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Towards computer-assisted surgery in shoulder joint replacement

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Abstract

A research programme that aims to improve the state of the art in shoulder joint replacement surgery has been initiated at the Delft University of Technology. Development of improved endoprostheses for the upper extremities (DIPEX), as this effort is called, is a clinically driven multidisciplinary programme consisting of many contributory aspects. A part of this research programme focuses on the pre-operative planning and per-operative guidance issues. The ultimate goal of this part of the DIPEX project is to create a surgical support infrastructure that can be used to predict the optimal surgical protocol and can assist with the selection of the most suitable endoprosthesis for a particular patient. In the pre-operative planning phase, advanced biomechanical models of the endoprosthesis fixation and the musculo-skeletal system of the shoulder will be incorporated, which are adjusted to the individual's morphology. Subsequently, the support infrastructure must assist the surgeon during the operation in executing his surgical plan. In the per-operative phase, the chosen optimal position of the endoprosthesis can be realised using camera-assisted tools or mechanical guidance tools. In this article, the pathway towards the desired surgical support infrastructure is described. Furthermore, we discuss the pre-operative planning phase and the per-operative guidance phase, the initial work performed, and finally, possible approaches for improving prosthesis placement.

Keywords: pre-operative planning; per-operative guidance; navigation; computer-assisted orthopaedic surgery; shoulder arthroplasty; medical applications; data registration; tracking; visualisation; MRI; CT; X-ray

1. Introduction

1.1. Background

Joint replacement of the hip and the knee is a successful procedure for the treatment of rheumatoid arthritis, osteoarthrosis, and trauma. In contrast, replacement of the shoulder joint is far less successful: about 44% of the endoprostheses were radiographically loose, with a mean follow-up of 9.7 years (Torchia et al., 1997). The desired improvement in shoulder mobility is often not attained.

The shoulder joint is a more complex construction than either the hip or knee joints. It forms the connection between the upper arm (humerus) and the shoulder blade (scapula), which in turn is connected to

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the thorax via the collarbone (clavicle). The scapula is free to glide to some extent along the back of the thorax and this movement, together with the movement in the shallow socket (glenoid cavity) in which the head of the humerus rotates, allows the arm an extensive range of motion (Fig. 1).

In addition to the general complexity of the shoulder joint, two other factors contribute to the unsatisfactory results of shoulder replacement: shoulder prosthesis design is far from fully developed, and placing these shoulder prostheses is exceptionally difficult due to the shoulder anatomy. During surgery, the field of view of the orthopaedic surgeon is very limited, because the incision is kept small to limit damage to surrounding tissue. Consequently, only the socket of the scapula and the head of the humerus are exposed. Furthermore, due to the orientation of the patient, the scapula slides downward underneath the skin. In the current surgical procedure, it is impossible to register this motion of the scapula and for that reason it cannot be corrected. As a result, placement of the glenoid component is likely to be inaccurate.

1.2. The DIPEX programme

At Delft University of Technology, a research programme has been started that aims to improve the state of the art in shoulder joint replacement surgery. Development of improved endoprostheses for the upper extremities (DIPEX), as this effort is called, is a clinically driven multidisciplinary programme consisting of many contributing projects. In Fig. 2, a flow diagram of the DIPEX programme is presented. Within the project, two main directions of research can be distinguished: the development of an improved shoulder prosthesis and the improvement of the surgical process. To be able to design improved shoulder prostheses and to perform an adequate pre-operative planning, CT, MRI, and X-ray images are essential, as well as pre-operative clinical and functional scores. Micro-CT images from cadaver shoulder blades provide information on bone properties. Data extracted from the images—parameters, surfaces, and muscle attachment sites—are used as input for a musculo-skeletal Delft Shoulder Model (DSM) and for Finite Element Analysis. These models are used not only to analyse and improve the design of the shoulder prosthesis, but also to study the effect of implantation of the implant on shoulder function. The improved implant design can be used in a clinical setting after it has been optimised using pre-clinical testing. In the pre-operative planning stage, all information—images, extracted information, and model outcome—can be used by the surgeon to plan the actual surgery. During surgery, the surgeon is supported by a per-operative guidance system. With time action analysis, the surgery is analysed, and suggestions can be given for optimisation of the surgical procedure. By means of post-operative scoring and image acquisition, feedback is generated by which shoulder arthroplasty can be improved further.

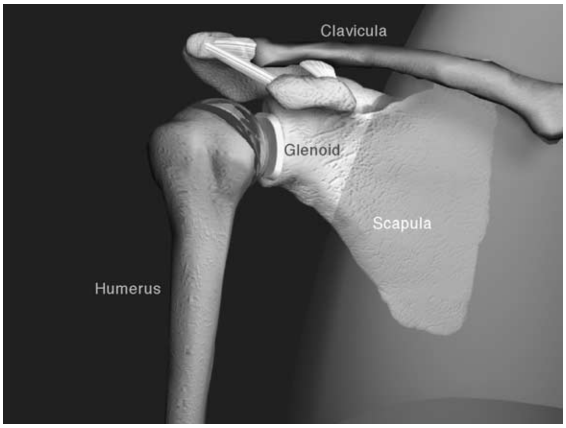


Fig. 1. Shoulder anatomy. In this shoulder, a total shoulder prosthesis has been inserted that replaces the humeral head and the glenoid cavity.

