Dismayed by the results of anatomical shoulder prostheses, Grammont and Baulot sought a shoulder prosthesis capable of addressing the most extreme pathoanatomical conditions observed in the final stages of shoulder arthropathy. Their belief was that such an implant should include design features that imparted: extraordinary stability; the capability of effective function in the absence of the rotator cuff or, as they stated, “…with the sole deltoid…”; and durable glenoid fixation. These principles materialized in their development of the ‘delta’ or ‘reversed’ shoulder prosthesis in 1987, and were espoused in their first publication in the English literature in 1993.¹

Numerous ill-fated constrained shoulder prosthetic systems pre-dated Grammont’s reverse shoulder prosthesis, which in its modern form has been used to treat disorders of the shoulder for more than 15 years. Initially limited to the countries of Europe, the opportunity for surgeons in the US to use a shoulder implant of reversed design in an unrestricted manner came with US Food and Drug Administration (FDA) approval in November 2003, with the first device implantation in March 2004 by Carl Basamania, MD, at Duke University. Subsequently, seven reverse shoulder arthroplasty systems have become available for use in the US: Delta CTA™ (DePuy, a Johnson and Johnson Company), Delta Xtend™ (DePuy, a Johnson and Johnson Company), Zimmer® Trabecular Metal™ Reverse Shoulder System (Zimmer, Inc.), Aequalis Reversed® Shoulder Prosthesis (Tornier, Inc.), Reverse® Shoulder Prosthesis (Encore Medical, L.P.), Anatomical Shoulder™ Inverse/Reverse (Zimmer, Inc.), and the Equinoxe® Reverse Shoulder (Exactech, Inc.). In conjunction with the arrival of these implants and the widespread dissemination of somewhat limited basic science and clinical information, surgeons in the US soon became captivated by both the power and the pitfalls of the application of reverse shoulder prostheses.

Grammont intended a functional, stable, and durable shoulder prosthesis for patients with “…shoulders that are broken, dislocated or unstable, stiff, or associated with irreparable lesions of the rotator cuff.”¹¹ This remains an apt description of the clinical disorders of the shoulders for which reverse arthroplasty is currently chosen as the preferred method of treatment: end-stage rotator cuff tear arthropathy; failed rotator cuff repair; shoulder trauma and its sequelae, including certain non-operative and operative failures; and failed shoulder reconstructions with and without the use of a prosthetic implant. With the use of reverse shoulder arthroplasty, surgeons strive to achieve outcomes that are improvements on Neer’s limited goals, which are the historical benchmark established for the cuff-deficient arthritic shoulder.²

The author identified 27 publications in the English literature—22 from Europe and five from the US—that report the results of reverse shoulder arthroplasty performed for a range of disorders.¹²⁻²⁸ These studies provide information on 915 patients followed for an average 38.7 months. Relatively meager follow-up, a 22% rate of complications, and an additional operation rate exceeding 20% notwithstanding, the patient benefit from reverse shoulder arthroplasty is undeniable. With the remarkable clinical outcomes achievable in these extreme cases alone, Grammont’s theories and concepts have been validated. However, as experience with reverse shoulder arthroplasty becomes more widespread and short-term follow-up evolves into and subsequently goes beyond mid-term follow-up, challenging scenarios are emerging that command the attention of investigators intent on understanding and refining the appropriate place of this procedure in their shoulder care armamentarium.

Prosthetic Center of Rotation
Fundamental to Grammont’s design of the hemisphere-shaped glenoid component with no neck is the concept that the center of rotation of the prosthetic joint is medial to the normal joint center of rotation. The purpose was two-fold: first, to improve deltoid muscle power by increasing its lever arm; and second, to reduce torque forces applied to the glenoid component. These principles were in stark contrast to earlier prosthetic solutions of constrained design, whose features included a more lateral center of rotation that amplified the torque forces on the glenoid component and shorter deltoid lever arm. As these prostheses were unable to withstand the forces generated during normal shoulder function, high rates of component failure and loosening were observed, leading to the abandonment of constrained shoulder prostheses.

A reverse shoulder prosthesis with the center of rotation lateral to the glenoid, as in the normal shoulder, was developed to address the perceived...
Shoulder

shortcomings of the Grammont reverse concept. These shortcomings included inferior scapular neck notching, motion limitations, loss of rotational strength, and loss of deltoid contour. Biomechanical studies have raised concerns about higher forces generated at the baseplate-bone interface in a prosthesis of this type; however, these forces can be effectively neutralised by enhanced initial fixation of the implant to the bone. In a laboratory model, glenoid implant positioning that favored a slight inferior tilt (~15°) reduced the tensile forces and micromotion at the implant-bone interface while increasing compressive forces. A greater lateral offset may have the theoretical advantages of improving glenohumeral range of motion compared with a model with lesser offset and generating sufficient compressive forces to enhance glenohumeral stability.

The rotational weakness experienced by patients undergoing reverse shoulder arthroplasty is a byproduct of many factors, most importantly, perhaps, the pathoanatomy of their disease process. A comparison of the published results of the reverse shoulder prosthesis with a medial center of rotation versus a reverse shoulder arthroplasty system with a lateralized center of rotation indicates that for the latter notching has been eliminated, forward elevation is significantly reduced, the incidence of complications is no different, and the rate of re-operation is higher.

