Trauma Mon. 2018 May; 23(3):e58163. doi: 10.5812/traumamon.58163.

Published online 2017 July 24. **Review Article**

A brief Review of Reverse Shoulder Prosthesis: Arthroplasty, Complications, Revisions, and Development

Neriman Ozada,[1] Sina Ghafoorpoor Yazdi,[1] Amirsalar Khandan,[2,*] and Mohammad Karimzadeh[1]

[1]Mechanical Engineering Department, Eastern Mediterranean University, Gazimağusa, TRNC, Via Mersin 10 Turkey
[2]Young Researchers and Elite Club, Khomeinishahr Branch, Islamic Azad University, Isfahan, Iran

[*]*Corresponding author*: Amirsalar Khandan, Ph.D, Young Researchers and Elite Club, Khomeinishahr Branch, Islamic Azad University, Isfahan, Iran. Tel: +98,9135719626, E-mail: sas.khandan@iaukhsh.ac.ir

Received 2016 November 07; **Accepted** 2017 May 27.

Abstract

The shoulder is considered to be an important flexible and movable part in the human body. However, it is a wobble joint as its range of motion (ROM) is high. This unstable status increases the rate of joint injury. The processes leading to shoulder joint dysfunction are arthritis, hemiarthroplasty failure, and pseudoparalysis; in turn, one of the main factors contributing to these problems is rotator cuff tear (RCT). Reverse shoulder arthroplasty (RSA) may be a proper treatment for shoulder dysfunction and pain. This treatment elevates shoulder movement and has been augmented by recent advances in the development of the reverse shoulder prosthesis (RSP) design. This current review highlights the recent developments, revisions, and complications. A review of the published literature has been done to determine the overall rates of problems, complications, reoperations, and revisions after RSA. Furthermore, this review discusses the problems concerning RSP, shoulder joint replacement, and improvement in shoulder joint movement after arthroplasty.

Keywords: Reverse Shoulder Arthroplasty, Postoperative, Dysfunction, Complications, Development

1. Context

Shoulder joint dysfunction has attracted researchers' attention globally, and some methodologies have been proposed for the treatment of the shoulder (1-4). However, most of these treatments did not result in pain relief or improvement in shoulder joint function, and they even caused some complications after treatment (5-8). Hemiarthroplasty has been a common treatment for the last 3 decades; however, there was a need for enough glenoid allograft, where the glenoid component should be fixed to (9). Grammont, a French surgeon, designed an inverse (10) type of shoulder prosthesis with 2 components, glenoid and humeral, to treat shoulder joints with nonfunctioning rotator cuff (RC) (11). The glenoid component was made up of metallic or ceramic ball, but the humeral component was made up of polyethylene. Nevertheless, Grammont did more modifications on reverse shoulder prosthesis (RSP) as a result of low postoperative range of motion (ROM) and several failures (12). The second available model of RSP was known as Delta III with fixation of glenoid part using central pig, and some screws were placed on divergent directions (11-13). Reverse shoulder prosthesis have been modified and implanted during a course of 30 years (6, 12, 14, 15). De Buttet et al. have reported improvement in ROM after implantation of Delta III prosthesis (16). A recent study by Rittmeister and Kerschbaumer also confirmed the satisfactory outcomes in ROM for patients with rheumatoid arthritis. The postoperative outcomes of the Delta III RSP in improving shoulder function have been reported several times for different follow-up periods of patients, which are demonstrated in Table 1 (3, 13, 15, 17). Several studies have shown (18-21) a complication associated with an unconstrained total shoulder arthroplasty in the presence of a cuff-tear arthropathy (15, 21-23). According to the aforementioned developments in the treatment of the shoulder joint dysfunction and the complications concerning RSP arthroplasty, the objective of this review was to represent recent developments, complications, and postoperative outcomes of Delta III reverse prosthesis.

2. Hemiarthroplasty of the Shoulder

One of the most serious surgical challenges has been the treatment of shoulders with irreparable RC because the target was pain alleviation, but the results were generally poor. In partial replacement of the shoulder, hemiarthroplasty, the humerus (arm bone) is replaced with a

prosthetic metal implant, and the remaining part of the shoulder joint, ie, the glenoid, is left intact. Shoulder hemiarthroplasty is seen in austere, continuing conditions of shoulder osteoarthritis, in which only the humeral head is hurt.

There are 2 types of hemiarthroplasty (Figure 1):

- Stemmed hemiarthroplasty replaces the head of the humerus with a metal ball and stem, which is similar to the piece used in a total shoulder replacement. Stemmed hemiarthroplasty is useful when the humeral head is strictly cracked or arthritic, but the socket is normal, or there is a large rotator cuff tear, and thus a complete shoulder replacement might be unsuccessful over time.

- Resurfacing hemiarthroplasty includes replacing the joint surface of the humeral head with a cap-like prosthesis and no stem. Resurfacing hemiarthroplasty keeps the bone and evades the dangers of component wearing and loosening, which could happen in total shoulder replacement over time.

Although hemiarthroplasty reduces the pain in the treatment of a patient with cuff tear arthritis, it does not eliminate the pain. Several studies have shown unpredictable results (2-4, 17, 24, 25) of hemiarthroplasty for cuff deficient arthritis (26, 27). Despite hemiarthroplasty ability for smooth surface creation for joint articulation, there is not fulcrum stabilization, which is not adequate for elevation. Pain relief is chiefly good after surgery, but can get worse during the course of time along with glenoid arthritis and acromial wear or fracture. The results of hemiarthroplasty are even more problematic in patients, who show a pseudo-paralysis of the shoulder (28, 29). Primary hemiarthroplasty of the shoulder is used to treat complex proximal humeral fractures although the reported functional results following this method of treatment vary widely (30). Improvement of hemiarthroplasty results may be the procedure of choice for young patients with end-stage glenohumeral arthritis (29).

2.1. Reverse Shoulder Prosthesis

Because there was some problems concerning conventional shoulder arthroplasty, Grammont designed an inverse type of shoulder prosthesis (Depuy-International Ltd) to treat shoulder joints with nonfunctioning RC. The first Grammont shoulder prosthesis was the opposite of the conventional one, with 2 parts invented in 1985 (13). One of them was glenoid head, which was the concave part and the other was the humeral shaft, which was the convex part (Figure 2). The glenoid head and humeral shaft were made up of metallic or ceramic ball and polyethylene, respectively.