The design of shoulder prostheses might be improved by optimising existing prosthesis designs or by the development of conceptually new designs (Oosterom et al., 2000). Additionally, new fixation techniques, new materials, and a new surface topology are considered.

Finite element analysis (FEA) will play an important role in this design process. Input for FEA will be provided by a musculo-skeletal model of the shoulder (van der Helm, 1994a,b) in combination with functional and clinical data of patients. Additional inputs for FEA are the shape of the bone surfaces and the position of muscle attachment sites that will be extracted from Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) images; micro-CT will be used to assess bone properties.

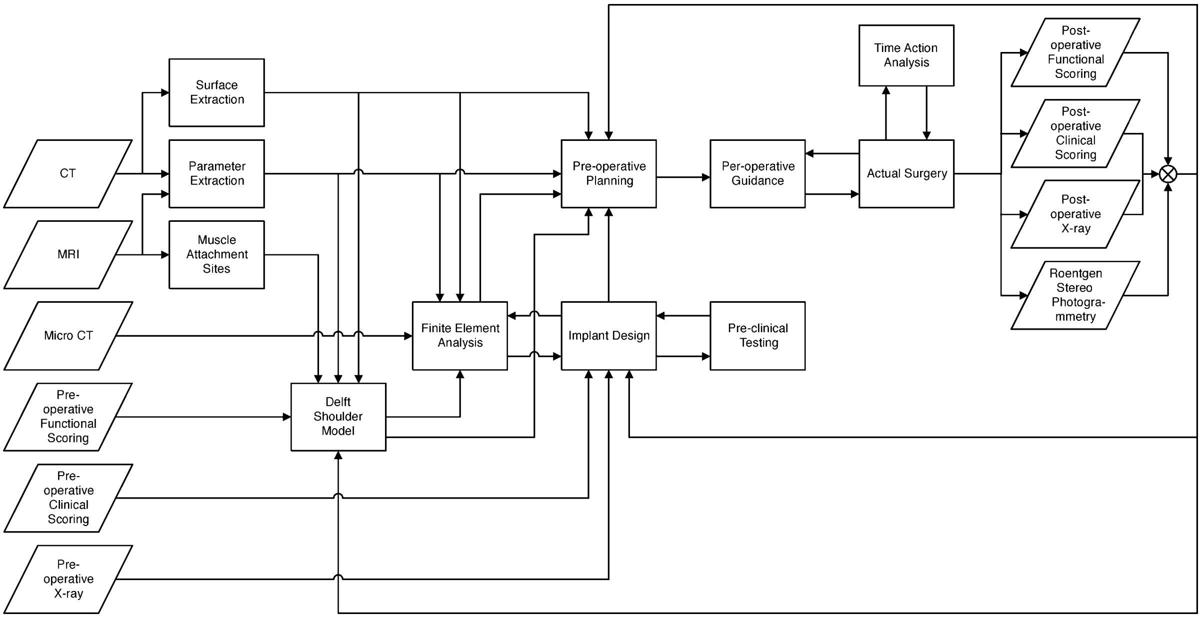


Fig. 2. Flow diagram of envisaged procedures in shoulder joint replacement surgery within the DIPEX project (see explanations in text).

The surgical process might be improved by using more advanced three-dimensional imaging techniques—like CT and MRI—instead of two-dimensional X-rays that are used currently, and by analysing the current surgical process.

A thorough analysis of the surgical procedure is done with per-operative time action analysis and post-operative evaluation of surgical outcome. Time action analysis is a quantitative method in which the number and duration of the actions needed for an operator to achieve his goal and the efficiency of these actions are measured by means of video analysis (Minekus et al., in press).

Evaluation of surgical outcome is done by measuring the range of motion and muscle strength of the operated shoulder. This evaluation can also provide loading data necessary for the redesign of the shoulder prosthesis. Prosthesis–bone fixation is assessed using Roentgen stereophotogrammetry (Nagels et al., 2002).

Shoulder replacement can be considered as a process consisting of two successive phases: the pre-operative planning phase, during which information is gathered and analysed and the operation is planned by employing the predicted outcomes; the per-operative guidance phase involving the actual surgery, which is executed according to the pre-operative planning with the assistance of mechanical and/or computer-based systems.

The ultimate goal of this part of the DIPEX project is to create a surgical support infrastructure that can be used to predict the optimal surgical protocol and can assist with the selection of the most suitable endoprosthesis for a particular patient. Subsequently, this support infrastructure must assist the surgeon during the operation in executing his surgical plan.

