GEOMETRIC ANALYSIS OF THE GRAMMONT REVERSE SHOULDER PROSTHESIS: AN EVALUATION OF THE RELATIONSHIP BETWEEN PROSTHETIC DESIGN PARAMETERS AND CLINICAL FAILURE MODES

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Introduction
In the early 1990’s, Paul Grammont designed a novel reverse shoulder prosthesis. Like previous designs, the Grammont inverted the anatomic concavities of the glenohumeral joint to create a physical stop; thereby, preventing superior humeral head migration. Unlike previous designs, the Grammont shifted the center of rotation medially (on the glenoid fossa) to reduce the effective lever arm and distally to tension the deltoid and improve its mechanics. These design improvements have been demonstrated to alleviate pain and improve function in patients suffering from cuff tear arthropathy, a degenerative condition that has been previously treated with unpredictable results. Not surprisingly, these successes have led to an expansion of its indications and an increase in the number of analogous reverse shoulder designs available in the marketplace, despite the well-documented complication rates. The incidence of scapular notching is reported to be high as 50%; the incidence of instability/dislocation is reported to be as high as 10%. Such rates have led surgeons to intentionally implant the prosthesis in a manner not intended by the manufacturers (e.g. fixing the glenosphere with a 15° inferior tilt or with a 4mm distal shift). For these reasons, the purpose of this study is to evaluate the relationship between the design parameters associated with the Grammont reverse shoulder and the commonly reported clinical failure modes.

Definitions
Inferior Impingement is defined as the point where the medial portion of the humeral liner extends past the distal portion of the glenosphere.
Superior Impingement is defined as the point where the lateral portion of the humeral liner extends past the superior portion of the glenosphere.
Range of Motion (ROM) is defined as the humeral rotation occurring between inferior and superior impingement. It should be noted, scapular rotation is not considered in this measurement; for comparative purposes, only humeral rotation is considered.
Jump Distance is defined as the lateral distance necessary for the glenosphere to escape from the humeral liner; it is a measure of the resistance to dislocation (assuming no impingement).
Offset is defined as the vertical distance between the center of the humeral liner and glenosphere; it is related to deltoid tensioning.
Humeral Constraint is defined as the ratio between humeral liner depth and width (at its face). For clarification, a constraint > 0.5 is a constrained joint.

Methods
The Grammont reverse shoulder was geometrically modeled using 3-D computer-aided design software (Unigraphics; UGS, Inc.). An assembly analysis was conducted to quantify the effect of several prosthetic design parameters (humeral neck angle, humeral liner constraint, glenosphere thickness, and glenosphere diameter) on several functionally relevant measurements (ROM, jump distance, and offset) during simulated humeral abduction/adduction. By implication, the relationship between the aforementioned design parameters and functional measurements will elucidate the failure mechanisms associated with the commonly reported clinical complications for reverse shoulder arthroplasty (scapular notching, dislocation, improper deltoid tensioning, etc…). Specifically, ROM, jump distance, and offset were quantified and compared for each of the following design conditions: as humeral neck angle varied from 130 to 165°; as humeral constraint varied from 0.250 to 0.3125; as glenosphere thickness varied from 17 to 21 mm; and as glenosphere diameter varied from 34 to 44 mm.

Results
The Grammont reverse shoulder (i.e. 155° neck angle, humeral constraint of 0.275, 36x19mm Glenosphere) was observed to impinge inferiorly and superiorly at 35° and 95° abduction, respectively. (Figure 1) Modifying the humeral neck angle by 5° shifts the ROM by 5° (in the same direction) by changing the points of impingement. (Figure 2) Modifying humeral neck angle by 5° also changes the offset from 0.25 to 0.5mm (in the same direction), depending upon the angle. Modifying the humeral constraint by 0.0125 changes the ROM by 4° (in the opposite direction) and the jump distance by 0.5mm (in the same direction). Modifying the glenosphere thickness by 1mm (when the humeral constraint is held constant) changes the ROM by 5° (in the same direction). Modifying the glenosphere diameter by 2mm (when the humeral constraint is held constant) changes the jump distance by 0.5mm (in the same direction).

Figure 1. Grammont Reverse Shoulder ROM

Discussion and Conclusions
The results of this study demonstrate the relationship between each design parameter and functional measurement. Furthermore, the results demonstrate the Grammont impinges on the glenoid inferiorly prior to the patient being able to adduct his/her arm to their side, as is necessary during activities of daily living (ADL). Similar results have been verified radiographically. For these reasons, the authors conclude that the 155° humeral neck angle makes the Grammont design susceptible to scapular notching and dislocation via inferior impingement. Future reverse shoulder designs should consider shifting the inferior impingement point to a location that permits a ROM better resembling a patient’s ADL. The application of these relationships is useful in the design of a reverse shoulder prosthesis that maximizes ROM and jump distance, minimizes impingement, and provides sufficient offset to tension the deltoid and maintain the well-documented biomechanical benefits associated with the design.

References