Summary and Answers to the questions

With the introduction of the Delta™ reverse prosthesis by Grammont from Dijon, in 1985, a new era began for the treatment of patients with massive unbalanced rotator cuff tears with arthritis. However, there are still some unsolved mechanical problems with this reverse shoulder prosthesis and the clinical results are variable and not always predictable. Therefore, in this thesis we performed a number of clinical and biomechanical studies and obtained more detailed information on the motion pattern and force-generating capacity of shoulders in patients with a Reverse Shoulder Arthroplasty (RSA) and correlated these data with the clinical outcome. Furthermore, new developments and future potentials of this relatively new and still evolving prosthetic design are discussed, to create a more stable, better predictable and more consistent result in this patient population.

Chapter 1 provides a general introduction to the topic and raises a number of research questions to be addressed in the subsequent chapters.

In Chapter 2, in a biomechanical study, the active and passive kinematic motion pattern, with special attention to their differences, was measured in 19 primary Reverse Shoulder Arthroplasties (RSA) and 20 primary Total Shoulder Arthroplasties (TSA), using the “Flock of Birds” (FoB) which is a six-degree of freedom electromagnetic tracking device (Ascension Technology Corp, Burlington, VT, USA) together with the MotionMonitor software (Innovative Sports Training Inc., Chicago, Illinois, USA) providing shoulder motion not only expressed as thoracohumeral (TH) motion, but also in the two components glenohumeral (GH) motion and scapulothoracic (ST) motion. There were no differences in passive Range of Motion (ROM) between the two types of prosthesis in both planes. However, primary TSA patients demonstrated more active ROM for the TH motion compared to primary RSA patients during forward flexion and abduction, but not during active axial rotations. By measuring both active and passive ROM, we found that the TSA showed an equal ROM during active and passive elevation in the scapular plane (abduction), while the RSA showed less excursion in the
active motion compared to passive motion in both sagittal and scapular plane. This demonstrates that patients with a TSA are better able to actively utilize the possible GH motion of the prosthesis, which approaches the motion pattern of a normal shoulder.

However, when considering the contribution of the two different parts of the total motion (GH/ST motion, expressed as the GH/ST ratio), although both types of prostheses behave differently, interestingly enough the ratio’s were comparable but different from normal shoulders, thus showing that shoulders with either prosthesis generally do not perform as normal shoulders.

**Chapter 3**, is also a biomechanical clinical study, comparing the difference in force generating capacity of 18 primary RSA patients (21 shoulders) and 12 primary TSA patients (14 shoulders), measured with an isokinetic dynamometer, the Biodex System 3 Pro (Biodex Medical Systems, New York, NY, USA) and correlating the obtained joint torques to the post-operative clinical outcome, measured with the Constant-Murley score. The relatively low velocity of 60º per second, used for this study, appeared to be too high for a lot of the RSA patients, especially for the rotation tasks, but not for the TSA patients. The RSA patients demonstrated significantly lower joint torques for both protocols (abduction/adduction and external/internal rotation) compared to TSA patients, which is probably caused by the absence of the rotator cuff muscles in RSA patients. In RSA patients the external rotation torques are strongly correlated to the post-operative subscores of the Constant-Murley score activity, mobility and strength, demonstrating that active external rotation is essential for a good clinical outcome. For TSA patients all joint torques are only moderately to strongly correlated to strength.

In **Chapter 4**, the shoulder kinematics with special emphasis on the ST contribution in the total shoulder motion were measured in 17 patients (20 shoulders) with a TSA and 8 patients (9 shoulders) with an RSA as well as in 15 healthy individuals, during rehabilitation exercises (anteflexion and elevation in the scapular plane) using 3 different loading conditions (without
external load, 1kg load and elastic resistance). The excursions were measured till 90° of elevation/abduction, using the "Flock of Birds" (FoB) electromagnetic tracking device. Compared to the healthy subjects, RSA and TSA patients were demonstrating a larger scapulothoracic contribution to the shoulder motion in all 3 scenarios. By adding the external load, the scapulothoracic contribution became larger both in the healthy subjects as well as in the RSA and TSA patients. The type of load (elastic resistance (teraband) or 1 kg dumbbell) did not make any difference. Following these data it can be expected, that during arm movements in a shoulder rehabilitation program, patients with a shoulder arthroplasty will demonstrate more scapulothoracic motion, compensating for the loss of glenohumeral motion and provoked by the external load.

In Chapter 5, a clinical prospective study, the difference in clinical outcome as well as complication rate between RSA and TSA used in revision surgery was evaluated by obtaining clinical outcome scores (Constant-Murley, Disability of Arm Shoulder and Hand score (DASH), Simple Shoulder Test (SST), Oxford Shoulder Score (OSS) and SF-36). The indication for revision was divided in 2 groups: group 1) glenoid erosion or component loosening; group 2) infection, pain of undetermined origin or instability/soft-tissue problems. The post-operative clinical outcome scores demonstrated that generally revision surgery is associated with moderate clinical outcome and a high complication rate. TSAs do better than RSAs and revision for soft-tissue problems leads to inferior results compared to revisions for bone related problems. Consequently, it can be advised that in revision shoulder surgery, when the rotator cuff is still sufficient, it is worthwhile to try to revise to a TSA, because this will provide better post-operative results.

