Shoulderprostheses: clinical and biomechanical aspects

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ABSTRACT - Replacement of a shoulder joint with an endoprosthesis is very effective for the relief of pain. The improvement of motion and function is limited. An important causative factor may be the change of the position of the rotation centre of the new glenohumeral joint. This is substantiated by an electomyographic study of the shoulder muscles after replacement of the humeral head and by simulations in a biomechanical model of the shoulder.

INTRODUCTION

After replacement of the shoulder joint the pain will disappear but the range of motion and the function will be limited. In the literature several causative factors are mentioned for the limitation of the range of motion. In the rheumatoid shoulder the rotator cuff is often degenerated, thinned or ruptured by the infiltration of the rheumatoid tissue. Another factor is sometimes the changed position of the geometric centre of the humeral head and the centre of rotation caused by the altered geometry of the glenohumeral joint after the replacement. In other patients one may see a disturbance of the scapulohumeral rythm. The importance of these factors was studied in a patient population who had had a replacement of the shoulder. The biomechanical aspects were studied in a three dimensional musculoskeletal model of the shoulder.

MATERIALS AND METHODS

Since 1979 125 shoulder arthroplasties were performed in the University Hospital Leiden. In 26 patients the diagnosis was osteoarthritis, in 81 rheumatoid arthritis and 18 patients had a degenerated shoulder as a late sequel of a fracture. For the clinical evaluation the global scoring system of the Hospital for Special Surgery was used. This 100 point scoring system allocates 30 points to pain, 25 points to power, 25 points to motion and 20 points to function. All patients were scored preoperatively and at regular intervals afterwards.

In another group of patients EMG recordings were made from 12 shoulder muscles during abduction movement (Daanen et al, 1988). Implantation of a humeral head prosthesis is an accepted treatment in the elderly patient for a displaced four part fracture of the proximal humerus. The range of motion after hemi-arthroplasty for a displaced four part fracture tends to be somewhat disappointing. With electromyography we tried to evaluate the function of the shoulder muscles as a possible limiting factor. Nine patients with a Neer type I prosthesis and an intact rotator cuff (checked with arthrography) were electromyographically studied.

During abduction in the scapular plane, EMG recordings were made of 12 muscles:

- M. latissimus dorsi,
- M. trapezius p. descendens,
    - p. transversum,
    - p. ascendens,
- M. deltoideus p. anterius,
    - p. medius,
    - p. posterior,
- M. pectoralis major (p. sternalis),
- M. serratus anterior,
- M. infraspinatus + M. teres minor,
- M. teres major and
- M. supraspinatus.

Simultaneously the abduction angle was recorded by an electronic goniometer attached to the elbow. Wire electrodes were used for the supraspinatus muscle and surface electrodes for the other muscles. The abduction angle was monitored with an electronic goniometer.

The exact localization of all the electrodes was checked during the experiment by test registrations of each muscle contracting against resistance, and afterwards by calculating the cross-correlation function of the recorded signal to estimate the amount of cross-talk.

A preamplifier attached between the shoulders amplified the signal 100 times. Further variable amplification was achieved with a main amplifier. When the patient was 'wired up', three abduction movements in the scapular plane ware recorded up to maximal abduction for the prosthetic and normal shoulder. The registrations were stored on a 14-channel instrumentation recorder. Subsequently, these registrations were sampled at 1,000 times per second for every channel and low-pass filtered at 500 Hz. With a PDP 11/70 computer the EMG was rectified and averaged.

The influence of a changed geometry of the glenohumeral joint on the function of the muscles after performance of a shoulder arthroplasty was studied

Table 1- *Clinical results of 31 total shoulder replacements in rheumatoid patients expressed in the HSS global score.*

Clinical results	**total score**	pain max=30	power max=15	function max=30	motion max=25
preoperative	38	8	12	10	8
follow-up 1 yr	68	29	13	19	10
follow-up > 2 yrs	71	26	12	21	11

clinically (Rietveld et al, 1988) and in a three dimensional musculoskeletal model of the shoulder (Leest et al, 1996). This shoulder model was developed at the section Man Machine Systems Group of the Delft University of Technology (Helm et al, 1992).