In 1987, the results of this research, with 8 patients as the study sample, were published (31). The patients had no pain during the follow-up period, but with variable function. Most patients had active anterior elevation of 100° to 130°, but 3 of them showed less than 60° elevation. Fewer results led to more modifications of Delta prosthesis, resulting in the current design. Because there were several problems concerning the first type of RSP design, some modifications were applied by Grammont, and finally the current available design in the market, Delta III, was produced. Nowadays, 3 different types of RSP are available and different manufacturer modifications have been applied. However, the glenoid base plate is the common part in all modifications. The most common difference between these modifications is that in some of them base plates are fixed to the glenoid through using a screw, whereas the other models use a peg for fixation (Figure 3). Other differences among the different models are glenoid head diameter, humeral shell neck shaft angle, and humeral concave polyethylene diameter. Generally, different parts of the currently available design of RSP are base plate with peg and screw fixation and glenohumeral head and humeral component (Figure 3). The humeral component consists of 2 parts itself, stem and proximal, and a concave polyethylene part, which is located into the proximal end of the humeral stem. The overall RSP assembly procedure during arthroplasty is (1) fixation of the base plate to glenoid, (2) insertion of the glenoid head over the base plate, (3) insertion of the concave polyethylene part on humeral component, and implanting humeral stem into arm, for some of which cementing is needed.

To cancel the shearing forces for initial abduction in the current type of Grammont prosthesis, a triangular divergent arrangement of screws has been invented. The glenoid head or glenosphere part is manufactured in 2 diameters, 36 and 42 mm, and is made up of cobalt-chrome. For cemented or cementless fixation of the humeral component, it is coated by hydroxyapatite or polished, respectively. There are 3 available lengths for humeral stem: 100 mm for the standard prosthesis, and 180 and 150 mm for revision.

2.2. Biomechanics of the Reverse Shoulder Prosthesis

In the reverse type of the shoulder prosthesis (Delta III), glenoid head, which has a hemispherical shape, is combined with screw fixation of the baseplate. This unique design increases the ROM of the prosthesis compared to the first Grammont design (ball and socket). By appropriate placement of this prosthesis, which uses more deltoid muscle fibers for elevation and increases the deltoid lever arm, the COR is made more distal, putting the deltoid muscle at greater tension. This parameter elevates the mechanical ability of deltoid muscle to provide rotational torque.

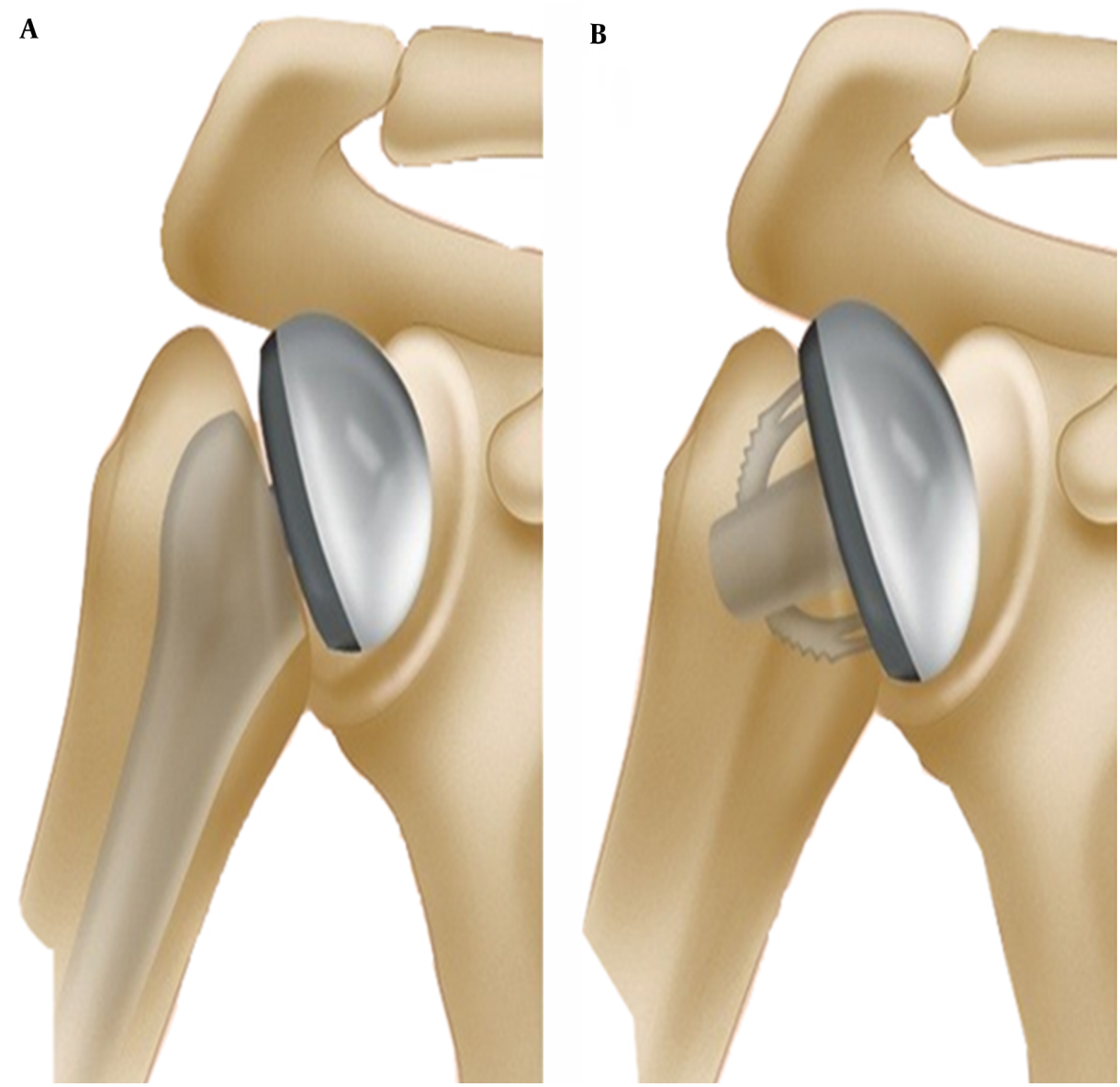

Figure 1. Two Types of Total Shoulder Arthroplasty; A, Conventional Total Shoulder Arthroplasty; B, Stemless Minimally Total Invasive Shoulder

2.3. Literature Survey of ROM and COR

Nyffler et al. (33) have studied glenoid component positioning to improve ROM to decrease the component impingement and scapular notching. They have determined that to elevate abduction angle before component impingement and to decrease scapular notching, more inferior and distal positioning of the glenoid part is needed, which allows the glenoid component to extend beyond the inferior rim of the glenoid. In biomechanical terms, this impingement is reasonable because it is the immediate result of the lack of a synthetic neck on the glenoid side and lowering of the humerus. There are severe reasons for impingement of the concave part of the humeral component in the scapular neck, particularly if the notch is wider than what impingement can describe alone (34). Grammont determined that the solution for increasing the deltoid power and preventing high range of forces on the glenoid component is medializing the COR at the level of the glenoid surface and orienting the humeral cup almost. To date, these biomechanical solutions have been

Figure 2. The Initial Design of Grammont RSP with Only Two Components

used. However, the wear of polyethylene part of humeral component and scapular notching seem to be the complications, which are not preventable. Furthermore, lateralization of the COR outside the scapula increases the likelihood of glenoid component loosening. Likewise, the possibility of the prosthesis instability increases if inclination of the humeral part decreases to prevent scapular notching.