1.3. Scope of this paper

In this paper, we will focus on the pre-operative planning and per-operative guidance issues. The pathway towards the aforementioned surgical support infrastructure will be described in the context of the two-phase replacement process. We will discuss the phases in turn, look at the initial work that we have performed, and document possible approaches for improving prosthesis placement. Since we are at the start of our research, the emphasis in this paper will be on the general setup of our research and its “photogrammetric” aspects, rather than on the presentation of results.

2. Pre-operative planning

Traditionally, orthopaedic surgeons plan shoulder prosthesis placement by making use of a radiograph of the patient's shoulder as well as 2D contour representations of several prosthesis designs on transparencies. These transparencies are then each overlaid (by the surgeon) on the radiograph until a satisfactory fit is found. This assists the surgeon with his decision on a type and configuration of prosthesis as well as its placement.

By using a three-dimensional reconstruction of the patient's shoulder from CT (Computed Tomography) and MRI (Magnetic Resonance Imaging) images, a much better understanding of the geometry of the bones can be derived than would be possible with conventional 2D radiographs.

In addition, higher level parameters can be estimated by making use of this 3D image data. These parameters can be used to personalise musculo-skeletal and finite element models for simulating expected performance and operational outcome. The CT data can also be used for a more direct guidance of the replacement procedure, e.g. assisting the surgeon in choosing a good site for prosthesis implantation by indicating the existing centre of rotation of the shoulder joint. In order to make the pre-operative planning an interactive procedure, effective visualisation of medical image data, extracted parameters, and simulated performance is also very important.

2.1. Parameter and information extraction

2.1.1. Assessment of the glenohumeral rotation centre

During motion of the shoulder, the geometric centres of the humeral head and the glenoid coincide with the centre of rotation of the glenohumeral joint. It has been established that the preservation of this centre of rotation after joint replacement increases the chances of a satisfactory outcome (De Leest et al., 1996).

Pre-operative detection of the joint's centre is achieved by detecting the centre of the sphere that fits onto the articular surface of the humeral head in CT or MRI images. Note that the humeral head is not a complete sphere, but only covers about 40% of a spherical surface. This precludes the use of fitting techniques to find the spherical surface. Instead, we have developed a novel Hough-based sphere detection algorithm (Van der Glas et al., 2001). This algorithm can automatically determine the 3D centres and radii of partial spheres in unsegmented 3D images by employing the orientation and magnitude of the grey-scale gradient in these images. It does not require a user-defined first estimate of the centre and the radius, but functions fully automatically.

The method was tested on artificial images containing synthetic spheres and on real-world MRI and CT data sets of the glenohumeral joint. In one experiment, artificial images of size $84 \times 84 \times 84$ voxels were created containing one complete sphere, with grey-value 1 for the object and grey-value 0 for the background. The edge of the sphere was blurred with Gaussian distributed noise with sigma ranging between 1 and 8 voxels. Furthermore, the radius of the sphere was varied between 26 and 40 voxels to cover the whole range of variations present in clinical images. For every combination of radius and noise, 20 artificial images were generated by changing the centre position within 1 voxel. The overall average error in centre detection was less than 0.1 voxel. In clinical practice, typical voxel sizes vary between 0.7 and 1.5 mm, so the error will be between 0.07 and 0.15 mm.

The method was also tested on real-world CT and MRI data sets. Because in this experiment there was no golden standard for the centres of rotation, the results were inspected visually. For example, Fig. 3 shows that the automatically detected sphere correlates well with the spherical part of the humeral head. In Fig. 4, a 3D representation of a spherical description of a humeral head is displayed within a humerus that was reconstructed from CT images.

As the method does not require segmentation, it can be directly applied to clinical images. It works robustly on noisy images where only a fraction of a sphere surface is present. Apart from that, it can be used on anisotropically as well as on isotropically sampled data.

2.1.2. Accurate triangulated surface generation

The automatic extraction of accurate polygonal surface descriptions is important for visualisation, measurement, structure modelling, and as a first step for further data analysis. In the case of CT data sets, one can assume that iso-surfaces exist at the bounda-

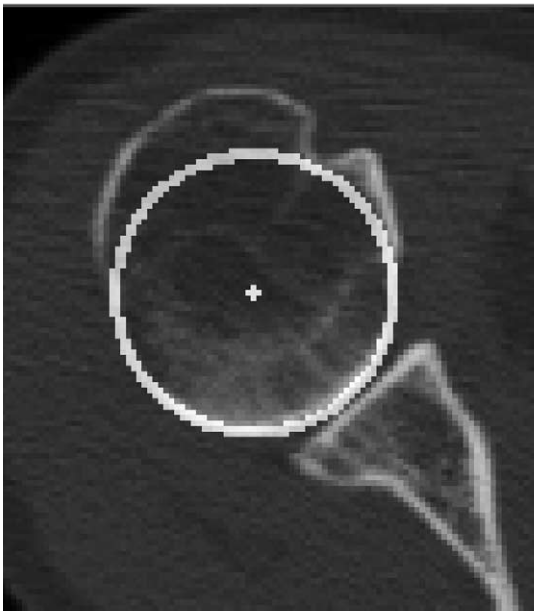


Fig. 3. Detected humeral head centre and radius on CT image.

ries between bones and surrounding soft tissue, so we make use of the well-known Marching Cubes algorithm (Lorensen and Cline, 1987) in conjunction with pre- and post-processing refinements.

