8 General discussion

In this thesis we investigated the supportive role of medical visualisation in the making of orthopaedic treatment decisions that affect the ROM and articulation of spheroid joints. To this aim, we have studied medical visualisation applications in image processing, diagnosis, pre-operative planning and post-operative evaluation. In the following sections we will summarise and discuss our conclusions.

8.1 Image processing

In spite of the improved quality and resolution of modern scanning equipment, image data of pathological joints can be difficult to interpret by automated processes. This leads to challenging segmentation problems. One such segmentation problem is seen in shoulder replacement surgery for patients with rheumatoid arthritis, where the automated extraction of bone models is complicated as a result of the deteriorated state of the joint. The difficulty of this segmentation problem depends on the extent of joint space narrowing and the variations in bone density.

In the literature, optimal solutions to segmentation challenges often consist of a combination of several segmentation techniques (Van Ginneken et al., 2007, Metz et al., 2008). To solve our particular segmentation problem we have adopted volume and surface processing techniques and combined them with interactive visualisation. The applicability of Hough-transforms as a solution to segmentation tasks that involve curved shapes is well-known (Van der Glas et al., 2002, Illingworth and Kittler, 1988). However, the combination of a Hough-transform with visualisation of minimum-curvature is novel and appears to be effective for the segmentation of
severely arthritic shoulder joints. We have demonstrated that semi-automatic segmentation of rheumatoid joints in CT can be performed quickly and accurately, in spite of varying acquisition parameters.

8.2 Diagnosis & pre-operative planning

In orthopaedics, image data is commonly used to assess the state of joints. However, clinically relevant derivations of the data, e.g. the articulation of a joint or the volume of a muscle, are difficult to extract by merely depicting the data. In the assessment process clinicians will generally evaluate these parameters and base treatment decisions upon their expert judgement (Preim and Bartz, 2007). Many of these parameters can be accurately simulated by simulation models, provided that the underlying assumptions are validated. Examples of simulation models are finite element models to evaluate bone strength and musculoskeletal models to predict muscle function.

In this thesis we studied the simulation and visualisation of bone-determined ROM of spheroid joints such as the shoulder and hip joint. This is an important factor in the prediction of post-operative joint mobility.

The simulator was initially applied in a pre-operative planning system for shoulder replacement surgery. Interactivity of the system was realised by the development of two optimisation techniques that were presented in Chapter 3. Besides its application to shoulder replacement surgery, the simulator was used to analyse a series of 79 proximal humerus fractures (PHF) with two observers. The high inter-observer agreement found in this study is an indication that ROM simulation of PHFs is a promising approach that may substitute classification systems commonly used to decide on treatment. Conclusions that followed from this study are that a smaller retroversion angle leads to limited ROM for all types of PHFs and that intra-articular fractures generally have a worse prognosis with regards to bone-determined ROM.

The application of our system to PHFs demonstrates that the concept of ROM simulation is extensible to other pathologies. This claim is further supported by the case studies presented in Chapter 7, where the system was successfully applied to treat a patient with a PHF, a patient with a malaligned hip prosthesis that increased the risk on dislocation, and finally a patient with femoroacetabular impingement.

A currently unaddressed question is whether pre-operative planning has added value when no intra-operative guidance method is used to ascertain that the operation is carried out in accordance with the pre-operative plan. The purpose of pre-operative planning is to provide the surgeon with an accurate and complete mental image of the joint that he is going to operate on. This is exactly what a surgeon does when he uses conventional methods such as radiographs or CT to prepare for surgery. Simulations
and medical visualisation add to this image and support the surgeon in the decision-making process during surgery, also in the absence of coupled surgical guidance. This was confirmed by the case studies presented in Chapter 7.

Besides the support of diagnosis and pre-operative planning, visualisation systems can be used to train surgeons. In addition, they allow surgeons to explain to patients what pathology they have and how it should be treated. Improved understanding by the patient may result in better compliance with the chosen treatment and more correct expectations regarding the result of treatment.

8.3 Evaluation

In orthopaedic research and rehabilitation medicine, joint function in subjects is recorded to monitor disease progression and surgical intervention. The recordings assist in answering fundamental research questions on kinematic behaviour. The data that follows from motion recordings often consists of many parameters that vary over time. The most frequently used visualisation technique for this type of data is the angle-angle plot, which displays only two kinematic parameters. In the case of multi-joint kinematic data, more advanced techniques facilitate data analysis.

We investigated the clinical applicability of a series of new visualisation approaches in a Delphi study format (Rowe and Wright, 1999). The resulting visualisation technique was designed in accordance with the well-known Visual Information-Seeking mantra of Shneiderman (Shneiderman, 1996): *overview first, zoom and filter, then details-on-demand*. This principle can be used to guide the development of visual analysis applications that deal with large amounts of data. The challenge of these visualisation tasks lies in hiding excess data and emphasising data that is of interest to the researcher.