3. Postoperative Results and Related Problems

Investigation of some postoperative RSP problems indicates a 15% complication rate with a 5% revision rate; 96% of the patients complained of little or no residual pain. A different evaluation of patients with cuff tear arthropathy (CTA) illustrated good results after more than 5 years of follow-up, with no evidence of progressive glenoid loosening or changing the results over time. Stevens et al. (35) have reviewed functional results of bilateral RSP replacement on 15 patients with a mean age of 73. They used 4 different types of RSP and have reported that RSP can be a good treatment for pain relieving and increasing forward elevation, and improving function. Sirveaux et al. reviewed the postoperative outcomes of Grammont's prosthesis (Delta III) in patients with irreparable rotator (15). They found that the early results achieved from inverted shoulder arthroplasty are promising. Valentiet al. (36) studied 60 patients, who were suffering from CTA, and for whom RSA was done. They have observed improvement in the shoulder function of the patients. It is suggested that Grammont RSP is a new treatment and useful for old patients, who suffer from osteoarthritis and have enough bone for fixation of the base plate. A comparative postoperative outcomes review of RSA by different researchers to active abduction is illustrated in Table 1. In addition, the arthroplasty results for active elevation angle between hemiarthroplasty of the shoulder and RSA are compared in Table 2.

3.1. Complication and Unsolved Problems with Delta III

Improvement in the shoulder joint dysfunction is gained by the novel postoperative results of the RSP and pain relief for those who suffer from any kind of diseases related to the shoulder joint. Many complications have been reported by numerous scientists, who performed and followed the patients after surgery. Complications can be classified in different categories as follow: notching of the bones and parts, which is the most common complication; prosthesis instability (48); dislocation; hematoma formation; infection; nerve damage (19) (a conventional model); implant loosening; and acromial stress fractures. The most important complications of RSP will be addressed and defined in detail as follow.

3.2. Indications

It has been determined that 3 distinct conditions of RSP are convenient for the treatment of the shoulder. The primary indication is shoulder with cuff tear arthritis in which patients suffer from pain and are unable to do abduction; the second circumstance of using reverse type of shoulder prosthesis is severe scapular fracture; the third circumstance for which RSP arthroplasty is useful is for those patients with failed hemiarthroplasty in the past or comminuted fracture of proximal humerus. Implementation of the RSP presents a considerable pain relief and active elevation restoration.

3.3. Scapular Notching

It is reported that scapular notching is the most regular complication associated with RSP (40). Also, it is suggested that scapular notching is due to the prosthesis design. Notching was firstly reported by De Wilde et al. who observed the phenomenon of notching in half of the monitored cases (42). Furthermore, radiographic data have shown that scapular notching is a potentially adverse complication, which occurs in 50% to 96% of the cases. The position of the COR of revert prosthesis, variations of scapular neck morphology, positioning, and orientation of the base plate have been shown to influence the development of scapular notching, especially in inferior position (32). The consequences of scapular notching were investigated in 326 consecutive patients undergone revers total shoulder surgery from 1991 to 2003 (49). Their studies revealed that scapular notching is common in RSP and that the first

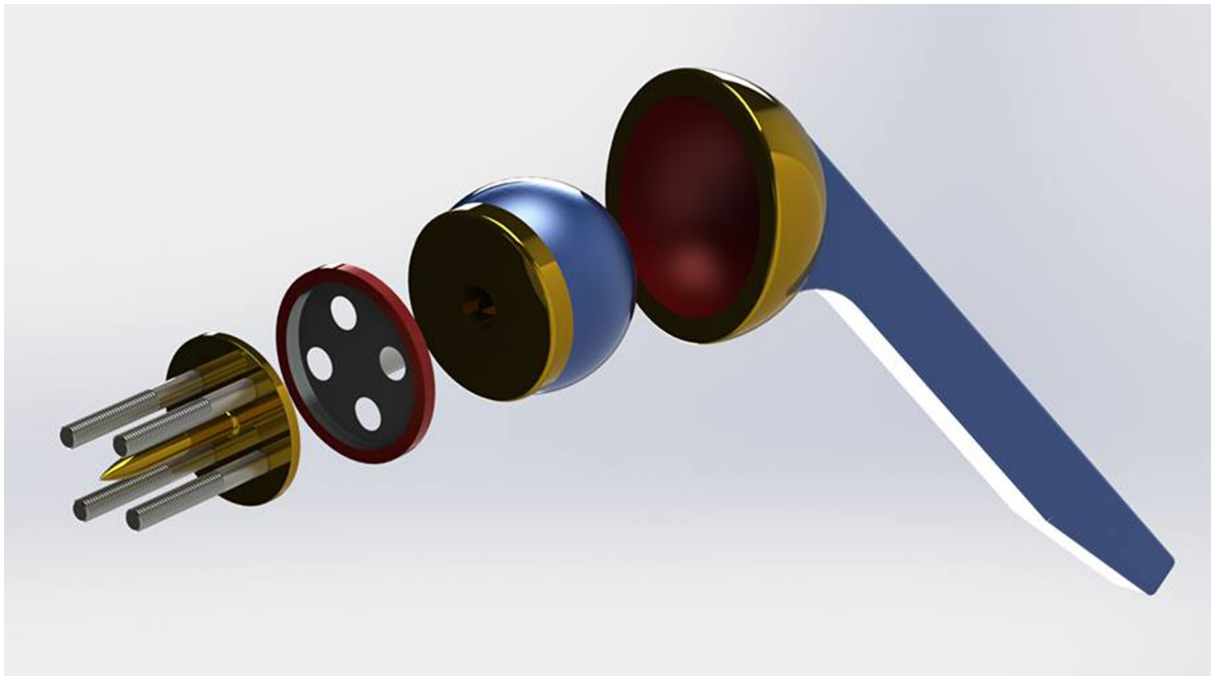

Figure 3. A, Different Components of Delta III Prosthesis, Humeral Shaft, Epiphysis, Polyethylene Inlay, Glenosphere, and Baseplate with Central Peg

Table 1. Reverse Shoulder Prosthesis Postoperative Outcomes for Active Abduction

Study	Number of Patients	Follow-Up, mo	Mean Active Abduction, °	Mean CM, %
De wilde et al. (14)	4	38	175	85
De wilde et al. (14)	7	112	163	78
De wilde et al. (14)	2	16	135	71
Beekman et al. (37)	11	24	-	56
Flury et al. (38)	21	46	90°	56
Gallinet et al. (39)	16	12	91	53
Boileau et al. (12)	42	50	-	56
Simovitch et al. (40)	77	44	111	78
Stevens et al. (35)	15		107	

Abbreviation: CM, constant-Murley.

radiographic marks usually begin to appear within the first months after surgery; furthermore, they found that positioning of the baseplate definitely influences scapular notching and high positioning of the baseplate and stated that superior tilting should be evaded (Figure 4).

