Principles of reverse shoulder endoprosthetics with a focus on stemless prostheses

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Principles of reverse shoulder prosthetics

Reverse shoulder endoprostheses allow for a marked improvement in function with a significant reduction in pain for typical defect arthropathy [1].

Implantation of Grammont-style classical reverse prostheses leads to the reversal of articular surfaces, impeding further misalignment of the humerus bone. The alteration in biomechanics can effectively compensate for the lack of a rotator cuff for defect arthropathy (▶Fig. 1) [2, 3].

Distalisation of the centre of rotation:

- improvement of the moment arm of the M. deltoideus by 25%
- medialisation of the centre of rotation: rotation centre in projection reduces the implant-bone load on the glenoid bones
- increased risk of scapula notching
- loss of deltoid contour
- reduction in the moment arm of the infraspinatus muscle (M. infraspinatus) and therefore in range of external rotation

The main indication for the implantation of a reverse shoulder endoprosthesis is irreparable rotator cuff rupturing with existing defect arthropathy [1, 2]. In addition to classic defect arthropathy [2, 3], indication expansion results after successful implantation. This includes:

- massive, irreparable rotator cuff ruptures without relevant osteoarthritis [4]
- rheumatoid arthritis in combination with cuff defects [5]
- poor clinical outcomes after hemi- and total endoprosthesis implantations [6-8]
- tumours [9]
- post-traumatic resulting in conditions with poor clinical outcomes [7]
- new proximal humerus fractures generally in older patients [10]

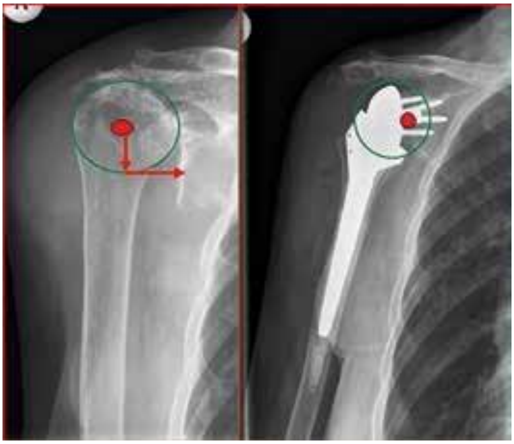

Fig. 1 *| Biomechanics of reverse Grammont prostheses*

Fig. 2 *| Early reverse prosthesis with a centre of rotation (red dot) lateral to the implant-bone interface (line), which can lead to early relaxation of the glenoid due to the "rocking horse" phenomenon.*

A trend has emerged in endoprostheses over the last decades towards using reverse prostheses for fractures. Prospective randomised studies [11] show the superiority of reverse prostheses in comparison with anatomic prostheses concerning the functional results:

- anteversion only 120 versus 80
- abduction only 113 versus 79
- Constant Murley Score [CMS] 56 versus 40

The rate of complications for reverse prostheses is 19.4%, which is higher than anatomical prostheses at 5.6%. However, at the same time, a lower revision rate for reverse shoulder prostheses at 5.9% in comparison with anatomical ones at 9.1% was found [12]. A cost-benefit analysis from 2017 shows that reverse shoulder prosthesis is more cost-effective for proximal humerus fractures [13].

Biomechanics of reverse prostheses

The first reverse prostheses that were developed in the 1970s had a centre of rotation [CoR] relatively close to the original, anatomical centre of rotation. This led to larger loads on the glenoidal fixation with subsequent relaxation (▶Fig. 2).

This medialisation of the centre of rotation for Grammont prostheses led to medialisation of the humerus at the same time. The horizontal humerus osteotomy with an osteotomy angle of 155° was thought to improve joint stability but in fact lead to mechanical contact between PE (polyethylene) inlay and the neck of the scapula (notching, ▶Fig. 3) with PE grit (▶Fig. 4).