Before performing the iso-surface extraction, bony structures can optionally be segmented by making use of a double threshold and a 3D region-growing algorithm. The user indicates a seed-point in a bony structure of interest as well as approximate lower and upper bounds for the imaged bone density. The resulting surface description is highly detailed and this can make it impractical to work with. Optionally, the mesh can be decimated (Schroeder et al., 1992; Schroeder and Citriniti, 1997), i.e. simplified without significant loss of object topology. This process can result in a significant (configurable) reduction of the number of polygons at the cost of some accuracy.

Such a surface can be used as an initial step in a volume tetrahedralisation suitable for finite element modelling of a structure. In this case, the quality of the triangles (i.e. average ratio between longest and shortest side) making up the surface is important. The triangles generated by the iso-surface extraction and subsequent decimation are not optimised with regards to quality, but rather with regards to surface accuracy. Fortunately, we can make use of an elegant algorithm that applies analogue-filtering concepts to polygonal meshes in order to improve mesh quality (Taubin, 1996, 2000).

Measuring on an extracted surface, although convenient, has inherent inaccuracies. These inaccuracies are obviously dependent on the nature and configuration of the surface extraction algorithms. One of our challenges is to quantify the inaccuracies and also to establish the exact requirements of our measurement applications.

2.1.3. Muscle geometry and attachment sites

MRI would be the most suitable technique to assess muscle geometry and muscle attachment sites. Work by Kaptein (1999) showed that automatically extracting this information from MRI images is prohibitively difficult. The only way to differentiate between muscles in MRI images is by using the layers

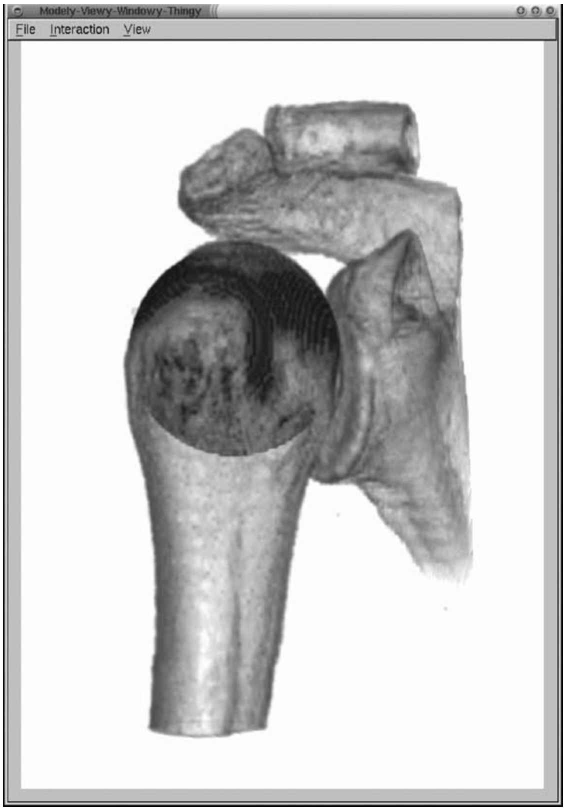


Fig. 4. The position of the estimated sphere representing the humeral head, displayed within a reconstructed humerus.

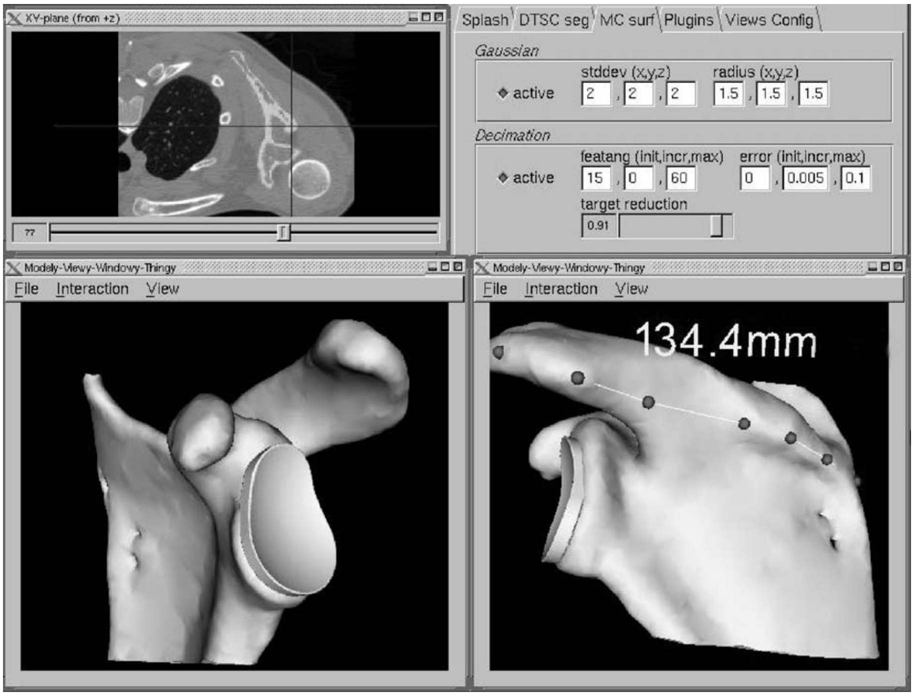
of tissue that surround each muscle (fascia). However, these layers are so thin that they often cannot be visualised completely. Another difficulty with MRI is that it is not possible to distinguish between locations where the muscle is adjacent to the bone and locations where the muscle is attached to the bone.

