D) cranial models gained from a CT patient dataset converted from the DICOM into system specific format. They evaluate the robot-guided resection based in laboratory and anatomy studies.

Hayashibe et al. (2006) [052] have developed a preoperative planning system with simulation for robotic surgery in virtual space. For clinical evaluation they use volume rendering of DICOM images and automatic positioning by applying an inverse-kinematics computation of surgical robot. Integrated with a haptic interface, surgeons can drag and edit the arms of the virtual surgical robot. Five doctors were interviewed about the motion of the system and the 3d visualization mode. During evaluations doctors generally preferred the volume rendering to the surface rendering due to all information of inner structure as provided b DICOM.

Kronreif et al. (2003) [083] develop a robotic system assisting interventional radiologists in image-guided percutaneous biopsies of pathologic tissue. A preclinical test using a needle-penetrable medical phantom was accomplished in order to validate the elaborated concept as well as the accuracy of the robot prototype for US-guided biopsies. Biopsy was successfully performed for all 20 targets with only one needle pass necessary.

Coste-Manière et al. (2001) [103] propose an integrated and formalized planning and simulation tool for medical robotics, and present their experimental validation results on an artificial skeleton and heart.

Voss et al. [106] evaluate the planning software used in the context of a robot aided spine surgery.

6.7 Discussion

ICT support in Image-Guided Medical Interventions

The studies identified in this review do not provide a unified view of current practice. Most of the few studies we identified discuss intra-operative applications only. Only the lessons learned report of Documet et al. (2009) discussing the implementation of a ePR system for minimally invasive spinal surgery aiming at integration of pre-, intra- and post-intervention data to improve the surgical workflow.

Strength of Evidence

There are several systems for judgment of strength of evidence researchers can use to to restrict the type of studies to include in a systematic review. Kitchenham and Charters (2007) as well as others propose the concept of a hierarchy of evidence. This system suggests evidence from systematic reviews and randomised controlled experiments at the top of the hierarchy and evidence from quasi-experiments and expert opinion at the bottom of the hierarchy.

Out of the 17 studies identified in this review we found, the vast majority were lessons learned reports and only 4 empirical studies. Considering the study design we conclude that the strength of evidence is very low.

Implications for Industry and Research

While the industry concentrates on the development of actual IGI techniques there is less research on the infrastructure supporting the treatments. PACS (Picture archiving and Communication System) must support the appropriate DICOM data protocols (like RTSTRUCT, RTIMAGE, RTPLAN etc.) to provide a solid backbone to the IGI-IT.

There is a scarcity of empirical studies.

6.8 Conclusions

In this study we have identified 93 studies on planning of ICT supported medical interventions, of which we chose 17 for evaluation in context of the project. The selected studies discuss Minimally Invasive Procedures and Robot Assisted Surgery.

Most of the few studies we identified discuss pre- and intra-operative applications only. These studies concentrate on actual image guided techniques. The planning in these applications exclusively deals with the concrete IGI procedure and planning. The strength of evidence is very low which makes giving an advice to industry hard. Only one application involves post operational support, providing lessons learned about system integration to different vendors.

These applications are not necessarily interoperable and mostly require vendor constrained standards, making their use stiff. A lot needs to be done in terms of integration, both in research as in development.

7 Summary

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In this document the state of the art in several relevant aspects of operational execution is described. These are: Image Guided Therapy, decision support in interventional planning and mobile solutions. Although some special tooling exists, most parts of the treatment planning have to be done manually. Moreover, the results of the planning do not automatically flow towards the actual treatment procedure, and there is a time delay of several days between planning and the actual treatment. This may give rise to errors during the treatment, as the patient condition may have changed. For navigation during actual treatment very limited support is available that also may lead to errors during treatment.

For decision support during planning no only the EGADSS tool is presently available. This tool has several problems for actual use, mainly since it does not incorporate workflow, and time is not a notion the tool can deal with. New developments can upgrade the solution to make it better applicable for treatment planning support.

A lot of initial solutions exist for mobile healthcare support. However, they are mostly targeted at blood pressure, chemicals in the blood and weight measurements. A few are able to interchange medical images; none deals with workflow support during medical intervention.

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