To reduce the risk of notching, the following measures were taken:

- varisation of the humeral inclination angle with the risk of increased joint instability
- inlays with lower conformity (known as "high mobility" inlays with lower

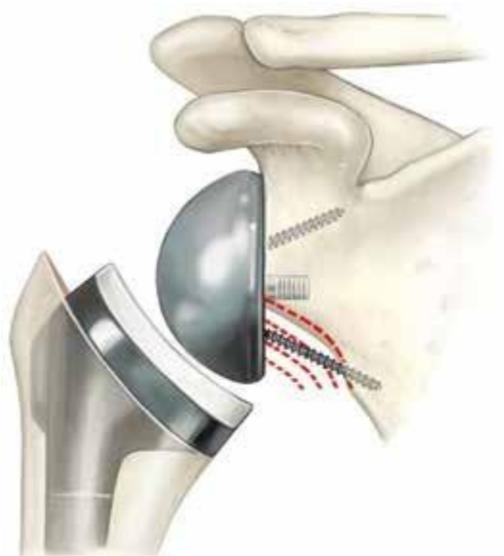

Fig. 3 *| Scapular notching according to Sirveaux [14]: Grade 0 = no notching; Grade 1 = small notching confined to the neck of the scapula, does not reach the inferior screw, Grade 2 = notch reaches the end of the inferior screw, Grade 3 = large notch reaching past the inferior screw, Grade 4 = notch reaches the baseplate*

Fig. 4 *| Polyethylene grit due to inferior notching*

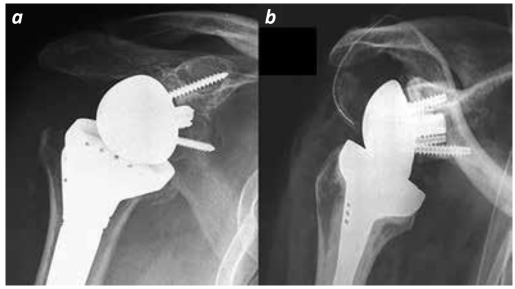

Fig. 5 | a) Grammont prosthesis without inferior offset of the glenoidal component; b) Grammont prosthesis with inferior offset of the glenoidal component

conformity), which on the other hand reduces the stability of the joint.
- inferior translation (inferior offset) of the glenoidal component through inferior offset glenoidal spheres or inferior placement of the glenoidal baseplate (▶Fig. 5)
- lateralisation of the glenoidal sphere
- lateralisation of the metaglene/baseplate by using an autologous bone graft (BIO-RSA™, bony-increased offset-reverse shoulder arthroplasty)

Additionally, Grammont prostheses have reduced stability due to deterioration of the M. deltoideus deflection angle around the large tubercle (tuberculum majus). The remaining rotator cuff parts also had a lower stabilising effect due to a marked shortening of the muscle.

During the subsequent development of the original Grammont prostheses, care was taken to ensure that the advantages were retained but that the disadvantages were compensated. In concrete terms, this means:

- medialisation of the centre of rotation
- lateralisation of the humerus
- an increased inclination of the humeral osteotomy and the humeral joint

Medialisation of the centre of rotation and diameter of the glenoidal sphere

The biomechanics of reverse implants are extremely dependent on the localisation of the centre of rotation of the shoulder joint. If the centre of rotation is near the bone-implant interface, the load is reduced and the moment arm of the deltoid muscle (M. deltoideus) is increased. However, Medialisation of the centre of rotation leads to notching. Medialisation of the centre of rotation also is associated with the glenoidal sphere diameter. The apparent relationship is that for every 1 mm increase in the glenoidal sphere, 5° of range of movement is gained. This naturally leads to attempts to increase the thickness of the glenoidal sphere. On the other hand, the increase in thickness of the glenoidal sphere reduces the medialisation effect of the centre of rotation and increases the load on the implant-bone interface, leading to a higher relaxation rate such as that seen in the case of the Encore prosthesis (2.5% aseptic relaxation [Grammont] versus 11.7% relaxation rate [Encore]) [15]. The 10-year results on the other hand are quite pleasing for this prosthesis with a 10-year survival rate of 90.7% [16].

Glenohumeral offset increase

This can be achieved through various methods. One option is the lateralisation of the humeral prosthesis component (e.g. using an off-centred epiphyseal component); a varus-forming configuration in the sense of a reduced inclination angle or a lateralised glenoidal sphere [17, 18]. The advantages of lateralisation lie in reduced notching as well as improved range of motion [17-19]. A disadvantage is that the centre of rotation lies externally to the bone-implant interface and therefore can lead to an increase in the relaxation rate of the metaglene [20]. In the 10-year follow-up, however, new angle-stable implants also showed a decrease in the failure of the baseplate [21].