Nowadays, RSP design is offered by several prosthetic manufacturers: ie, DePuy (Warsaw IN) Tornier SA, (Montbonnot, FR), etc. Several adjustments have been done by different manufacturers to address possible problems of notching, which will be discussed in following sections (Figure 5). Stephenson et al. examined the effect of humeral part version in Aequalis Reversed shoulder prosthesis (Tornier, Edina, MN) on impingement of scapula. They suggested that placing the humeral component between 20° and 40° of retroversion provides the opportunity for greater external rotation before impingement (34). The model designed by Encore Medical, Austin, TX, attempted to address the issue of scapular notching by providing the option for a more lateral center of rotation (COR) (50).

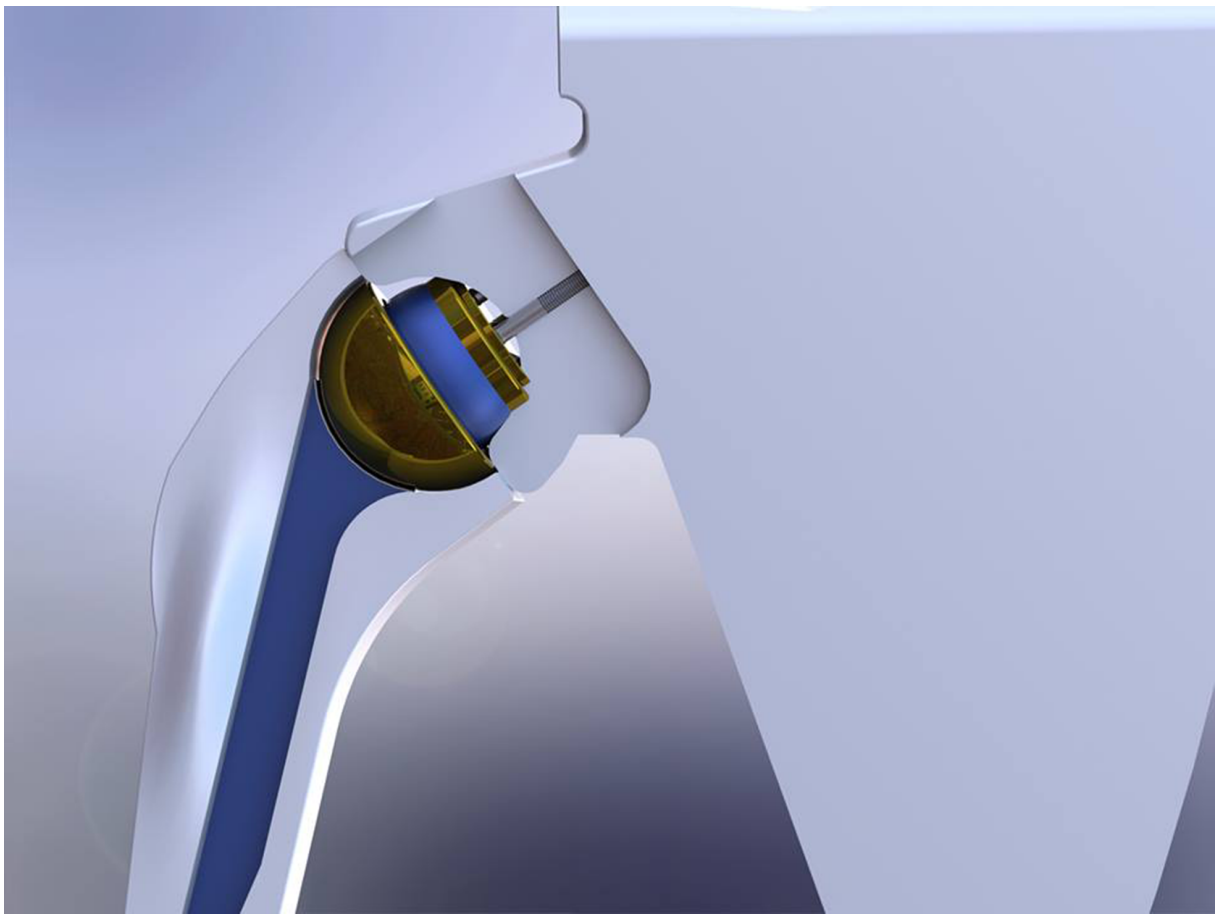

Figure 4. Scapular Notch: Radiographic Classification of Sirveaux in 4 Grades: (a) The Defect Concerns Only the Pillar; (b) Contact With the Lower Screw of the Baseplate; c) Extension Over the Lower Screw; and(d) Extension Under the Baseplate

3.4. Dislocation

Just like real shoulder, a shoulder revert prosthesis can dislocate. Dislocation is one of the most common serious complications concerning RSP. It has been seen in all follow-up results of RSA, with rates as high as 9%, responsible for almost half of the complications in some series (51). Implant dislocation resistance is measurable using stability ratio, representing the ratio of the maximum dislocation force to a given compressive axial load. One theorized cause is subscapularis insufficiency because the tendon cannot be repaired at the time of the surgery. In 2005, Boileau et al. proposed that an anterosuperior transdeltoid method may reduce instability after RSA because the subscapularis is preserved (12). Using the Aequalis reversed system, Edwards et al. recently revealed that the risk of dislocation after RSA was almost twice as high (relative risk, 1.90) in cases with an unrepaired subscapularis tendon vs. those with a repaired subscapularis tendon (52). It is proposed that RSP dislocation merely occurs in the anterior direction (53, 54). Clark et al. studied the impact of subscapularis repair on dislocation after RSA with the reverse shoulder prosthesis (RSP, DonJoy Surgical, Austin, TX, USA). They have shown that if the subscapularis is not repaired by employing the RSP through a deltopectoral method, there would not be a noteworthy effect on postoperative complication or dislocation rates (51).