The design of the humeral and glenoid components, as well as the placement of these components at the time of surgery determine the geometry of the new glenohumeral joint and especially the position of the centre of rotation (Figure 1). Because the glenoid component and the ball of the humeral component were modelled as a ball and socket the centre of rotation coincides with the geometrical centre of the glenohumeral joint. The articular surface of the humeral head is part of a sphere which is described by a centre and a radius. The position of this centre in relation to the humeral shaft is often changed at the time of surgery by removing the humeral head and the glenoid surface and replacing is with a prosthesis. The thickness of the prosthetic humeral head that can be used is dependent on the space left after removal of the diseased head at the time of surgery. The radius and the thickness of the prosthetic head will influence the position of the centre of rotation relative to the humeral shaft.

RESULTS

Clinical improvement

The clinical status of the patient was expressed in a global score. From the 125 shoulder arthroplasties a subgroup was selected which consisted of patients with rheumatoid arthritis with a total shoulder arthoplasty including a glenoid and humeral component and a follow-up of more than 2 years. In this group of patients the average pre-operatieve HSS-score was 38 points, the score at one year follow-up was 68 points and at two years follow-up 71 points. The maximum score which could be reached on the HSS scale is 100 points. The pain relief in this group of patients was very good and almost all of them score maximum on the pain score which meant no pain on motion and no pain at rest (Table 1). The improvement of the range of motion is disappointing. At follow-up of two years or more the average abduction angle that could be reached was only 60 degrees and the average flexion angle 69 degrees (see Table 2). For this age group one would expect an abduction and flexion angle of almost 160 degrees.

Radiographic aspects

Of the group of 125 shoulder arthroplasties the radiographs of 81 shoulders were studied carefully for signs of loosening. Fifty-four had a total shoulder arthroplasty and twenty-seven a hemi-arthroplasty. Of the fifty-four glenoid components thirty-five components were fixed with cement and of the eighty-one humeral components nine were fixed with cement. The follow-up ranged from 3 to 163 months with an average of 31 months. Radiolucent lines around the cement of the humeral component were seen in three shoulders but in only one shoulder there was a progression of the radiolucency. In eight shoulders the position of the humerus component in the bone was changed, which is a sign of loosening. A complete or incomplete radiolucent line around the glenoid com-

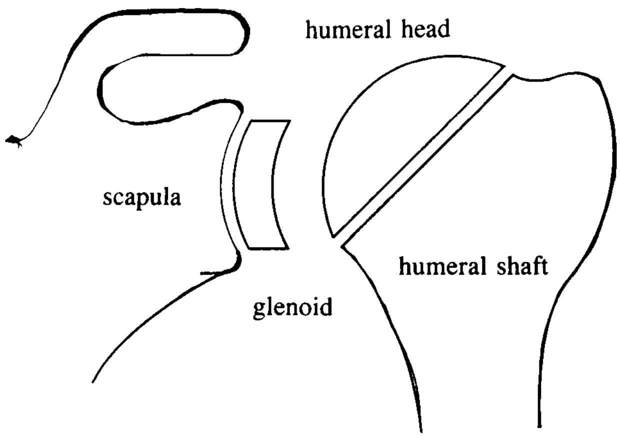

Figure 1 - *Schematic drawing of a glenoid and humeral component of a shoulderprosthesis.*

Table 2 - *Range of motion of 31 shoulder replacements*

Range of Motion	abduction (CI)	flexion (CI)
preoperative	46 ° (40.0-52.8)	59 ° (49.6-68.0)
follow-up 1 yr	56 ° (47.1-64.4)	70 ° (60.3-80.4)
follow-up > 2 yrs	60 ° (50.9-69.5)	69 ° (56.5-81.7)

CI:Confidence Interval

ponent was seen in thirty shoulders. And in twenty-two shoulders the radiolucency was progressive which is indicative for loosening.

ELECTROMYOGRAPHY

In nine shoulders with a hemi-arthroplasty for a displaced four part fracture the function of the shoulder muscles was evaluated as a possible limiting factor for a good range of motion. In all these shoulders the rotator cuff was intact. For two patients the results were rated as excellent, for three as satisfactory and for four patients as failures. In the failure group the distance from the geometric centre of the humeral head replacement to the greater tuberosity was found to be smaller than in the excellent group. This affects the lever arm of the glenohumeral abductor muscles.
In the shoulders that were clinically scored as a failure the muscles showed a sudden burst of ac-