In solving this problem for kinematic data, a multi-view application was developed that allows users to visualise a large collection of visible recorded poses (*overview first*). The user adds filters to occlude data that is not informative in the context of the current research question (*zoom and filter*). By filtering and zooming in on interesting motion patterns, the visualisation becomes more clear and depicts the relationship that is under investigation. When interesting poses have been found, the user can select these poses and request details of that specific pose (*details-on-demand*). Examples are the individual joint angles and their respective 3-D representation. This can be further extended by incorporating more complex data derivations, such as limb speed, force measurements and musculoskeletal model simulations.

One of the observations following from this work is that kinematic data can be easily dealt with using a modular data-flow approach as is common for image pro-
cessing. This can be achieved by means of a network editor such as DeVIDE or ME-VISlab (Botha and Post, 2008, Koenig et al., 2006). Network editors represent data and the operations upon the data as blocks that can be connected with each other to derive modified versions of the data or to produce visual representations of the data. The advantage of choosing a network oriented approach for kinematic data would be that the kinematic model and the representation of the data can be easily adjusted to accommodate different users, as is often required in research on kinematics.

8.4 Conclusion

In this thesis we have demonstrated that medical visualisation can support several clinical decisions that affect the ROM of spheroid joints. In shoulder replacement surgery, the decision for a type, size and alignment of prosthesis was facilitated by demonstrating the effects of surgery on the bone-determined ROM of the glenohumeral joint. In proximal humerus fractures, the decision whether or not to operate was supported by simulating the bone-determined ROM and the articulation of the fractured joint, thereby indicating what fragments of the fracture should be reduced to avoid impingement complications and malarticulation. In femoroacetabular impingement, we demonstrated that our system can be used to support the decision on whether or not to operate and what part of the femoroacetabular joint should be shaved off to avoid further impingement.

8.5 Future Work

As the quality and resolution of existing scanning equipment improves and more image modalities become available, it is expected that decision-support systems will be capable of simulating additional aspects that are relevant for treatment. Examples are the analysis of vascularity around joints and finite element analysis of bones, prosthetic components and muscles. To further enhance the post-operative function prediction with soft-tissue influence, musculo-skeletal models such as the Delft Shoulder & Elbow Model should be integrated in a pre-operative planning system (Van der Helm, 1994), together with techniques to establish patient-specific parameters such as muscle volume from the image data.

In continuation of this research a new project has been initiated that will address intra-operative guidance for shoulder arthroplasty. The objective of this project will be the development of an adaptive surgical instrument that mechanically guides prosthesis placement. At the time of writing, no surgical guidance method for shoulder arthroplasty has been shown to be sufficiently accurate, fast and cost-efficient.
When we evaluate the course of medical visualisation research, two notions are of special interest. The first notion is that medical visualisation techniques often face difficulties in the introduction to clinical practise (Preim and Bartz, 2007). The added value of 3-D visualisations to common 2-D representations is sometimes disputable, especially since the conversion may occlude significant details in the data. With the development of new visualisation systems comes the responsibility to validate results. Clinicians, on the other hand, should keep in mind that all imaging modalities are supportive instruments that are sometimes inconclusive. Future medical visualisation solutions should assist clinicians in this, for example by visualisation of uncertainty (Pang et al., 1997).

A second interesting notion is that the academic value of medical visualisation is sometimes disputed (Van Wijk, 2005). Medical visualisation seldomly follows a scientific model that starts with a hypothesis other than the hypothesis that the clinical problem can be addressed with a visualisation system. In addition, there are often multiple solutions to the research question, the effectiveness of solutions being subjective.

One could argue that the scientific aspect of medical visualisation lies in its underlying principles and techniques. The Visual Information-Seeking mantra by Shneiderman is an example of such a principle, teaching us how to cope with large amounts of data when a visualisation method is built (Shneiderman, 1996). Other examples include research on colour coding (Christ, 1975), perception analysis (Tory and Möller, 2004) and visual encoding principles that deal with the applicability of visual channels (e.g. colour, size, shape, etc.) in conveying information (Mackinlay, 1986). Closely related are the effects of the human visual working memory on user performance regarding 2-D, 3-D and multi-view approaches (Plumlee and Ware, 2006). A last example is the work by Munzner, that deals with standardisation of visualisation grammar and the hierarchy of classes in visualisation research (Munzner, 2009). This provides researchers with a framework that allows them to more accurately describe their contribution to visualisation research.

The described fundamentals also apply to medical visualisation applications. It is conceivable that the data characteristics in combination with our perception and working habits imply that certain approaches are to be preferred above others, depending on the visualisation problem. Future research includes the study of systematic approaches in solving these visualisation problems, for example, by means of a decision tree. In this way, applied medical visualisation benefits from fundamental research, allowing clinical problems to be solved even more effectively.
General discussion