3.5. Prosthesis Instability

Prosthetic instability is a prominent problem after arthroplasty. In some cases, prosthesis instability may be a result of impingement. Wust et al. (55) reported that the humeral component is important for intrinsic stability. Instability problem could be solved by increasing the offset to restore deltoid tension, which is achievable by putting an extension under polyethylene cup. This can be performed by inserting a humeral neck extension under

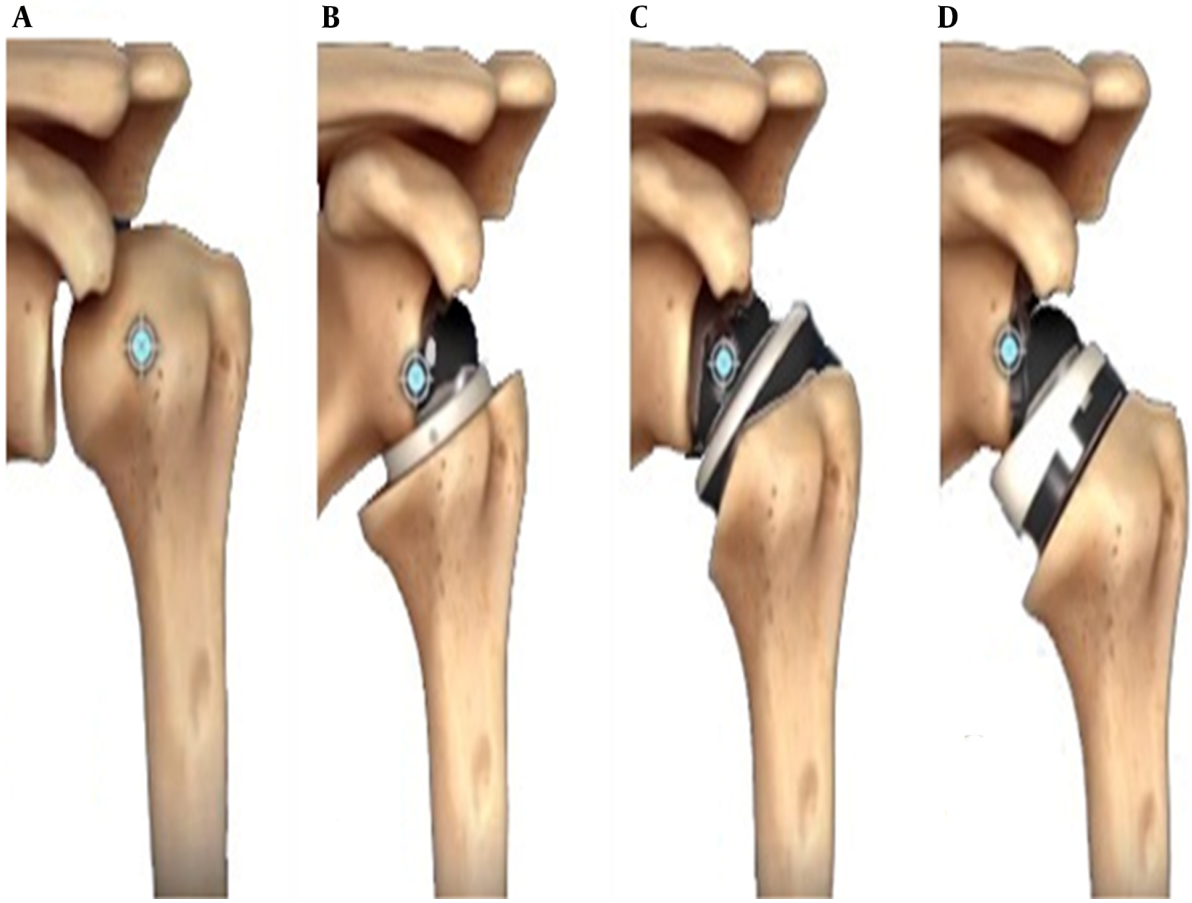

Figure 5. Manufacturers Adjustment of Reverse Shoulder Prosthesis to Resolve Scapular Notching; A, Anatomic Shoulder Joint; B, Grammont (Medial Glenoid/Medial Humerus Design); C, Lateral Glenoid/Medial Humerus Design; D, Equinox (Medial Glenoid/Lateral Humerus Design

the polyethylene cup and/or by increasing the size of the glenosphere and the cup (eg, 42 mm instead of 36 mm). Although implant instability is not an ordinary problem, almost all series report some cases (7, 42, 44, 45). Implant instability seems to be less seen when the implant is inserted through an anterosuperior transdeltoid approach, perhaps because the remaining subscapularis is not separated. Another important motive for instability of prosthesis is hematoma formation after arthroplasty in the gap under the acromion. Nevertheless, stability is a great concern and instability remains as a complication in RSA. Eventually, frequent revision surgery of reverse prosthesis is associated with instability of prosthesis because of a weak anterior deltoid muscle, and thus rehabilitation should be done more cautiously after surgery.

3.6. Prosthesis Loosening

The first Grammont ball and socket approach was modified to the current hemispherical configuration in 1991 because of some problems with loosening in its first days (13). Nevertheless, loosening remained as a severe problem in RSA. The glenoid component is typically the main point of loosening in total shoulder arthroplasty, especially with a constrained design (56, 57). Boileau et al. recognized some reasons concerning prosthesis loosing and suggested 3 possible solutions to prevent the following: (1) the use of a cemented humeral stem or perhaps a hybrid humeral component with the humeral neck part being uncemented and the stem being cemented, (2) the use of long stems in revision and fracture sequelae cases, and (3) the performance of a 2-step operation if there is any suspicion of infection (12). Considering several researches evaluating the additives in the prosthesis coatings (such as zirconia (ZrO2), ZrO2-Al2O3, nanocrystalline HA (NHA), Flurine-

Table 2. Hemiarthroplasty of the Shoulder Postoperative Active Elevation Outcomes (First Part) Compared to Reverse Shoulder Prosthesis (Second Part)

Study	Number of Patients	Follow-Up	Active Elevation, °
Pollock et al. (24)	19	3	112
Arntz et al. (1)	18	4	112
Williams and Rockwood (17)	21	6	120
Field et al. (2)	16	3	100
Zuckerman et al. (25)	15	5	86
Favard et al. (41)	60	3	96
Sanchez-Sotelo et al. (4)	33	2	91
Grammont et al. (13)	16	2.2	NA
De Buttet et al. (16)	71	2	120
De Wilde et al. (42)	5	2.5	"Fair"
Rittmeister et al. (7)	8	4.5	NA
Jacobs et al. (43)	7	1.3	NA
Sirveaux et al. (44)	80	3.6	138
Valenti et al. (36)	39	7.1	120
Boulahia et al. (45)	16	3	138
Delloye et al. (46)	5	6.7	72
De Wilde et al. (47)	6	1	106
Boileau et al. (12)	45	3.3	121

Abbreviation: NA, not available.

NHA, TCP, diopside, scaffold diopside, akermanite, baghdadite, bredigite, and nanocrystalline HA fabricated from eggshell source etc.), we sought to find a new additive with better mechanical and biological characteristics (58-68). Various techniques that can be applied to coat bioceramics composites on the metallic or nonmetallic implants, like plasma spraying process (59,60), thermal spraying (59), sputter coating, pulsed laser ablation, dip coating, sol–gel and electrophoretic deposition (61,62).