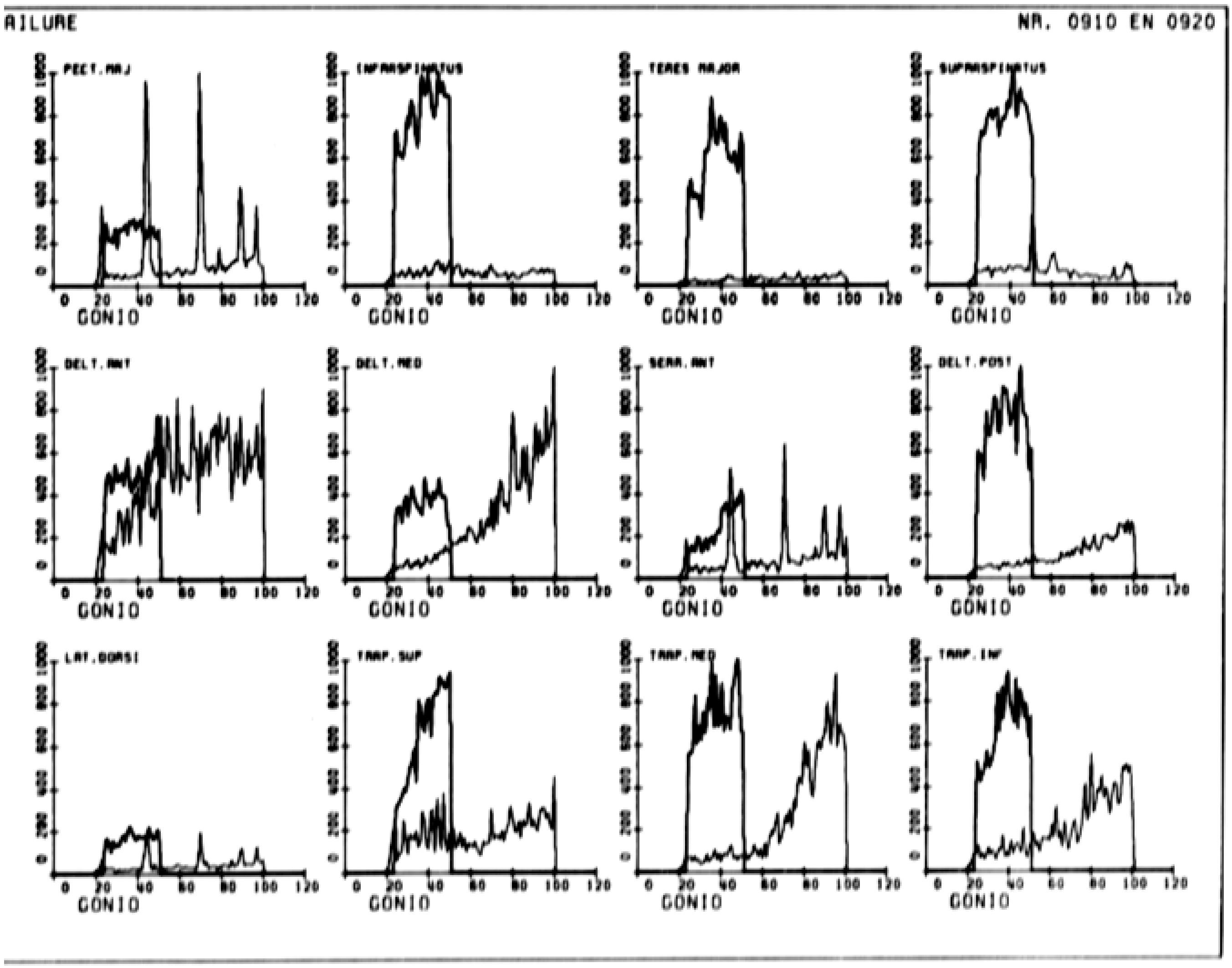

Figure 2 - The integrated EMG of 12 shoulder muscles. The lines idicate the difference in EMG between the operated shoulder and the non-operated shoulder against abduction. The solid lines represent the shoulder with a replacement of the humeral head.

tivity making active abduction of the arm impossible although passively there was a sufficient range of motion.
During abduction in the scapular plane the most remarkable differences in EMG were found in the rotator cuff muscles and the laterorotators of the scapula (Figure 2). There was no difference in the increase between the healthy shoulders and operated shoulders with an excellent or satisfactory result. In every subject the reproducibility of the EMG to angle relation was remarkably high.