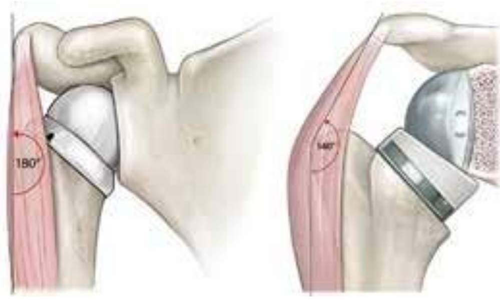

***Fig. 6** | Deltoid deflection angle around the large tubercle (tuberculum majus)*

A varus (reduced) deflection angle increases compression in the glenohumeral joint, which in turn increases stability.

Lateralisation of the humerus leads to increased tension in the tendons of the remaining rotator cuff and an improvement of the deltoid deflection angle (▶Fig. 6). Lateralisation of the humerus depends on humeral inclination and humeral concavity. The concavity can be superimposed directly on the stemless as in Grammont prostheses or placed on an additional, separate baseplate medial of the stem axis. Stemless reverse systems offer special advantages, especially as the anchor system of onlay prostheses can be placed medially for epiphyseal fixation, leading to the lateralisation of the humerus. The EASYTECH® prosthesis also offers the possibility to place the polyethylene onlay medially and off centred on the epiphyseal anchor system, which increases the lateralisation effect on the humerus.

Humeral inclination angle

Varisation of the inclination angle of the humerus from 155° to 135° can achieve a reduction in notching [22]. This also improves the range of movement [17]. Some newer systems allow for varisation of the inclination angle from 135° to 155°. Lädermann et al. [17] showed an optimal inclination angle of 144° in their biomechanical study.

BIO-RSA™

The BIO-RSA™ typically consists of a biological autologous allograft from the head of the humerus. This is positioned under the glenoid baseplate using the central peg to lateralise the glenoidal sphere [22]. Boileau et al. [23] were able to show incorporation into the bone during healing in 94% of cases. Athwal et al. [24] established a significant reduction in scapular notching comparing the BIO-RSA™ with medialised Grammont prostheses. The increase in range of movement and the clinical function score was not found, however.

■ Introduction to reverse prostheses

Reverse prostheses can be classified into four groups based on the following considerations (▶Fig. 7):

- MGMH (Medial Glenoid/Medial Humerus) (▶Fig. 7a)
- LGMH (Lateral Glenoid/Medial Humerus) (▶Fig. 7b)
- MGLH (Medial Glenoid/Lateral Humerus) (▶Fig. 7c)
- LGLH (Lateral Glenoid/Lateral Humerus) (▶Fig. 7d)

MGMH (Medial Glenoid/Medial Humerus)

The centre of rotation is positioned close to the glenoidal joint line. The humeral concave socket portion is positioned close to the intramedullary canal. Grammont prostheses typically fall into this category (▶Fig. 8). This type of prosthesis can be identified by the following characteristics:

- reduced risk of glenoidal relaxation
- good recovery of active abduction of the arm due to the larger deltoid moment arm
- higher rate for scapula notching
- limited internal and external rotation due to the shortening of rotators

LGMH (Lateral Glenoid/Medial Humerus)

The centre of rotation is lateral to the glenoidal fixation. This is achieved, for example in the case of the Encore prosthesis, using a thicker glenoidal sphere (▶Fig. 9) or

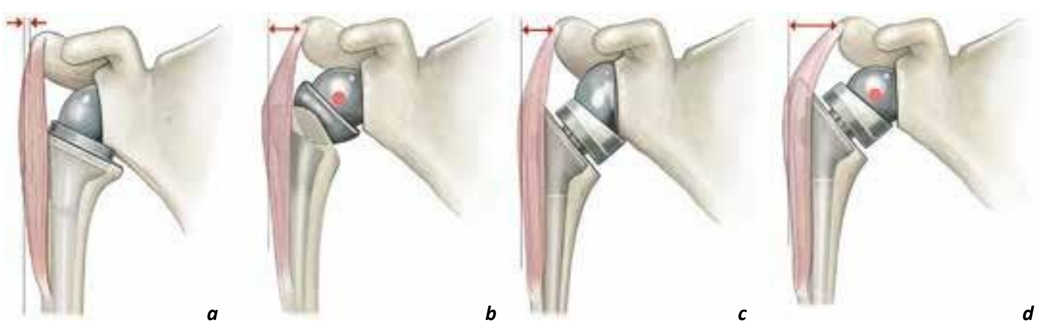

***Fig. 7** | Classification of reverse prostheses regarding their humeral and glenoid offsets.*
a) MGMH: Medial Glenoid/Medial Humerus; b) LGMH: Lateral Glenoid/Medial Humerus; c) MGLH: Medial Glenoid/Lateral Humerus; d) LGLH: Lateral Glenoid/Lateral Humerus