4. Conclusions

Treatment of the shoulder with irreparable CT has been always a great concern. Hemiarthroplasty is frequently used for shoulder joint treatment, however, pain relief was not satisfactory and stabilization was not enough for elevation. Although the first Grammont reverse prosthesis resulted in pain relief after arthroplasty, active anterior elevation was variable and not satisfying, in some cases less than 60°. The second Grammont RSP is an innovative prosthesis designed for the treatment of the patients with irreparable RCT associated with glenohumeral osteoarthritis, failed hemiarthroplasty, or superior subluxation of the humerus due to RC disease. This innovative design has been identified as a sufficient treatment for shoulder joint function restoration, increasing the ROM compared with the first design and pain relief in patients with RCT. Although RSA is an alternative approach for the treatment of the shoulder joint dysfunction, it has some complications, which are frequent following both primary and revision procedures, but they rarely affect the final outcome. Instability and notching were the 2 most frequent complications leading to revision. From review endeavor, it can be concluded that scapular notching is a common problem that occur in almost 50% of the cases after arthroplasty. Scapular notching could be improved through changing the position of the COR of prosthesis, variations of scapular neck morphology, positioning, and base plate orientation. For instance, insertion of humeral component between 20° and 40° of retroversion (Neck-shaft angle), which results in greater external rotation before impingement; more lateral COR and glenosphere position had the most important effect on inferior scapular impingement. Instability is another complication, which could be solved by inserting an extension under humeral polyethylene cup. Prosthesis loosening problem could be addressed through (a) cemented hybrid humeral part, (b) long stem, and (c) the performance of a two-step operation if there is any suspicion of infection. Function advancement is stable in postoperative outcomes of RSP implementation at least in short- term. This review discussed the developments, advantages, and complications of the RSP to show the ability of this design for the treatment of the patients with irreparable shoulder joint function. Although many studies have been done on patients with severe RCA, the treatment of RCA is still a matter of debate. Future reviews or studies on RSP may shape optimization to address the complication concern about this type of prosthesis.

References

1. Arntz CT, Jackins S, Matsen FA. Prosthetic replacement of the shoulder for the treatment of defects in the rotator cuff and the surface of the glenohumeral joint. *J Bone Joint Surg*. 1993;**75**(4):485–91. doi: 10.2106/00004623-199304000-00002.
2. Field LD, Dines DM, Zabinski SJ, Warren RF. Hemiarthroplasty of the shoulder for rotator cuff arthropathy. *J Shoulder Elbow Surg*. 1997;**6**(1):18–23. [PubMed: 9071678].
3. Neer C2, Watson KC, Stanton FJ. Recent experience in total shoulder replacement. *J Bone Joint Surg Am*. 1982;**64**(3):319–37. [PubMed: 7061549].