BIOMECHANICAL STUDY

Glenoid

The placement of the articular surface of the glenoid after replacement of the glenoid with a prosthesis was performed by modelling the original glenoid at four different planes by shifting it in medial and lateral direction. In each plane a grit was attached to the glenoid and the geometric centre was modelled in each plane on 9 different positions. The optimal position of the glenoid component occurs if the glenoid is displaced medially, inferiorly and posteriorly. The medial displacement corresponds clinically with a severely eroded glenoid and a lateral displacement with a thick glenoid component. At surgery the glenoid component may be placed in a tilted position because the bone of the glenoid is eroded away. To mimic this situation the glenoid was tilted 20° in different directions. The optimal glenoid direction was 20° tilting anteriorly and inferiorly. An unfavourable direction was if the glenoid was redirected superiorly and posteriorly.

The position of the geometric centre of the prosthetic humeral head in relation to the humeral shaft can be changed by varying the radius and thickness of the humeral head prosthesis and by changing the position of the humeral head in relation to the humeral shaft. The most favourable position is a placement of the geometric centre in a postero-inferior direction in relation to the humeral shaft. An anterior-superior placement of the geometric centre in relation to the humeral shaft is very unfavourable and in this position more muscle force is needed for movement. When replacing a humeral head with a prosthetic head the prosthetic head may have a different radius. In that case if the thickness of the prosthetic humeral head is the same as the amount of bone removed from the humeral head the position of the centre of rotation in relation to the humeral shaft will change. To keep the centre of rotation relative to the humeral shaft at the same place or the same radius or a different thickness of the prosthetic head has to be used. In the calculations the optimal radius of the prosthetic head appears to be the same as the original radius of the humeral head. The use of a thick head with a large radius to increase the lever arm of the muscles appears to be unfavourable in the calculations probably by the negative effect of the lateral displacement of the humeral shaft in relation to the glenoid. This effect is the same as placing the glenoid surface more laterally, an unfavourable situation which was discussed earlier.

DISCUSSION

The replacement of the shoulder joint has not yet reached the level of succes of the endoprosthetic replacement of the hip and the knee. The range of motion after shoulder replacement is often disappointing even when the rotator cuff muscles are intact. In the electromyography study it was shown that for a proper functioning of the rotator cuff muscles the position of the centre of rotation after an arthroplasty is of utmost importance. This aspect was studied in a biomechanical model of the shoulder. The position of the centre of rotation after an arthroplasty is determined by the design of the prosthesis and the placement of the components at surgery. The finding that the smallest criterion values in the model produces a favourable functional situation emphasizes the importance of the geometry of the new glenohumeral joint and the position of the centre of rotation. Some recommendations could be made about the position of the head in relation to the humeral shaft and the position of the glenoid component in relation to the glenoid bone. Those findings from the biomechanical study still have to be validated in a clinical study.

With regard to the design of the shoulder prosthesis the fixation of the glenoid component remains a concern. Progressive radiolucent lines, a sign of loosening is seen in almost 50% of the cemented glenoid components. The fixation may be improved by using a better surgical exposure and modern cementing techniques. Another option is the use of uncemented glenoid components. Those uncemented components are not yet widely used but just like prosthesis of the hip and the knee they might be an improvement. For an improved design of an uncemented glenoid component the charataristics of the glenoid must be studied more extensively with regards to the biomechanical properties, the bony architecture and the interaction between the prosthesis and the bone. Our research will be focused in the near future on those aspects.

REFERENCES

Daanen HAM, Rozing PM, Rietveld ABM. Functional assessment of the shoulder with electromyography. *Rev Surg Rheumatoid Arthritis. Rheumatol* 1990;13:164-71.

Helm FCT van der, Veeger HEJ, Pronk GM, Woude LHV van der, Rozendal RH. Geometry parameters for musculoskeletal modelling of the shoulder system. *J Biomech*. 1992; 25(2): 129-144.

Leest O de, Rozing PM, Rozendaal LA, Helm FCT van der. Influence of glenohumeral prosthesis geometry and placement on shoulder muscle forces. *Clin Orthop* 1996; 330: 222-233.

Rietveld ABM, Daanen HAM, Rozing PM, Obermann WR. The lever arm in glenohumeral abduction after hemi-arthroplasty. *J Bone Joint Surg* (Br) 1988; 70B: 561-565.