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Features of Biomechanics and Rehabilitation of the Shoulder Joint after Reverse Arthroplasty: a Review

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ABSTRACT

Reverse shoulder arthroplasty is one of the methods used to treat shoulder joint diseases. The indications for this type of surgery are as follows: clinically expressed arthrosis, including defect arthropathy, rheumatoid arthritis, fracture–dislocation and fractures of the humeral head, oncopathology of the shoulder joint, avascular necrosis, massive rotator cuff tear and dysfunction of the previously installed prosthesis. To date, various models of reverse endoprostheses based on the principles of P. Grammont are used in clinical practice. Shoulder joint arthroplasty is now being used more and more frequently worldwide. The number of shoulder joint replacement surgeries is expected to increase by more than 200% by 2025. One of the features of reverse arthroplasty is the change of the polarity of the articular surfaces. The design of the prosthetic implant significantly changes the biomechanics of the shoulder joint. Different variations of the design parameters affect the functioning of the joint. In order to achieve optimal volume of movement, it is necessary to carefully select the following characteristics of the implant: the diameter of the glenoidal sphere, the displacement of the scapular component, the displacement of the rotation center and the change in the angle of inclination of the neck of the shoulder component. Understanding the biomechanical features of the shoulder joint after reverse endoprosthetics makes it possible to determine the optimal approach to the rehabilitation treatment of patients after surgery. The main goals of rehabilitation after reverse arthroplasty are: pain minimization and ensuring the healing of postoperative wounds, prevention of postoperative complications (dislocations and periprosthetic fractures), gradual progress of the shoulder motion range, increasing the strength and endurance of the muscles of the shoulder girdle, especially the deltoid muscle. Despite the existence of standard protocols, there are differences in many issues related to postoperative management of patients. This topic needs further development.

KEYWORDS: reverse shoulder arthroplasty, glenosphere, humeral component, defect arthropathy, shoulder joint, biomechanics, rehabilitation, physiotherapy, muscle strength, muscle endurance, range of motion

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Особенности биомеханики и реабилитации плечевого сустава после реверсивного эндопротезирования: обзор

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РЕЗЮМЕ

Реверсивное эндопротезирование является одним из методов хирургического лечения заболеваний плечевого сустава. Показаниями для проведения данного вида операции являются: клинически выраженный артроз, в том числе дефект артропатия, ревматоидный артрит, многофрагментарный перелом и переломовывих головки плечевой кости, онкопатология плечевого сустава, аваскулярный некроз, массивный разрыв вращательной манжеты и дисфункция ранее установленного протеза. На сегодняшний день в клинической практике применяют различные модели реверсивных эндопротезов, основанных на принципах P. Grammont. Наблюдается рост частоты проведения реверсивной артропластики плечевого сустава во всем мире. Ожидается увеличение количества операций эндопротезирования плечевого сустава к 2025 г. более, чем на 200%. Особенностью реверсивного протеза является смена полярности суставных поверхностей. Конструкция протезного импланта вносит существенные изменения в биомеханику плечевого сустава. Различные вариации параметров конструкции оказывают влияние на функционирование сустава, поэтому для достижения оптимального объема движения необходим тщательный подбор таких характеристик, как: диаметр гленоидальной сферы, смещение лопаточного компонента, смещение центра ротации и изменение угла наклона шейки плечевого компонента. Понимание биомеханических особенностей плечевого сустава после реверсивного эндопротезирования позволяет определить оптимальный подход к восстановительному лечению пациентов после операции. Главными целями реабилитации после реверсивного эндопротезирования являются: обезболивание и обеспечение заживления послеоперационных ран, профилактика послеоперационных осложнений (вывихи и перипротезные переломы), разработка объема движений в суставе, увеличение силы и выносливости мышц плечевого пояса, в особенности дельтовидной мышцы. Несмотря на наличие стандартных протоколов, существуют разногласия во многих вопросах послеоперационного ведения пациентов. Данная тема нуждается в дальнейшей разработке.