In a pilot study, CT data of 14 cadaver shoulders were used to generate 3D models of the shoulder bones. Muscle attachment sites of these shoulders were obtained by means of dissection and then registered to the bone models by means of markers. Each of the 3D models was nonrigidly registered onto all other models. This resulted in a precise overlap of the muscle attachment sites for 45% of the muscles, and a partial overlap for 40% of the muscles. A total of 15% of the muscle attachment sites did not overlap, and were qualified as measurement errors by visual inspection afterwards (Kaptein, 1999). These results call for further studies with better dissection protocols, larger data sets, and improved registration methodologies.

2.2. Delft Shoulder Model

The Delft Shoulder Model (DSM) is an advanced finite element musculo-skeletal model that allows the simulation of kinematics and dynamics of the upper extremity on the basis of parameters describing the bony structure of the shoulder, the ligaments and capsules, the dynamics of the muscles, and the sensory feedback system (van der Helm, 1994a,b). The basic information used in building the model was derived from cadaver studies and taken from the literature (Veeger et al., 1991). The DIPEX programme is continuing the development of the shoulder model and is appropriating significant resources on extensive validation.

The scientific and clinical challenge is to apply the model to the treatment of a particular patient by predicting the effect of a particular endoprosthesis, including the fixation technique used, on the resultant mobility of the upper extremity.



Gaussian

◆ active stddev (x,y,z) 2 , 2 , 2 radius (x,y,z) 1.5 , 1.5 , 1.5

Decimation

◆ active featang (init,incr,max) 15 , 0 , 60 error (init,incr,max) 0 , 0.005 , 0.1

target reduction 0.91

Fig. 5. Screen layout of DSCAS. In the upper left corner, a single CT slice of the shoulder is displayed. In the lower left corner, a scapular surface reconstructed from in vivo CT data is shown with an "implanted" glenoid component. On the right, this same assembly has been used to measure the length of the scapular spine.