Fig. 8 | *MGMH-type reverse shoulder prosthesis (Grammont prosthesis)*

Fig. 9 | *LGMH-type reverse shoulder prosthesis (Encore™ prosthesis)*

BIO-RSA™. The humeral component remains in the axis of the humerus so that medialisation occurs. This type of prosthesis can be identified by the following characteristics:

- reduced scapula notching
- better recovery of active internal and external rotation due to increased tension in the rotator cuff.
- potential increase in risk of glenoidal relaxation due to the increased load on the glenoid implant interface

MGLH (Medial Glenoid/Lateral Humerus)

The centre of rotation is located more medially from the anatomical glenoid. The stemless of the humerus is lateralised and the humeral joint component sits outside of the stemless of the humerus, which also has been achieved by some stemless systems (▶Fig. 10). This principle is especially useful with stemless reverse onlay prostheses.

This type of prosthesis can be identified by the following characteristics:

- reduced risk of glenoidal relaxation
- reduced risk of scapula notching
- improved recovery of active arm elevation due to an increased deltoid moment arm
- increased large tubercle (tuberculum majus) deflection angle
- improved active internal and external rotation due to better tension of the rotator cuff

LGLH (Lateral Glenoid/Lateral Humerus)

The centre of rotation is again located laterally to the glenoidal anchor, which according to Boileau is achievable using a BIO-RSA™. The stem of the humerus is also lateralised or the humeral joint component sits outside of the humeral stem. This

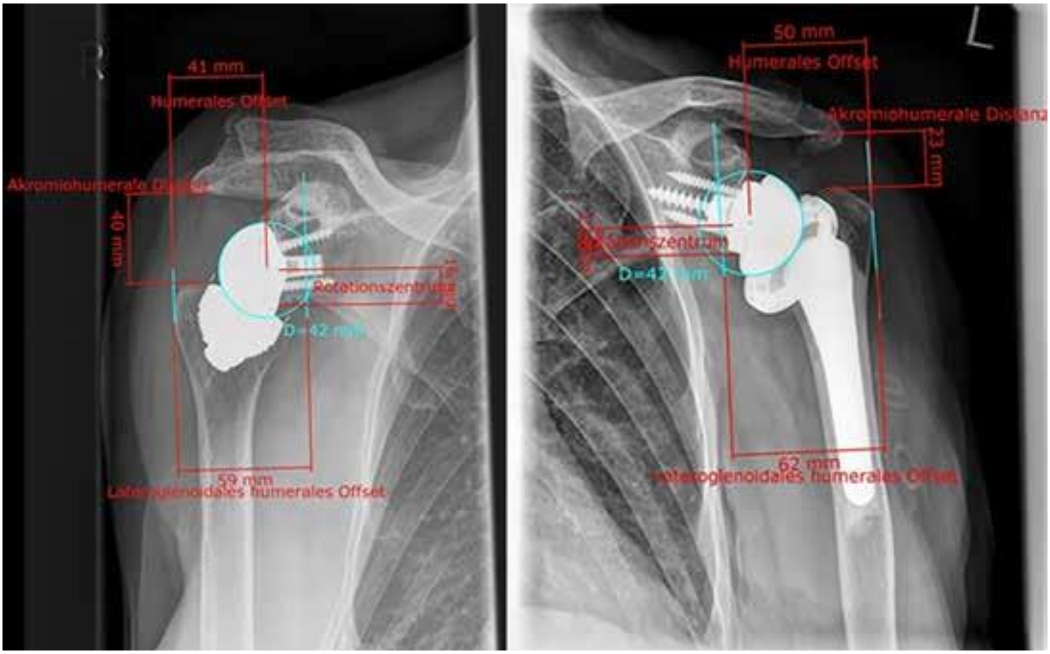

Fig. 10 *| MGLH-type reverse shoulder prosthesis*

principle is within reach for stemless reverse onlay prostheses. This type of prosthesis can be identified by the following characteristics:

- even lower risk for scapula notching
- better recovery of active internal and external rotation due to increased tension in the rotator cuff.
- potential increase in risk of glenoidal relaxation due to the increased load on the glenoid implant interface
- improved recovery of active arm elevation due to an increased deltoid moment arm and improved deltoid deflection angle

Range of movement with reverse prostheses

An improvement in the range of movement can be achieved with the following measures:

- inferior positioning of the baseplate
- subsequent refixation of the tubercula
- resection/partial resection of the supraspinatus tendon

Inferior positioning of the baseplate

A caudal positioning of the baseplate and consequently the glenoidal sphere shows an improved range of movement for adduction and abduction as well as internal and external rotation [25]. The superior tilt leads to increased relaxation rates for the baseplate. The effect of the inferior tilt has yet to be explained fully [26, 27].

Refixation of the tubercula

Originally the refixation of the tubercles for reverse prostheses was not mandatory. However, for external rotation, it has unequivocal advantages. Anakwenze et al. show an improvement by 10° in the external rotation with refixation of the tubercula using reverse endoprostheses [28]. Differing fixation mechanisms including wire cerclage systems are described for stable fixation [29].

Resection/partial resection of the supraspinatus tendon

Literature shows a stable construct through resection of the supraspinatus tendon [30]. The positive effects of supraspinatus resection depend on the medialisation and lateralisation of the glenoid sphere [20].

But why stemless shoulder endoprosthetics?

We have perceived the following classifications for stem length:
Type A, stemless: <50 mm, with isolated- fixation
Type B, short stem: 50-100 mm stem length
Type C, standard stem: 100-150 mm stem length
Type D, long stem: >150 mm stemless length (generally for revisions)

Razfar et al. [31] compared joint loading between a stemless prosthesis, a short stem prosthesis and a standard prosthesis using finite element analysis. They showed that the cortical load in the proximal humerus in comparison with a normal load amounted to 48% for a standard stem, 78% for a short stem and 101% for a stemless system. It is expected that the stress shielding of the humerus will be reduced drastically using short stems or completely stemless systems.

The question of stress shielding is already being pursued for anatomical stemless prostheses. Churchill et al. [22] reported no osteolysis zones in the proximal humerus using the Simpliciti™ prosthesis *(Wright Medical)* in a prospective trial with 49 patients after 2 years.

Huguet et al. [32] reported no stress shielding or other signs of relaxation after 3 years of use of an anatomical stemless TESS prosthesis. Hawi et al. [33] reports on the Eclipse™ prosthetic *(Arthrex)* and after five years found no evidence of relaxation. Habermeyer et al. [34] reported in only one case of tuberculum majus osteolysis after a 5-year follow-up of 39 patients with the same prosthesis; the authors observed a relaxation line in one patient and partial proximal osteolysis in three patients.

But why not also have stemless reverse shoulder prostheses?

The aforementioned principles of reverse prostheses can also be applied directly to stemless systems; in some cases, they are easier to attain with stemless prostheses.

If one considers primary care as well as revisions with a steadily increasing number of reverse shoulder prostheses [35], bone-saving concepts are of interest for the reasons described above. An additional advantage is the situation with a periprosthetic fracture after endoprosthetic care. Fractures often occur in anatomically unfavourable areas along the course of the radial nerve (N. radialis) after using conventional reverse protheses (▶Fig. 11). In contract the fractures using stemless reverse prostheses are located directly subcapitally in anatomically more favourable areas (▶Fig. 12).

When considering stemless reverse systems, one must differentiate between inlays systems and onlay systems. With inlay systems (e.g. the TESS™ system) the resection level is higher, which allows for more bone to be preserved. With onlay systems (e.g. EASYTECH®) the resection level of the head of the humerus is lower; this gives the operating surgeon more room to prepare the glenoid.

Fig. 11 *| Typical facture localisation during insertion of a reverse prosthesis with a stemless in the anatomical height of the radial nerve (N. radialis)*

Although this concept is still relatively new, several stemless models of reverse shoulder endoprostheses have been launched onto the market. Inlay systems need to be differentiated from onlay systems in this case.

A typical representative of the inlay system is the Total Evolutive Shoulder System (TESS™, *Zimmer Biomet*)

The TESS prosthesis is the first and best researched stemless-free reverse system [32, 36-39]. A reverse corolla is characteristic of the TESS system, in which the reverse polyethylene can be accommodated at different heights (▶Fig. 13).