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INTRODUCTION

Reverse shoulder replacement (arthroplasty) is the gold standard for the final stage of arthritis, including arthritis caused by massive tears of the rotator cuff of the shoulder (defect arthropathy) and rheumatoid arthritis, multifragmentary fractures and fracture–dislocation of the humeral head, oncopathologies of the shoulder joint, avascular necrosis and massive tears of the rotator cuff without arthritis, and in cases of unsuccessful arthroplasty with an anatomical prosthesis [1-7].

The first generation of Delta reversible prostheses based on the concept of medialization and reduction of the center of rotation proposed by P. Grammont and E. Baulot was introduced into clinical practice in 1987 and described in detail in 1993 [8, 9]. Since 1994, a new generation of endoprostheses (Delta III), has been in place and is the most widespread in the world. It is still considered the "gold standard" of reversible arthroplasty and is the prototype for the development of all subsequent reversible systems. Currently, various models of reversible endoprostheses based on the principles of P. Grammont are used in the clinical practice. The absence of motion range limitation and preservation of joint stability are important conditions. For this reason, the designs of the different endoprostheses provide a balance between the various parameters that increase motion range and joint stability. There are at least 29 designs that differ in these parameters [10, 11].

In November 2003, the Food and Drug Administration (FDA) approved reverse arthroplasty in the United States [12]. Between 2011 and 2017, the rate of reverse shoulder arthroplasty increased by 191.3%, and from 2017 to 2025, the number of shoulder arthroplasties per year is predicted to increase by ~235% [13].

Reverse prostheses include two components: a humeral component and a scapular (glenoid) component. However, in contrast to the normal anatomy of the shoulder joint, the scapular component in this prosthesis is a sphere and the humeral head is replaced by an articular cup [14]. For this reason, this type of prosthesis is referred to as a reverse prosthesis.

The scapular component of the endoprosthesis is a spherical surface fixed in the bone tissue with a central screw of the glenoidal sphere holder and four lateral screws directed sideways at an angle of 10º relatively to the central screw. The humeral component is represented by a cup fixed on a stem inside the diaphysis of the humerus [15].

Performing reversible arthroplasty introduces significant changes in the biomechanics of the shoulder girdle. A number of researchers note a decrease in muscle strength of the shoulder girdle after arthroplasty: reduction of deltoid muscle strength by ~30% and insufficiency of internal and external rotation of the shoulder joint [16-18]. This necessitates rehabilitation measures to restore the shoulder joint function, with the recovery depending largely on the implant design [19-21].

However, currently, there is no common approach to the rehabilitation of patients after reverse shoulder arthroplasty.

Influence of endoprosthesis design on shoulder biomechanics

Considering the influence of reverse shoulder endoprosthesis design, it should be noted that an increase in the range of motion in the joint is influenced by: an increase in the diameter of the glenoid sphere, eccentric displacement of the scapular component, lateralization of the rotation center and a decrease in the angle of the neck of the humeral component [11, 19, 22-25]. The so-called semi-constrained prosthesis principle has been proposed to increase the range of motion even further. This principle consists in increasing the relative diameter of the glenosphere relatively to the cup of the humeral component. The surface area of the humeral component covers less than half of the hemisphere of the glenoid component.

The so-called scapular notching syndrome (bone tissue erosion due to collision with endoprosthesis components) is a factor leading to the limitation of the range of motion [25, 26].

Since the range of motion in the joint is maximally preserved and the function of the rotator cuff muscles is lost due to a trauma or surgery, the risk of dislocation of the joint increases. The stabilization of the shoulder joint is affected by prosthetic parameters, such as an increase in glenoid diameter, medialization of the center of rotation and an increase in the size of the cup of the shoulder component [22, 24, 25].

Principles of the Reverse Shoulder Endoprosthesis

The latest generation of reverse systems is based on the following principles proposed by P. Grammont:

- Medialization of the center of rotation in relation to a normal joint;
- Increasing the role of the deltoid muscle in shoulder joint movement;
- Stabilization of the endoprosthesis components in the bone tissue;
- Increasing of the scapular component diameter relatively to the humeral component to provide greater articular mobility.