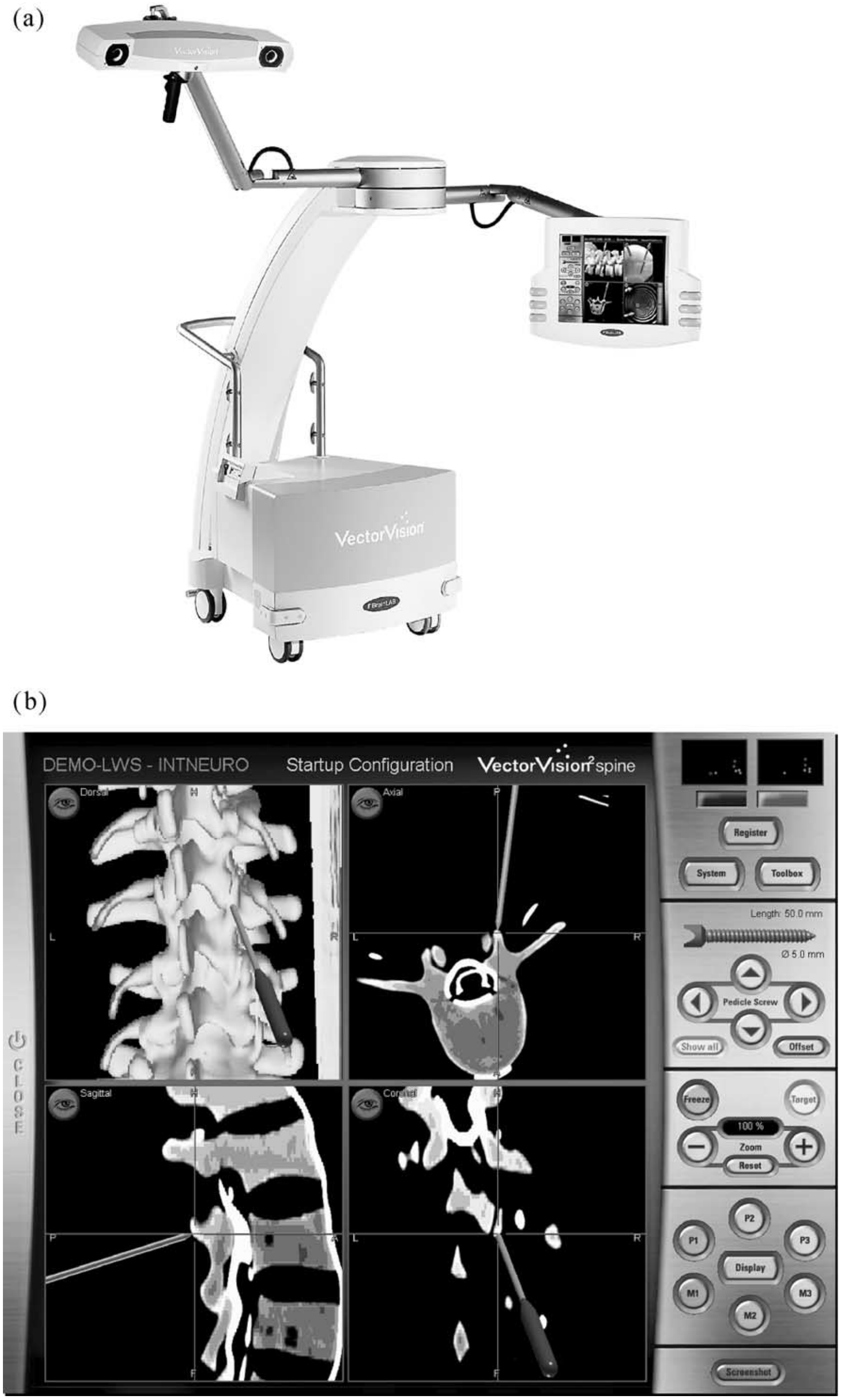

(a)
VectorVision
(b)
DEMO-LWS - INTNEURO
Startup Configuration
VectorVision² spine
Dorsal
Axial
Sagittal
Coronal
CLOSE
Register
System
Toolbox
Length: 50.0 mm
Ø 5.0 mm
Pedicle Screw
Show all
Offset
Freeze
Target
100 %
Zoom
Reset
P1
P2
P3
Display
M1
M2
M3
Screenshot

Fig. 6. (a) Brainlab's Vector Vision surgical navigation system (Brainlab, 2002). The camera system consists of two infrared cameras that detect the infrared signal of the passive markers that are attached to the patient, the implant, and the surgical instruments. (b) On the monitor of the Vector Vision system, several views of the pre-operatively acquired CT images can be visualised simultaneously with a 3D reconstructed surface of the area or joint of interest—in this case a part of the spine. In this view, a representation of an instrument and its actual position and orientation is also presented in real-time mode. (c) An instrument with a marker tree that holds passive markers attached to it. (Courtesy of Brainlab.)

Information on a particular patient may be extracted not only from CT and MRI images, but also from the functional scores on the range of motion of the shoulder joint.

2.3. Visualisation

The medical image data, extracted information, and models have to be integrated and made available to the (clinical) user. This process requires an effective human–machine interface for both interaction and visualisation. For this purpose, we are developing an experimental visualisation tool called Delft Shoulder Computer-Assisted Surgery (DSCAS) (Botha and Post, 2001). DSCAS is able to perform a range of visualisations and analyses on any medical data in a flexible and extensible fashion, useful for both surgeons and researchers.

Polygonal surface representations of bony structures in the CT data can be reconstructed easily by employing built-in 3D region growing and surface extraction routines. DSCAS can provide a fully 3D reconstruction of the operative situation thereby allowing the surgeon to perform prosthesis placement within this information-rich environment (Fig. 5).

In the near future, the Delft Shoulder Model will be integrated with DSCAS so that it can be used interactively. This would mean that a researcher or surgeon would be able to make changes to a specific shoulder configuration interactively in this graphical environment (e.g. relocating a muscle force line). Information on muscle forces, joint reaction forces etc. will be presented to the surgeon so that he receives a direct feedback on the decisions made. Other types of predictive modelling (e.g. FEA of prosthesis–bone interfaces) will also be integrated with the platform.

3. Per-operative guidance

Concerning per-operative guidance, two approaches are considered: using camera-based systems and using mechanical systems. These systems both have their advantages and disadvantages. Fine-tuning of a camera-based system and the development the mechanical system are within the scope of the DIPEX project. Comparison of the two types of systems in an experimental as well as clinical setting will be essential to decide for the best system for shoulder joint replacement, with its particular problems and requirements.