Based on the inlay principle, the resection level of the humerus is higher and more bone remains on the proximal humerus; however, this complicates the preparation of the glenoid in comparison with only systems. For this reason, reconstructing the glenoid often requires increased retractor pressure, often leading to partial destruction of the cortical rings on the metaphysis. This in turn reduces the primary stability after including the reverse corolla.

The reverse Corolla of the TESS™ system can be lengthened by using a stem and anchored

Fig. 12 *| Typical fracture localisation after a fall with a stemless reverse prosthesis*

Fig. 13 *| Humeral corolla for the reverse TESS™- prosthesis*

Fig. 14 *| Stemless reverse TESS™ prosthesis with glenoidal component*

distally with or without the use of cement. The baseplate has a central peg as well as angle-stabilising screws or optional spikes to mounting (▶Fig. 14).

The metal-back glenoid of the TESS™ prosthesis has properties that are characterised by comparatively long survival times in more recent studies [40, 41].

Joint geometry after treatment with the reverse TESS™ prosthesis

Depending on individual investigations, the desired and expected change in the geometry of the joint after implantation of a TESS™ prosthesis could be determined [39]. A scattering range of 8-20 mm was found through medialisation of the centre of rotation using a reverse prosthesis [2, 42-44]. We could show an average medialisation of approximately 20 mm. The increase in acromiohumeral distance in our study was 16.1 mm on average. This is at the upper end of literature references [2, 38, 43, 45-47]. Part of this distalisation should be achieved preferably by positioning the baseplate distally to the glenoid. This corresponds to the height of the centre of rotation around the lower edge of the glenoid. In our study this value decreased significantly by an average of 4.3 mm after prosthesis implantation. This corresponds somewhat to the measurements from Boileau et al. [2], who described on average a similar distalisation of approximately 4 mm.

Clinical results

The various shafted reverse shoulder prostheses showed a large range from 40 to 60 points for the postoperative absolute Constant score [2, 48-51]. We observed patients treated with the reverse TESS™ prosthesis with an absolute Constant score of 55 points (and therefore in the upper range).

The differences in the indication groups were also interesting. They showed that patients with defect arthropathy had a relative Constant score of 79.7%. Revision cases of previous treatment with prosthesis showed a relative Constant score of 73.5%. Patients who were treated with the reverse TESS™ system due to fractures with or without prior osteosynthesis showed a relative Constant score of only 67.3%.

Reverse TESS™ and inferior notching

Notching was described in 0-88% of cases [2, 8, 50-54]. In the Zumstein review [15], the total rate of notching was 35.4%. In addition to offset increase [55] and the use of off-centred glenoidal spheres [26], the inclination angle of the humeral component can also reduce notching significantly [56].

The most commonly used reverse shoulder systems, such as the Delta X-tend™ (DePuy Synthes), the Aequalis Reversed™ (Tornier) and the Affinis reverse™ (Mathys) have a neck-shaft angle of 155°. Kempton et al. [56] described a significantly lower incidence for notching using a prosthesis with a neck-shaft angle of 145°.

Humeral relaxation

The rate of humeral relaxation cannot be disregarded even with convention shaft systems. A multicentric analysis showed a rate of aseptic stemless relaxation of 6% [57]. Further works on reverse shaft shoulder systems showed humeral relaxation rates of 1.3% [15], 2%
and 3% [58].

Ballas et al. [36] found no humeral relaxation in 56 reverse TESS™ implantations in patients with the results of a fracture as well as revision cases where stemless treatment was discarded.

Restraint is advisable before shaft-free reverse treatment of the resulting conditions of fractures as well as revisions of implanted anatomical stemless prostheses or surface replacement prostheses. In a pathohistological examination we were able to prove with explants from surface replacement prostheses that the bone quality underneath the implant decreases significantly with increasing implantation time and therefore no longer seems suitable for the use of stemless implants [59].

■ A typical representative of an onlay system is the EASYTECH® system (FX SOLUTIONS)

The reverse version of the shaftless EASYTECH® system has been implanted approximately 1,000 times.

Glenoid

The baseplate has a diameter of 24 mm and therefore is deliberately kept very small. The central stem has a length of 17 mm and a diameter of 7.5 mm. This can be extended by 6 and 10 mm with the corresponding adapters. The four screws that stabilise the angle allow for angulation of +/- 12 degrees (▶Fig. 15).