In contrast to the normal shoulder joint, where the rotation center is predominantly in the region of the humeral head, after reverse shoulder arthroplasty the rotation center is medialized and located in the region of the scapular component within the entire range of motion, regardless of the plane. [27]. This feature positively affects the stability of the joint by increasing the pressing force of the humerus cup against the scapular hemisphere due to the tension of the deltoid muscle.

The deltoid muscle fibers start from the spine of the scapula, acromion and distal part of the clavicle, pass through the humerus head, and are attached to the deltoid tuberosity. Thus, the projection of the rotation center of the normal shoulder joint is in the region of the deltoid muscle center. Therefore, the three deltoid muscle bundles are involved in different movements: abduction, adduction, flexion, extension, and rotation [27].

In contrast to the anatomy of the normal shoulder joint after reverse arthroplasty, all bundles of the deltoid muscle are located above the center of rotation. The efficiency of this muscle during abduction increases. This compensates for the function of shoulder abduction initiation provided by the supraspinatus. In all other movements, however, the role of this muscle decreases. [28].

In reverse endoprosthetics, the humeral head is removed, so the deltoid muscle fibers are stretched from the acromion to the deltoid tuberosity directly. Due to the relative extension of the humerus, the tension of the deltoid muscle increases even more, which leads to an increase in compressive forces directed towards the scapular component of the endoprosthesis. Thus the stabilization of the shoulder joint is ensured.

The structure of the prosthesis components is specifically designed to maximize fixation in the bone tissue. The scapular component, which is particularly sensitive to possible misalignment, is fixed in position by a central screw and four screws pointed in different directions at an angle of 10° from the central screw. This way it is firmly fixed in the scapular bone. The humeral component is less prone to displacement force. That is why fixation by means of a wide stem inside the diaphysis of the humerus is sufficient.

In reverse arthroplasty, the force vectors acting on the shoulder joint change. When considering these forces, two dominant directions are identified: the compressive force and the shear force. These forces are formed due to the tension of the deltoid muscle [25].

Due to the shear force, the articular surfaces slide against each other without rotation, which increases the risk of dislocation and destabilization of endoprosthesis components in the bone tissue. In contrast, compressive forces stabilize the articular components in the bone tissue and the joint as a whole. The compressive and shear forces in reverse arthroplasty reach their maximum at 60º-70º of abduction or more, whereas in a normal shoulder these forces are maximal at 90º [19].

The more the articular pair is shifted medially, the more pronounced is the compressive force of the deltoid muscle. Thus, medialization of the rotation center increases the stability of the endoprosthesis components in the bone tissue [25].

Another significant factor influencing the stabilization of the implant in the bone is the initial density of the bone tissue. This factor is important for the patients with osteoporosis [19].

Subscapularis repair

The function of the shoulder joint is influenced by the subscapularis, so it is important whether the muscle was repaired during reverse arthroplasty or not. Vourazeris J. et al. compared groups of patients with and without recovery of the scapular muscle after the reverse arthroplasty and found no significant differences in range of motion (external rotation 24° and 26°, respectively) in the shoulder joint, as well as muscle strength and frequency of postoperative complications. No differences were found in the upper limb functional scores according to scale questionnaires (ASES, SPADI, UCLE, Constant) [29]. However, shoulder internal rotation scores improved significantly in patient groups with restored subscapularis [30-31]. A newer study confirms the positive effect of subscapularis repair on the upper limb functional activity according to Constant score [31].

Role of the scapula in shoulder movement

Proper scapular movement is important for the normal functioning of a healthy shoulder [32]. But, with total endoprosthetics, its role increases. Joelly Mahnic de Toledo et al. [33] showed that with the same range of motion, patients after shoulder arthroplasty will have more expressed scapular movements, compensating for the loss of shoulder joint (prosthesis) motion even at low angles (i.e., up to 90° of abduction). In addition, the scapular kinematics of patients with shoulder arthroplasty are also affected by additional resistance (1 kg dumbbell or elastic band resistance). For this reason, patients are expected to demonstrate more expressed scapular functioning during arm movements with both types of load.

Electromyographic analysis showed that the shoulder girdle with reverse endoprosthesis has more expressed muscle activation of the deltoid and trapezius muscles compared to a healthy joint. It is worth noting that this excessive muscle activation is not normal, and, ultimately, muscle functioning efficiency is decreased [34].