3.1. Camera-based systems

Several camera-based systems for computer-assisted surgery are available commercially (Vector Vision, Brainlab; Surgigate, Medivision; Navitrack, Orthosoft; Stealthstation, Medtronic). Originally, most of these systems were developed for neurosurgical application, such as brain tumour resection (Lee et al., 2000; Schackert et al., 2001), and for accurate placement of screws in spinal surgery (Laine et al., 1997; Nolte et al., 1995). In orthopaedics, these systems are used for reconstruction of the anterior cruciate ligament in the knee (Sudkamp and Haas, 2000), placement of knee prostheses (Kohn and Rupp, 2000; Mielke et al., 2001), and positioning of cups in hip replacement (DiGioia et al., 1998). Because these systems are dedicated to these specific joints, each having its particular problems and requirements, they cannot be used for shoulder replacement. Therefore, a dedicated module for shoulder replacement has to be developed.

In general, camera-based systems rely on CT images, although systems that make use of 2D fluoroscopy images are becoming available. During surgery, the continuously updated 3D reconstruction (of patient anatomy and all instrument positions) together with the pre-operative surgical planning can be viewed on a computer screen (Fig. 6). For accurate guidance, the relation between the patient's anatomy (as well as actual surgical instruments) and the reconstructed geometry has to be determined accurately and maintained throughout the surgical procedure by registration and tracking, respectively.

We will discuss registration and tracking in more detail, after which we will briefly document the actual use of a per-operative guidance system.

3.1.1. Registration

In this setting, registration refers to finding corresponding points in the operational environment and its virtual geometric description. These points might be well-known anatomical landmarks, artificial landmarks (fiducials), or arbitrary points on surfaces. A new and more advanced technique for registration is fluoroscopy-based registration.

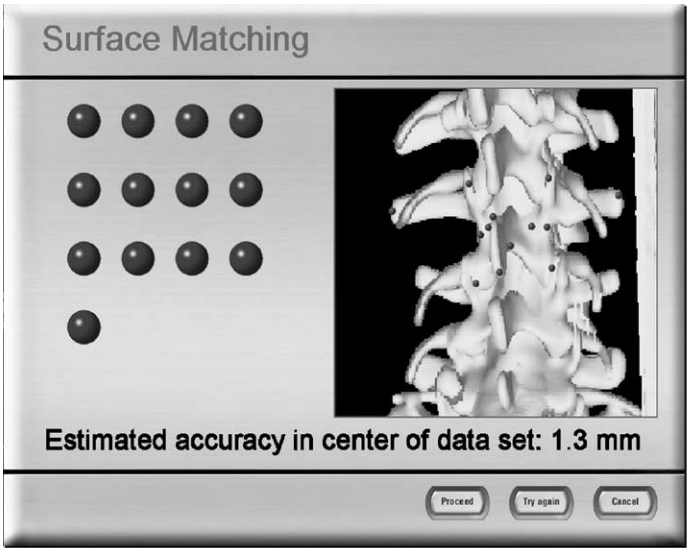
3.1.1.1. Paired point registration. Establishing the relation between discrete points on the patient's reconstructed 3D geometry and points on the patient's actual anatomy might be used for registration of the patient. These points might either be anatomic landmarks or artificial landmarks, so-called fiducials. Fiducial landmarks might be glued to the patient's skin or inserted in the patient's bone (Ellis et al., 1996). The latter method requires an additional surgical procedure that is demanding for the patient, but it has an optimal accuracy because skin-mounted markers might move with respect to the underlying bone tissue.

Using anatomic landmarks is a common procedure in per-operative registration. However, it might be difficult to exactly identify the corresponding points on the patient's anatomy and in the CT scan. It can therefore take quite some time to perform, even by an expert, and the accuracy might be low.

With a minimum of three paired points, the linear transformation that aligns the scan and the patient can be determined if a rigid transformation is assumed. The transformation matrix contains information on rotations, translations, and scale parameters. In order to increase accuracy, in general, more than three points are used. Fitting of an over-specified set of markers with a controlled removal of those points outside pre-set error limits has been described by a number of workers.

3.1.1.2. Surface-based registration. In surface-based registration, points on the patient's anatomy are randomly measured and matched onto the triangulated surface of the reconstructed CT model (Fig. 7). In order to obtain a reliable match, at least 10–20 scattered points need to be digitised. The advantage of this method is that the surgeon does not have to find points that exactly match each other: this will speed up the registration. An important disadvantage in this type of registration is that the optimisation algorithms are highly susceptible to local minima and erroneous data. To avoid local minima, one might consider using a paired point registration of three points to roughly estimate the registration transformation, and next refine registration using surface matching.

3.1.1.3. Fluoroscopy-based registration. Another technique for registration that does not require digitisation of points by the surgeon is fluoroscopy-based registration (Penney et al., 2001). Registration is done using per-operative fluoroscopy images. The pre-operative CT images are used to artificially generate fluoroscopy images that are matched onto the per-operative fluoroscopy images. This method requires a lot of computing power but it relieves the surgeon from a tedious registration task. By increasing the number of fluoroscopy images, the accuracy of this method can be increased drastically.