A distance of 12 mm from the lower boundary of the glenoid is recommended for the localisation of the central hole in the glenoid.

The recommendation from Kelly et al. [60] was used in this case; it was determined using investigations of cadavers that the best stabilisation of the baseplate is possible at this position. After removing the surrounding soft tissue from the glenoid, the 12-mm rule should be observed when installing a "Matsen Cross". For less experienced operating surgeons, the company sells an instrument to measure 12 mm from the inferior edge of the glenoid.

The glenoidal sphere is available and slightly lateralised (3.5 mm) in diameters of 36 mm and 40 mm. A small inclination of 10 degrees is also implemented. The glenoidal sphere is fixed to the baseplate with a central locking screw, which simplifies the process of securely placing the glenoidal sphere on the baseplate and the verification of placement. The glenoidal sphere is available in both centred and off-centred models. A titanium nitrate component is also available to those with allergies (▶Fig. 16).

Humerus

The osteotomy angle of the humerus is 145°. The EASYTECH® prothesis' epiphyseal anchor implant is available in three diameters (30, 34 and 38 mm). The length of the anchor implant is always 22 mm. It interlocks with the periphery of the epiphysis near the corticalis with 5 saw blade-like anchoring pegs (▶Fig. 17).

Fig. 15 | The EASYTECH® prosthesis' baseplate with central peg and angle-stabilising screws

Fig. 16 | Centred and off centred glenoidal sphere

Fig. 17 | The humeral anchor of the EASYTECH® prosthesis with central peg and 5 peripheral teeth with anchoring pegs

Fig. 18 | Stemless reverse EASYTECH® prosthesis

The onlay PE components are bound to the metal plug cone so that there is no risk of dissociation or incorrect fitting occurring intraoperatively. The PE components as well as the glenoidal sphere is available with diameters from 36 to 40 mm and with heights of +3, +6 and +9 mm. This can be combined with all anchor systems. Depending on the rotation adjustment of the only PE components in relation to the metaphyseal anchor plate, additional lateralisation of the humerus can be achieved, resulting in the MGLH (Medial Glenoid/Lateral Humerus). The onlay principle allows a deeper humeral resection, resulting in more space for glenoidal preparation (▶Fig. 18).

Personal experiences with this system show that glenoid preparation and implantation is easier than with inlay systems due to the onlay principle. The epiphyseal anchor system yields a surprisingly high stability and therefore can also be used in difficult anatomical conditions (▶Fig. 19).

Results

There are considerable differences in the case of reverse shoulder endoprostheses. The effects of a glenoidal or humeral offset increase must be taken into account.

Fig. 19 | Before and after implantation of an EASYTECH® reverse stemless prosthesis with a dysplastic humerus.

Stemless reverse prostheses are proving to be an interesting development. Onlay prostheses are of special interest as more space is available for glenoidal preparation and the humeral offset can be increased. However, clinical results with these prostheses are absolutely necessary. While clinical results with these prostheses are still necessary, the data and clinical experience available so far allow for the prediction that the market share of stemless reverse shoulder prostheses will also increase.

Conclusion

Reverse shoulder prostheses have become more important over the past decades. More reverse shoulder prostheses are being used than anatomical ones in some specialised centres for shoulders. Stemless systems are being used in greater numbers. This protects the bone substance for further interventions and reduces stress shielding. In this work the possibilities of reverse shoulder endoprosthetics are described based on the experience of the current study situation.

Jerosch J, von Engelhardt LV:

Stemless reversed shoulder arthroplasty – an interesting concept

Summary: Over the last decade the number of reverse shoulder replacement increased significantly more compared to anatomic replacement. Modern stemless designs come more and more in use. These however are observed still with caution. On the basis of a literature review the current stemless reverse systems are described.

Keywords: reversed shoulder replacement – stemless shoulder arthroplasty – cuff tear arthroplasty

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Conflict of interests: Prof. Dr. Dr. h. c. Jörg Jerosch declares that he has a connection to the *Corin Group* (EASYTECH®) as a lecturer. Prof. Dr. Lars Victor Baron von Engelhardt declares that he has a connection to the *Corin Group* (Mini Hip™) in the form of an allowance as a consultant for training courses.

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