Understanding the biomechanical features of the shoulder joint after reverse arthroplasty makes it possible to reduce the probability of complications, increase the efficiency of muscle adaptation to loads, stabilize the joint, and determine the optimal approach to the recovery treatment of patients after surgery [35].

Modern rehabilitation methods

Enhanced Recovery after Surgery (ERAS), a protocol that involves the use of multidisciplinary, comprehensive programs to improve the recovery outcomes of patients, has been increasingly used recently. The main goal of ERAS is to provide a faster and more effective recovery of patients using methods approved by evidence-based medicine [36].

According to several rehabilitation protocols, the most important concepts of postoperative management of patients with reverse endoprosthesis are: pain management and ensuring healing of postoperative wounds, prevention of postoperative complications (dislocations and periprosthetic fractures), development of range of motion, increasing strength and endurance of shoulder girdle muscles, especially the deltoid muscle. In clinical practice, these protocols are considered standard [37-43].

Rehabilitation after reverse shoulder arthroplasty can be divided into several stages. The first (early postoperative) stage lasts from three to six weeks after the surgery. During this period, the main goals are to reduce swelling and pain, maintain movement in the wrist and elbow joints, gradually begin passive movements in the shoulder joint, prevent atrophy and atony of the shoulder girdle muscles and prevent early postoperative complications. One of the frequent early postoperative complications after reverse arthroplasty is prosthetic dislocation, which, according to various estimates, occurs in 0.7-8.3% of cases [44, 45]. Endoprosthetic dislocations occur on average eight weeks after the surgery. Risk factors for this complication include male gender, fracture of the proximal humerus as an indication for reverse arthroplasty, and a anamnesis of prior open shoulder surgery [46]. Other risk factors have also been noted: insufficient soft tissue tension (muscle atony or hypotension) and heterotopic ossification [47]. Removal of the scapular muscle independently led to prosthesis instability. The authors point to the need for careful monitoring and prevention of postoperative dislocation of the shoulder joint. It is important to avoid rotation and extension of the shoulder joint (putting the arm behind the lower back), as this can lead to dislocation.

The first stage involves resting the operated joint and relieving pain syndrome. Immobilization of the shoulder joint using bandages of different types and designs is used to provide rest. There are 3 main types of immobilizers: the simple sling [48], the shoulder immobilizer [49], the abduction sling [50]. The immobilization lasts for up to three weeks (or six weeks in the case of revision arthroplasty). After this period the bandage is gradually removed. The arm is fixed primarily during sleep and is released for exercise (passive movements) or for hygienic procedures. Currently, there are disagreements as to the choice of design and time of shoulder immobilization [21].

In reverse arthroplasty, the recovery of motion range begins during the first week. At all stages, movement development is carried out within the pain-free range of motion. Mechanotherapy is one of the main methods of physical rehabilitation for the development of passive movement in the shoulder joint [50]. From about the third week, patients begin to perform exercises on their own: pendulums and seated flexion table slides (using a table or a couch). Also, at this stage it is mandatory to perform isometric exercises for the deltoid muscle.

From the fourth to sixth week, active movements of the shoulder girdle are taught and passive movements in the shoulder joint begin to progress (angle of passive motions is gradually increased). Patients begin gradual initiation of periscapular muscle activation. At this stage the shoulder joint exercises include shoulder supine flexion. It is recommended to gradually expand the range of active movements by means of the so-called active assistive exercises. The Edwards P. et al. study compared the effectiveness of delayed (standard rehabilitation protocol) and early rehabilitation of patients. The inclusion of active assistive and isometric exercises in the rehabilitation program from the second week (rather than the fourth to sixth week) resulted in an improvement in active shoulder flexion by the third month. However, no significant differences were found in clinical outcomes compared with patients, who underwent delayed rehabilitation. Nevertheless, rehabilitation with early activation of the shoulder joint is safe and has advantages over the delayed program, accelerating the recovery process [51].