Surface Matching

Estimated accuracy in center of data set: 1.3 mm

Fig. 7. The relation between the position of the actual vertebra and the reconstructed vertebra is established by measuring points on the surface of the bone and apply a surface match with the reconstructed bone. (Courtesy of Brainlab.)

3.1.2. Tracking

After registration, the relation between the peroperative pose of the patient and the pose of the patient during the CT scan has been established. During surgery, however, the patient might move, and the registration will become unreliable. Therefore, the pose of the patient will have to be monitored constantly. For this purpose, trackers are attached to the patient's anatomy. A position sensor obtains the positions of these trackers. For computer-assisted surgery in general, optical systems that rely either on active or passive markers are used. During surgery, an infrared camera system tracks the markers that are attached to the relevant bony structures of the patient, as well as the surgical instruments and the prosthesis.

In active systems, the markers emit infrared light and they are controlled by the camera system, provided that each marker gives its own unique signal facilitating identification. The emission of infrared light requires power that, in most systems, is supplied through a wire; these wires might interfere with the surgical process. New developments are ongoing in which the trackers are powered by battery (Northern Digital Optotrack 3020, Stryker Leibinger). A drawback of the battery-powered systems is that the trackers might become rather bulky and during long surgical procedures the system might run out of power.

Passive systems use markers that reflect infrared light that is emitted by the camera system. Since these markers do not need any external power to function, they are easier to handle. However, identification of markers might be difficult, as all markers generate the same signal.

3.2. Mechanical systems

Although several surgical instruments for the alignment and placement of shoulder prostheses exist, there is still much room for improvement with regards to placement accuracy. Several research groups are currently working on the development of new surgical instruments that have been optimised for computer-assisted surgery. These developments include moulds for accurate placement of dental implants, surgery of the pelvis (Brown et al., 2000), and for pedicle screws in spinal fixation (Brown et al., 2001). The moulds are created using rapid prototyping techniques.

At the Katholieke Universiteit Leuven, a mechanical navigation system for pedicle screws has been developed, which has been applied clinically (Goffin et al., 2001; Vander Sloten et al., 1998). This navigation system relies on CT images and rapid prototyping techniques. Pre-operatively, CT images are made that are subsequently segmented and used to design a mould that guides pedicle screws as they are installed by a surgeon. This technique might also be used for navigation of the glenoid and humeral component in total shoulder replacement. Because the moulds should be placed in a unique and stable position, high demands will be put on their design. A thorough validation of the technique will have to prove the applicability of this approach for shoulder replacement.

3.3. Advantages and disadvantages of both systems

With the camera-based approach as well as with the mechanical approach, the prosthesis will be implanted in a much more accurate way than would be possible with contemporary techniques that rely on 2D X-rays. Camera-based systems are flexible if, for instance, during surgery, the orthopaedic surgeon is not satisfied with the pre-operative planning, adjustments to that planning can be made by taking into account the per-operative situation. Mechanical systems lack flexibility, i.e. when the pre-operative planning is invalidated by an unforeseen per-operative circumstance, it cannot be corrected during surgery. In that case, the surgeon is driven back on using conventional instruments to position and align the implant.

Camera-based navigation allows minimal invasive surgery in situations where open surgery was previously required, because the navigation of the instruments is guided by the 3D reconstruction that is presented on the computer monitor. In contrast, mechanical systems cannot reach the same level of minimal invasive surgery because we need direct contact between the bony structures and the guidance moulds.

An important disadvantage of camera-based systems is that additional actions need to be carried out during surgery, resulting in a longer procedure. Since a direct line of sight is required for optical systems, the surgeon must be cautious not to block markers from the field of view of the camera. This might force the surgeon to execute the surgical procedure in a different way than he was accustomed to. In addition, care has to be taken to visualise the marker trees that have been attached to the patient and the instruments. Furthermore, failure of the software or electrical circuits of the system might cause malfunction of the system.

The mechanical approach does not have this disadvantage. During surgery, only one additional instrument—the guidance mould—is added to existing instruments. In general, the surgery will not take longer than with conventional surgery; the novelty of the operation technique mainly exists in the pre-operative planning phase.

4. Conclusion

In summary, a large research effort on improving the outcome of shoulder replacement surgery has been started by the DIPEX group and its clinical partners. Within our approach, an important role is played by 3D data sets of the anatomical structures of the patient, either CT or MRI data. These data sets are used for visualisation, pre-operative planning, and for per-operative guidance. The DSCAS platform will play a central role within the project, and is intended to form a solid basis for future developments. Concerning per-operative guidance, two approaches are considered—camera-based systems and mechanical systems—that have both their advantages and disadvantages. Comparison of the two types of systems in an experimental as well as clinical setting will be essential to decide for the best system for shoulder joint replacements, with its particular problems and requirements.

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