External Rotation Deficit
The rotational weakness experienced by patients undergoing reverse shoulder arthroplasty is a byproduct of many factors, most importantly, perhaps, the pathoanatomy of their disease process. While both the infraspinatus and the teres minor contribute to external rotation, the former assumes greater importance when the upper limb is in lower positions while the latter is more significant when the upper limb is in higher positions. This weakness of external rotation is further explained by medialization of the center of rotation (to the norm) of the prosthetic reconstruction. The effective length of the external rotators is diminished and the posterior deltoid is unable to effectively compensate as the upper limb is progressively abducted. This results in the ‘hornblower’s phenomenon,’ a sign of the functional loss of the teres minor, and impedes functions that require the use of the hand not only about the head—e.g. drinking from a glass or bottle, applying facial cosmetics, applying hair-care products, brushing/combining the hair, etc.—but away from the body as well. In the setting of reverse shoulder arthroplasty, an intact and relatively healthy teres minor results in better active external rotation as well as improved functional outcomes.

Theoretically, external rotation in the setting of reverse shoulder arthroplasty may be improved by simple measures, but only if the teres minor is healthy and functional. With the elimination of pain and the restoration of articular smoothness, muscle re-education and strengthening exercises are possible. Placement of the humeral component in retroversion may result in functional external rotation improvement as the excursion distance between the posterior edge of the articulating polyethylene surface and the scapular neck is increased. Musculotendinous transpositions utilizing primarily the latissimus dorsi improve functional external rotation in the rotator-cuff-deficient shoulder. When performed in the setting of reverse shoulder arthroplasty, transposition of the latissimus dorsi with or without transposing the teres major and effective active external rotation of the upper limb are possible.

The Glenoid
Many experienced shoulder surgeons believe that glenoid exposure, glenoid preparation, and glenoid prosthesis implantation without the use of bone cement represent the essence of reverse shoulder arthroplasty. The glenoid must be assessed radiographically. If it has been unaffected by the disease process and is perfectly displayed on both the anteroposterior and the axillary views, no additional imaging is employed. However, in the majority of cases the morphology of the glenoid only be determined can with the use of computed tomographic (CT) scanning, which helps to determine bone loss, orientation of the glenoid face with respect to the axis of the scapula, and the volume of the glenoid vault.

A requisite for a successful outcome is the initial mechanical security of the glenoid component, which, in turn, requires both structural adequacy and strength of the glenoid following preparation for component implantation. This is dependent on excellent screw fixation, fixation of the central post in the glenoid vault, and stable support for the baseplate in contact with the glenoid subchondral bone. Intrascapuloseous screw placement within the densest bone is suggested to be biomechanically superior based on experimental studies with bone models.

The glenoid vault must have sufficient depth to contain the central post of the baseplate. If depth is lacking, there are two possible explanations: either the baseplate lacks sufficient subchondral support or the post has violated the scapular vault integrity, creating a stress riser. Intrinsic disease, response to wear, or damage from previous surgery can change the orientation of the glenoid face with respect to the axis of the glenoid—the so-called ‘version.’ An upper limit of 15–20° from the neutral axis is probably all that can be tolerated without corrective measures such as lowering the high side or structural grafting for the low side.

If structural graft is being considered, more than half of the surface support of the baseplate should be native bone and at least two-thirds or more of the post should be within the native bone. Structural glenoid surface graft is considered if baseplate support is compromised by 20% or more. The baseplate must be stabilised by one or more of the following mechanisms: post security, baseplate support on subchondral bone, and/or dependable screw purchase. Sometimes a staged procedure is necessary to allow bone graft healing, followed by prosthetic implantation. Sometimes, it is simply not possible to perform reverse shoulder arthroplasty due to irreconcilable glenoid bone deficiencies.

Scapular Notching
Scapular notching is the byproduct of a glenoid implant with no neck, the surgical positioning of the glenoid implant, and a 155° humeral component. The phenomenon has long been recognized and appears to be the osseous response to repetitive abutment of the articulating
polyethylene cup with the neck of the glenoid that is in proximity to the perimeter of the glenoid component.35,36 While it may develop at any location around the glenoid component, it is most apparent radiographically at the most superior aspect of the lateral scapular border.

Notching was first reported in the English literature by De Wilde et al., who observed the phenomenon in three of five cases.13 Lesser degrees of notching are reliably explained by an impingement process, while greater degrees of notching probably represent osteolysis secondary to accumulated polyethylene debris. The position of the reverse shoulder prosthesis center of rotation, variations of scapular neck morphology, and baseplate positioning and orientation have been shown to influence the development of scapular notching, especially inferiorly.11,13,17,31,32,38

Nearly all authors have reported notching and the distinct absence of its impact on outcomes. A negative correlation between the localization and extent of notching, as well as between increasing notch size and functional scores, active range, and patient satisfaction, has been reported as well.9,17 This heightened concern of scapular notching means that measures should be taken to prevent it. Not only is placing the glenoid component as inferiorly as possible more biomechanically favorable, but it also serves to diminish notching. Optimally positioned pre-operative radiographs enable the effective use of implant templates. This information is extrapolated to the intraoperative placement of the guide pin, whose point of entry into the glenoid and angular orientation dictates the final position of the baseplate and, subsequently, of the entire glenoid component. Alternately, Simovitch et al. have described the concept of ‘notch index’ and demonstrated its potential utility for the placement of the glenoid component.17

Summary
Reverse shoulder arthroplasty has a significant role in the treatment of many disorders of the shoulder that have in common permanent anatomical or functional loss of the rotator cuff contributing to an unstable center of rotation of the glenohumeral joint. Within the next five to 10 years, no topic in shoulder reconstruction is likely to assume greater importance or command more attention than reverse arthroplasty. One can easily anticipate that the scientific data pertinent to its design and application will exponentially increase. Many of today’s challenges, a few of which are mentioned above, will be resolved; in their place will appear different challenges in need of their own solution. The recipients of these endeavors—patients—will undoubtedly be gratefully rewarded in a manner consistent with the rewards that they have obtained from reverse shoulder arthroplasty in its current state.