During the second stage of rehabilitation (the late postoperative stage) patients stop using immobilizers and continue to progress the range of active motion in the shoulder joint in all planes. Patients are encouraged to actively use the operated arm in everyday life. Also, at this stage a gradual increase in the passive motion range of internal rotation in the scapular plane begins. In standard protocols, this stage begins approximately from the sixth to seventh week after surgery.

At the same time, Lee J. et al. and Edwards P. et al. found that it is effective for patients to start early (24-48 hours after surgery) initiation of shoulder joint motion range progress and to stop wearing a restrictive bandage. This is effective for rapid recovery of shoulder joint function and prevention of such postoperative complications as traumatic periprosthetic fractures of bones caused by an unwanted fall and dislocation of endoprosthesis. The absence of an orthosis helps patients to maintain balance (this is especially true for the elderly), and also increases proprioception of the operated joint. [20, 51]. This approach correlates with the principles outlined in the ERAS protocols, one of the key components of which is the early activation of patients.

From the ninth week onward, patients proceed to the third stage – the training stage. At this stage it is recommended to start muscle strengthening exercises with the help of additional resistance (elastic bands, dumbbells, training machines, mechanotherapy complexes). Special attention should be paid to the deltoid muscle. As mentioned above, this muscle plays a special role not only in providing active movements in the shoulder, but also in stabilizing the articular endoprothesis components in the bone tissue and relatively to each other. Despite the differences in data from various studies, there is no doubt about the importance of recovering the strength of the shoulder muscle apparatus after the reverse arthroplasty. Moreover, a number of studies have shown that the limitation of motion range in the shoulder joint is caused by weakness of the musculature. Brett P Wiater et al. emphasized the importance of the deltoid muscle function, reporting that patients with greater volume of this muscle and less fat infiltration had better functional results and strength after reverse arthroplasty [16, 52, 53]. The special features of the shoulder joint biomechanics related to the significant contribution of the scapula to the shoulder joint range of motion emphasizes the importance of recovering the periscapular muscle strength and coordination in this muscle group [32].

The data on the outcomes of rehabilitation after reverse shoulder arthroplasty are currently very disparate. The effectiveness of the standard course of rehabilitation has been presented in a few studies [17, 20, 40, 42, 51, 54]. For example, an increase in the shoulder joint range of motion after a standard course of rehabilitation has been reported [17, 20, 40, 42, 51, 54]. However, Pereira V. et al. indicated a deterioration in such parameters as internal rotation, extension and adduction in the shoulder joint [17].

There was a decrease in pain syndrome [17, 20, 40, 51] and an increase in muscle strength of the shoulder joint [51]. At the same time, Uschok S. et al. observed no significant improvement of these parameters [54].

Also, according to the researchers reports, the patients noted the improvement of shoulder joint function after the course of the rehabilitation treatment according to the questionnaires such as DASH, Constant score, ASES, UCLA, etc. [17, 20, 40, 42, 51, 54].

Reverse arthroplasty is used for various shoulder joint diseases: primary osteoarthritis, defect arthropathy, massive tears of the rotator cuff, rheumatoid arthritis and dysfunction of a previously mounted prosthesis. Romano A. et al. showed the effectiveness of the standard course of rehabilitation for patients with these diseases. However, in case with rheumatoid arthritis and revision arthroplasty, the recovery of shoulder function (range of motion and Constant score) was significantly worse than in other diseases: the motion range and Constant score were lower [40].

Despite the availability of standard protocols, there are disagreements in many issues of patients' postoperative management, including the timing of the initiation of various rehabilitation measures [55]. The course of rehabilitation treatment should be chosen individually.

CONCLUSION

Shoulder arthroplasty significantly improves the quality of life of patients who have been limited in performing certain daily tasks due to shoulder pathology. Despite the relatively extensive experience with reverse shoulder arthroplasty, the information about shoulder rehabilitation after reverse arthroplasty is significantly limited and disparate. This necessitates further development of new approaches to the rehabilitation of patients who have undergone reverse shoulder arthroplasty.

ADDITIONAL INFORMATION

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All authors confirm their authorship according to the ICMJE criteria (all authors contributed significantly to the conception, study design and preparation of the article, read and approved the final version before publication).
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