4. Sanchez-Sotelo J, Cofield RH, Rowland CM. Shoulder Hemiarthroplasty for Glenohumeral Arthritis Associated with Severe Rotator Cuff Deficiency. *J Bone Joint Surg Am Volume*. 2001;**83**(12):1814–22. doi: 10.2106/00004623-200112000-00008.
5. Boileau P, Trojani C, Walch G, Krishnan SG, Romeo A, Sinnerton R. Shoulder arthroplasty for the treatment of the sequelae of fractures of the proximal humerus. *J Shoulder Elbow Surg*. 2001;**10**(4):299–308. doi: 10.1067/mse.2001.115985. [PubMed: 11517358].
6. Hatzidakis AM, Norris TR, Boileau P. Reverse Shoulder Arthroplasty Indications, Technique, and Results. *Techniques Shoulder Elbow Surg*. 2005;**6**(3):135–49. doi: 10.1097/01.bte.0000169730.36840.4b.
7. Rittmeister M, Kerschbaumer F. Grammont reverse total shoulder arthroplasty in patients with rheumatoid arthritis and nonreconstructible rotator cuff lesions. *J Shoulder Elbow Surg*. 2001;**10**(1):17–22. doi: 10.1067/mse.2001.110515. [PubMed: 11182731].
8. Woodruff MJ, Cohen AP, Bradley JG. Arthroplasty of the shoulder in rheumatoid arthritis with rotator cuff dysfunction. *Int Orthop*. 2003;**27**(1):7–10. doi: 10.1007/s00264-002-0406-9. [PubMed: 12582801].
9. McFarland EG, Sanguanjit P, Tasaki A, Keyurapan E, Fishman EK, Fayad LM. The reverse shoulder prosthesis: A review of imaging features and complications. *Skeletal Radiol*. 2006;**35**(7):488–96. doi: 10.1007/s00256-006-0109-1. [PubMed: 16570176].
10. BrostrOm LA, Wallensten R, Olsson E, Anderson D. The Kessel Prosthesis in Total Shoulder Arthroplasty: A Five-Year Experience. *Clin Orthopaed Relat Res*. 1992;**277**:155–60.
11. Grammont PM, Baulot E. Delta shoulder prosthesis for rotator cuff rupture. *Orthopedics*. 1993;**16**(1):65–8. [PubMed: 8421661].
12. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. *J Shoulder Elbow Surg*. 2005;**14**(1 Suppl S):147S–61S. doi: 10.1016/j.jse.2004.10.006. [PubMed: 15726075].
13. Grammont PM, Trouilloud P, Laffay JP, Deries X. Etude et realisation d'une nouvelle prothese d'epaule. *Rhumatologie*. 1987;**39**(10):407–18.
14. De Wilde L, Boileau P, Van der Bracht H. Does reverse shoulder arthroplasty for tumors of the proximal humerus reduce impairment? *Clin Orthop Relat Res*. 2011;**469**(9):2489–95. doi: 10.1007/s11999-010-1758-x. [PubMed: 21210310].
15. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Molé D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. *J Bone Joint Surg*. 2004;**86**(3):388–95. doi: 10.1302/0301-620x.86b3.14024.
16. De Buttet A, Bouchon Y, Capon D, Delfosse J. Grammont shoulder arthroplasty for osteoarthritis with massive rotator cuff tears: report of 71 cases. *J Shoulder Elbow Surg*. 1997;**6**(2):197.
17. Williams GJ, Rockwood CJ. Hemiarthroplasty in rotator cuff-deficient shoulders. *J Shoulder Elbow Surg*. 1996;**5**(5):362–7. [PubMed: 8933458].
18. Barrett WP, Franklin JL, Jackins SE, Wyss CR, Matsen FA. Total shoulder arthroplasty. *J Bone Joint Surg*. 1987;**69**(6):865–72. doi: 10.2106/00004623-198769060-00011.
19. Hawkins RJ, Bell RH, Jallay B. Total shoulder arthroplasty. *Clin Orthop Relat Res*. 1989;(242):188–94. [PubMed: 2706849].
20. Johnson RL. Total shoulder arthroplasty. *Orthop Nurs*. 1993;**12**(1):14–22. [PubMed: 8451056].
21. Franklin JL, Barrett WP, Jackins SE, Matsen F3. Glenoid loosening in total shoulder arthroplasty. Association with rotator cuff deficiency. *J Arthroplasty*. 1988;**3**(1):39–46. [PubMed: 3361319].
22. Brenner BC, Ferlic DC, Clayton ML, Dennis DA. Survivorship of unconstrained total shoulder arthroplasty. *J Bone Joint Surg Am*. 1989;**71**(9):1289–96. [PubMed: 2793880].
23. Torchia ME, Cofield RH, Settergren CR. Total shoulder arthroplasty with the Neer prosthesis: long-term results. *J Shoulder Elbow Surg*. 1997;**6**(6):495–505. [PubMed: 9437598].
24. Pollock RG, Deliz ED, McIlveen SJ, Flatow EL, Bigliani LU. Prosthetic replacement in rotator cuff-deficient shoulders. *J Shoulder Elbow Surg*. 1992;**1**(4):173–86. doi: 10.1016/1058-2746(92)90011-Q. [PubMed: 22971621].
25. Zuckerman JD, Scott AJ, Gallagher MA. Hemiarthroplasty for cuff tear arthropathy. *J Shoulder Elbow Surg*. 2000;**9**(3):169–72. [PubMed: 10888158].
26. Iorio R, Schwartz B, Macaulay W, Teeney SM, Healy WL, York S. Surgical treatment of displaced femoral neck fractures in the elderly: a survey of the American Association of Hip and Knee Surgeons. *J Arthroplasty*. 2006;**21**(8):1124–33. doi: 10.1016/j.arth.2005.12.008. [PubMed: 17162171].
27. Moeckel BH, Dines DM, Warren RF, Altchek DW. Modular hemiarthroplasty for fractures of the proximal part of the humerus. *J Bone Joint Surg Am*. 1992;**74**(6):884–9. [PubMed: 1634578].
28. Beckenbaugh RD, Tressler HA, Johnson Jr EW, editors. Results after hemiarthroplasty of the hip using a cemented femoral prosthesis. A review of 109 cases with an average follow-up of 36 months. *Mayo Clinic proceedings*. 1977. p. 349–53.
29. Burkhead WJ, Hutton KS. Biologic resurfacing of the glenoid with hemiarthroplasty of the shoulder. *J Shoulder Elbow Surg*. 1995;**4**(4):263–70. [PubMed: 8542369].
30. Robinson CM, Page RS, Hill RM, Sanders DL, Court-Brown CM, Wakefield AE. Primary hemiarthroplasty for treatment of proximal humeral fractures. *J Bone Joint Surg Am*. 2003;**85-A**(7):1215–23. [PubMed: 12851345].
31. Grammont P, Trouilloud P, Laffay JP, Deries X. Concept study and realization of a new total shoulder prosthesis. *Rhumatologie*. 1987;**39**(10):407–18.
32. Werner CML. Treatment of Painful Pseudoparesis Due to Irreparable Rotator Cuff Dysfunction with the Delta III Reverse-Ball-and-Socket Total Shoulder Prosthesis. *J Bone Joint Surg*. 2005;**87**(7):1476. doi: 10.2106/jbjs.d.02342.
33. Gutierrez S, Levy JC, Frankle MA, Cuff D, Keller TS, Pupello DR, et al. Evaluation of abduction range of motion and avoidance of inferior scapular impingement in a reverse shoulder model. *J Shoulder Elbow Surg*. 2008;**17**(4):608–15. doi: 10.1016/j.jse.2007.11.010. [PubMed: 18325795].
34. Stephenson DR, Oh JH, McGarry MH, Rick Hatch G3, Lee TQ. Effect of humeral component version on impingement in reverse total shoulder arthroplasty. *J Shoulder Elbow Surg*. 2011;**20**(4):652–8. doi: 10.1016/j.jse.2010.08.020. [PubMed: 21144775].
35. Stevens CG, Struk AM, Wright TW. The functional impact of bilateral reverse total shoulder arthroplasty. *J Shoulder Elbow Surg*. 2014;**23**(9):1341–8.
36. Valenti P, Sauzieres P, Katz D, Kalouche I, Kilinc AS. Do less medialized reverse shoulder prostheses increase motion and reduce notching? *Clin Orthop Relat Res*. 2011;**469**(9):2550–7. doi: 10.1007/s11999-011-1844-8. [PubMed: 21403989].
37. Beekman PD, Katusic D, Berghs BM, Karelse A, De Wilde L. One-stage revision for patients with a chronically infected reverse total shoulder replacement. *J Bone Joint Surg Br*. 2010;**92**(6):817–22. doi: 10.1302/0301-620X.92B6.23045. [PubMed: 20513879].
38. Flury MP, Frey P, Goldhahn J, Schwyzer HK, Simmen BR. Reverse shoulder arthroplasty as a salvage procedure for failed conventional shoulder replacement due to cuff failure–midterm results. *Int Orthop*. 2011;**35**(1):53–60. doi: 10.1007/s00264-010-0990-z. [PubMed: 20229269].
39. Gallinet D, Clappaz P, Garbuio P, Tropet Y, Obert L. Three or four parts complex proximal humerus fractures: hemiarthroplasty versus reverse prosthesis: a comparative study of 40 cases. *Orthop Traumatol Surg Res*. 2009;**95**(1):48–55. doi: 10.1016/j.otsr.2008.09.002. [PubMed: 19251237].
40. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. *J Bone Joint Surg Am*. 2007;**89**(3):588–600. doi: 10.2106/JBJS.F.00226. [PubMed: 17332108].
41. Favard L, Lautmann S, Sirveaux F, Oudet D, Kerjean Y, Huguet D. *Hemi arthroplasty versus reverse arthroplasty in the treatment of osteoarthritis with massive rotator cuff tear*. 2000.
42. De Wilde L, Mombert M, Van Petegem P, Verdonk R. Revision of