In Chapter 6, a kinematical analysis in 19 primary RSA and 16 RSA cases used in revision surgery was performed and differences were measured, using the “Flock of Birds” (FoB) electromagnetic tracking device. Furthermore, clinical outcome was measured by obtaining the Constant-Murley, Disability of Arm Shoulder and Hand score (DASH) and Simple
Shoulder Test (SST). Also the distance between the prosthesis and the acromion was measured on the AP post-operative radiographs. The kinematic analysis demonstrated that primary inserted prostheses have a significantly better glenohumeral motion in the sagittal and scapular plane compared to revision cases. However, the overall motion in the thoracohumeral plane was not different in the 2 groups. Therefore, this study is demonstrating that the difference in active ROM between primary and revision RSA cases is mainly taking place at the glenohumeral joint. In all the patients the Constant-Murley scores improved significantly post-operatively. Although we could not find any correlation with any of the kinematical parameters, we hypothesize, that soft-tissue contractures in revision cases play a role in the decreased glenohumeral motion in this group.

In Chapter 7, looking for another possible explanation, we evaluated the force generating capacity between 21 primary RSA and 16 RSA cases used in revision surgery, measured with the isokinetic dynamometer (Biodex System 3 Pro), correlating these findings with the post-operative clinical outcome, measured with the Constant-Murley, DASH, and SST. We compared the measured torque values with values of normal shoulders, obtained from the literature. The measurements were performed at the relatively low velocity of 60°/s, but this even proved to be too high for 35% of the patients. A difference in force-generating capacity was expected between the two groups in favor of the primary placed prosthesis. However, this could no be confirmed for the abduction and adduction tasks, because only 62% of the primary cases and 69% of the revisions cases were able to generate enough force to perform the tasks. When comparing the joint torques to normal shoulder values obtained from the literature, it can be concluded that RSA patients have significantly reduced strength in the shoulder. For abduction and adduction torque the strength was 19% to 78% of that of a normal shoulder and for external and internal rotation the strength was 13% to 71%. The correlation with the clinical outcome demonstrated moderately strong relationships, especially for external rotation. It is therefore likely that limited strength is a major factor in reduced ROM.
Following the success of the RSA, the indication for this type of shoulder arthroplasty is still expanded. In Chapter 8 we report the operative technique and the early to midterm results of a new, specially designed, reverse fracture shoulder prosthesis, in a multicenter prospective clinical study. Forty-nine consecutive patients (50 shoulders) of 70 years or older with a three- or four-part fracture of the proximal humerus and a minimal clinical and radiological follow-up of two years, were enrolled in this study. In all cases a cancellous bone graft was harvested from the fractured head and placed in the medial window of the prosthesis, together with a standardized technique for prosthesis positioning in height, retroversion and tuberosity fixation. The radiographic evaluation demonstrated greater tuberosity healing in 88% of the cases, which was significantly associated with better active external rotation. In comparison with the available literature, only one out of seven other studies, which used a standard RSA and where the tuberosities were also re-attached, reported similar results. Therefore, it can be concluded that in the elderly patient with a three- or four-part proximal humeral fracture, tuberosity healing can be achieved successfully with the use of the “low-profile” RSA for fracture stem.

ANSWERS TO THE SPECIFIC RESEARCH QUESTIONS

QUESTION 1: Is there a difference in ROM between RSA and TSA patients and where does this difference take place?

Kinematic analysis of primary RSA and TSA patients demonstrated that TSA patients have a better active ROM than RSA patients. By analyzing the passive ROM it is also demonstrated that in the sagittal plane TSA patients hardly show any difference between the active and passive ROM, suggesting that these patients better actively utilize the possible GH motion of the prosthesis.

QUESTION 2: Is the force generating capacity of RSA patients compared to TSA patients altered?
Isokinetic force measurements at a relatively low velocity of 60° per second in both patient groups demonstrate that the RSA patients have significantly lower joint torques for both protocols (abduction/adduction and external/internal rotation) which is probably caused by the absence of (part of) the rotator cuff muscles in RSA patients.

QUESTION 3: Does the application of external loads to the arm during rehabilitation exercises influence shoulder kinematics in RSA and TSA patients?

By analyzing the shoulder kinematics of RSA and TSA patients as well as healthy subjects during rehabilitation exercises (anteflexion and elevation in the scapular plane) using different loading conditions (without external load, 1kg and elastic resistance), it was demonstrated that by adding the external load, the scapular contribution of both the healthy subjects, and the RSA and TSA patients increased. The type of load (elastic resistance (theraband) or 1 kg dumbbell) did not make any difference.

QUESTION 4: Is revision surgery influencing the kinematics of the shoulder in RSA patients and where does this influence take place?

By analysing the kinematical difference between primary placed RSA cases and RSAs used in revision surgery, it was demonstrated that primary placed prosthesis did not have a better thoracohumeral motion in the sagittal and scapular plane compared to revision cases. The glenohumeral motion on the contrary, showed a significant difference in favor of the primary placed prosthesis. Therefore, it can be concluded that revision surgery is negatively influencing the ROM of RSA patients, mainly due to a decreased glenohumeral motion.

QUESTION 5: Does revision surgery alter the force generating capacity of RSA patients?

We hypothesized that there would be a difference in force-generating capacity between primary and revision RSA cases, in favor of the primary placed prosthesis because of the reported lower improvement in function and higher complication rate in revision cases and the results mentioned in Chapter 6. However, by measuring the isokinetic force generating
capacity this could no be confirmed for the abduction and adduction tasks, mainly because only 62% of the primary cases and 69% of the revisions cases were able to generate enough force to perform the tasks, demonstrating similar joint torque values. For that reason it cannot be concluded that revision surgery alters the force generating capacity of RSA patients.

QUESTION 6: *Is greater tuberosity healing facilitated by the use of a specific reverse shoulder fracture-prosthesis and does this provide better active external rotation?*

By evaluating the clinical and radiological results of the specially designed, reverse fracture shoulder prosthesis used in the treatment of three- and four-part proximal humeral fractures in patients of 70 years of age or older with a minimum follow-up of two years in a multi-center prospective study, it was demonstrated that in 88% of the cases greater tuberosity healing was obtained, which also was significantly associated with better active external rotation.