shoulder replacement with a reversed shoulder prosthesis (Delta III): report of five cases. *Acta Orthop Belg*. 2001;**67**(4):348–53. [PubMed: 11725566].
43. Jacobs R, Debeer P, De Smet L. Treatment of rotator cuff arthropathy with a reversed Delta shoulder prosthesis. *Acta Orthop Belg*. 2001;**67**(4):344–7. [PubMed: 11725565].
44. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Mole D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. *Bone Joint J*. 2004;**86**(3):388–95.
45. Boulahia A, Edwards TB, Walch G, Baratta RV. Early results of a reverse design prosthesis in the treatment of arthritis of the shoulder in elderly patients with a large rotator cuff tear. *Orthopedics*. 2002;**25**(2):129–33. [PubMed: 11866145].
46. Delloye C, Joris D, Colette A, Eudier A, Dubuc JE. Mechanical complications of total shoulder inverted prosthesis. *Revue de chirurgie orthopedique et reparatrice de l'appareil moteur*. 2002;**88**(4):410–4.
47. De Wilde LF, Van Ovost E, Uyttendaele D, Verdonk R. Results of an inverted shoulder prosthesis after resection for tumor of the proximal humerus. *Revue de chirurgie orthopedique et reparatrice de l'appareil moteur*. 2002;**88**(4):373–8.
48. Cuff DJ, Virani NA, Levy J, Frankle MA, Derasari A, Hines B, et al. The treatment of deep shoulder infection and glenohumeral instability with debridement, reverse shoulder arthroplasty and postoperative antibiotics. *J Bone Joint Surg Br*. 2008;**90**(3):336–42. doi: 10.1302/0301-620X.90B3.19408. [PubMed: 18310757].
49. Levigne C, Boileau P, Favard L, Garaud P, Mole D, Sirveaux F, et al. Scapular notching in reverse shoulder arthroplasty. *J Shoulder Elbow Surg*. 2008;**17**(6):925–35. doi: 10.1016/j.jse.2008.02.010. [PubMed: 18558499].
50. Harman M, Frankle M, Vasey M, Banks S. Initial glenoid component fixation in "reverse" total shoulder arthroplasty: a biomechanical evaluation. *J Shoulder Elbow Surg*. 2005;**14**(1 Suppl S):162S–7S. doi: 10.1016/j.jse.2004.09.030. [PubMed: 15726076].
51. Clark JC, Ritchie J, Song FS, Kissenberth MJ, Tolan SJ, Hart ND, et al. Complication rates, dislocation, pain, and postoperative range of motion after reverse shoulder arthroplasty in patients with and without repair of the subscapularis. *J Shoulder Elbow Surg*. 2012;**21**(1):36–41. doi: 10.1016/j.jse.2011.04.009. [PubMed: 21803609].
52. Edwards TB, Williams MD, Labriola JE, Elkousy HA, Gartsman GM, O'Connor DP. Subscapularis insufficiency and the risk of shoulder dislocation after reverse shoulder arthroplasty. *J Shoulder Elbow Surg*. 2009;**18**(6):892–6. doi: 10.1016/j.jse.2008.12.013. [PubMed: 19282204].
53. Mole D, Favard L. Excentered scapulohumeral osteoarthritis. *Revue de chirurgie orthopédique et réparatrice de l'appareil moteur*. 2007;**93**(6 Suppl):37–94.
54. Roberts CC, Ekelund AL, Renfree KJ, Liu PT, Chew FS. Radiologic assessment of reverse shoulder arthroplasty. *Radiographics*. 2007;**27**(1):223–35. doi: 10.1148/rg.271065076. [PubMed: 17235009].
55. Wust DM, Meyer DC, Favre P, Gerber C. Mechanical and handling properties of braided polyblend polyethylene sutures in comparison to braided polyester and monofilament polydioxanone sutures. *Arthroscopy*. 2006;**22**(11):1146–53. doi: 10.1016/j.arthro.2006.06.013. [PubMed: 17084288].
56. Post M, Haskell SS, Jablon M. Total shoulder replacement with a constrained prosthesis. *J Bone Joint Surg Am*. 1980;**62**(3):327–35. [PubMed: 7364806].
57. Fenlin JJ. Total glenohumeral joint replacement. *Orthop Clin North Am*. 1975;**6**(2):565–83. [PubMed: 1128882].
58. Karamian E, Motamedi MR, Khandan A, Soltani P, Maghsoudi S. An in vitro evaluation of novel NHA/zircon plasma coating on 316L stainless steel dental implant. *Progress in Natural Science: Materials International*. 2014 4 30;**24**(2):150–6.
59. Najafinezhad A, Abdellahi M, Ghayour H, Soheily A, Chami A, Khandan A. A comparative study on the synthesis mechanism, bioactivity and mechanical properties of three silicate bioceramics. *Mater. Sci. Eng.: C*. 2017 3 1;**72**:259–67.
60. Sharafabadi AK, Abdellahi M, Kazemi A, Khandan A, Ozada N. A novel and economical route for synthesizing akermanite (Ca 2 MgSi 2 O 7) nano-bioceramic. *Mater. Sci. Eng.: C*. 2017 2 1;**71**:1072–8.
61. Karamian E, Nasehi A, Saber-Samandari S, Khandan A. Fabrication of hydroxyapatite-baghdadite nanocomposite scaffolds coated by PCL/Bioglass with polyurethane polymeric sponge technique. *Nanomedicine Journal*. 2017 6 14;**4**(3):177–83.
62. Abdellahi M, Najafinezhad A, Ghayouri H, Saber-Samandari S, Khandan A. Preparing diopside nanoparticle scaffolds via space holder method: Simulation of the compressive strength and porosity. *J Mech Behav Biomed Mater*. 2017 8 31;**72**:171–81.
63. Karamian E, Khandan A, Kalantar Motamedi MR, Mirmohammadi H. Surface characteristics and bioactivity of a novel natural HA/zircon nanocomposite coated on dental implants. *BioMed Res. Int*. 2014 4 16;**2014**.
64. Khandan A, Abdellahi M, Barenji RV, Ozada N, Karamian E. Introducing natural hydroxyapatite-diopside (NHA-Di) nano-bioceramic coating. *Ceram Int*. 2015 11 30;**41**(9):12355–63.
65. Khandan A, Abdellahi M, Ozada N, Ghayour H. Study of the bioactivity, wettability and hardness behaviour of the bovine hydroxyapatite-diopside bio-nanocomposite coating. *Journal of the Taiwan Institute of Chemical Engineers*. 2016 3 31;**60**:538–46.
66. Khandan A, Karamian E, Bonakdarchian M, Ghayour H. Mechanochemical synthesis evaluation of nanocrystalline bone-derived bioceramic powder using for bone tissue engineering. *Dental Hypotheses*. 2014 10 1;**5**(4):155.
67. Karamian E, Abdellahi M, Khandan A, Abdellah S. Introducing the fluorine doped natural hydroxyapatite-titania nanobiocomposite ceramic. *J. Alloys Compd*. 2016 9 15;**679**:375–83.
68. Kazemi A, Abdellahi M, Khajeh-Sharafabadi A, Khandan A, Ozada N. Study of in vitro bioactivity and mechanical properties of diopside nano-bioceramic synthesized by a facile method using eggshell as raw material. *Mater. Sci. Eng.: C*. 2017 2 1;**71**:604–10.