REVERSE SHOULDER DESIGN PARAMETER OPTIMIZATION USING THE GRAMMONT REVERSE SHOULDER

+*Roche, C; **Flurin, PH; ***Wright, T; ****Crosby, L; *Mauldin, M; *****Zuckerman, J
+*Exactech, Gainesville, FL; ** Bordeaux Merignac Clinic, FR; ***Univ. of Florida Dept. of Orth., Gainesville, FL; Wright State, Dayton OH; *****Hosp. for Joint Diseases, NY (352) 377-1140. Fax: (352) 378-2617. chris.roche@exact.com

Introduction
In the early 1990’s, Dr. Paul Grammont designed a novel reverse shoulder prosthesis. Unlike previous reverse shoulder designs, the Grammont shifted the center of rotation medially (to 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 previously treated with unpredictable results. However, the Grammont reverse shoulder is not without complication. The incidence of scapular notching is often reported to be greater than 50%; whereas, the incidence of instability/dislocation is often reported to be greater than 10%, particularly in revisions. These concerns have led surgeons to modify the implantation technique in a manner not originally intended by the manufacturers (e.g. placing the glenosphere in an inferior position and/or with a posteriorly directed tilt). The purpose of this study is to expand on previous work to elucidate the relationship between these and other design parameters and the commonly reported clinical failure modes and to use this data to recommend design parameters that minimize inferior impingement and maximize range of motion (ROM) and stability without requiring removal of the inferior glenoid (i.e. “pre-notching”) or lateralizing the center of rotation.

Methods
The Grammont reverse shoulder prosthesis was geometrically modeled using 3-D computer-aided design software (Unigraphics; UGS, Inc.) and assembled to a 3-D digitized scapula (3-D male scapula; Zygoe Media Group, Inc.) to create a functional glenohumeral joint. Prior to assembly, <2mm of bone was digitally removed from the glenoid fossa of the digitized scapula to create a flat surface; simulating surgical preparation. A geometric computer analysis was then conducted to quantify the effect of varying prosthesis design parameters on functionally-relevant measurements during simulated humeral abduction/adduction in the scapular plane. The evaluated design parameters were humeral neck angle, humeral liner constraint, glenosphere thickness, glenosphere diameter, and glenosphere distal offset. The evaluated functionally relevant measurements were inferior impingement, superior impingement, ROM, and jump distance.

We defined humeral liner constraint as the ratio of humeral liner depth to width. It should be noted that a humeral liner constraint > 0.5 is a constrained joint. We defined glenosphere distal offset as the amount of glenosphere distal overhang achieved by shifting the glenosphere distally on the glenoid fossa. As a point of reference the glenoid plate (i.e. “metaglene”) was assembled so that 0mm of glenosphere offset corresponds to where the glenoid plate stem was slightly inferior to the center of the glenoid, the implantation position recommended in the manufacturers’ surgical technique. We defined inferior impingement as the humeral abduction at which point the medial portion of the humeral liner impinges on the scapula. We defined superior impingement as the humeral abduction at which point the lateral portion of the humeral liner impinges on the scapula. We defined ROM as the humeral abduction/adduction occurring between inferior and superior impingement. Finally, we defined jump distance as the lateral distance necessary for the glenosphere to escape from the humeral liner at varying degrees of abduction; it is a measure of prosthesis stability.

Specifically, inferior impingement, superior impingement, ROM, and jump distance were quantified and compared for each of the following design conditions: as humeral neck angle varied from 135° to 165°; as humeral constraint varied from 0.250 to 0.300; as glenosphere thickness varied from 18mm to 24mm; as glenosphere diameter varied from 34mm to 44mm, and as the glenosphere was distally offset from 0mm to 6mm of overhang. The effect of each was assessed independently to evaluate individual contributions on impingement, motion, and jump distance and in combination to evaluate combined contributions on impingement and motion. The coefficient of determination ($R^2$) was used to quantify the linear regression of each design parameter and each functionally relevant measurement.

Results
The geometric computer analysis demonstrated that the Grammont reverse shoulder (i.e. 155° neck angle, humeral constraint of 0.275, and 36x19mm glenosphere) impinged inferiorly and superiorly on the glenoid at 30.75° and 95° of humeral abduction thereby producing a total ROM of 64.25° with an average jump distance of 10.0mm over that range. By independently evaluating each design parameter the following linear relationships were elucidated: glenosphere thickness and ROM ($y = 5.3929x - 38.071; R^2 = 0.9995$), humeral liner constraint and ROM ($y = -224.59x + 126.05; R^2 = 0.9989$), glenosphere distal offset and ROM ($y = 4.0446x + 65.688; R^2 = 0.9744$), glenosphere diameter and jump distance ($y = 0.0092x - 0.0011; R^2 = 0.9999$), and humeral liner constraint and jump distance ($y = 1.8449x - 0.1781; R^2 = 0.9999$). Modifying humeral neck angle did not show a linear correlation with either jump distance or ROM; it did, however shift the points of impingement. To clarify, decreasing the humeral neck angle by 5° results in a 5° decrease in the inferior and superior impingement points.

Comparing the combined effect of each design parameter demonstrated that the largest improvements in ROM (from 58.75° to 108.5°) could be achieved by distally offsetting the glenosphere (from 0mm to 6mm) and increasing glenosphere thickness (from 18mm to 24mm); assuming a Grammont reverse shoulder design with a 36mm glenosphere, 155° humeral neck angle, and a 0.275 humeral liner constraint. The next largest improvements in ROM (from 51.75° to 95.25°) can be achieved by increasing glenosphere thickness (from 18mm to 24mm) while decreasing humeral liner constraint (from 0.300 to 0.250); assuming a Grammont reverse shoulder design with a 36mm glenosphere, 155° humeral neck angle, and a 0.250 humeral liner constraint. The next largest improvements in ROM (from 51.75° to 95.25°) can be achieved by distally offsetting the glenosphere (from 0mm to 6mm) while decreasing humeral liner constraint (from 0.300 to 0.250); assuming a Grammont reverse shoulder design with a 36mm glenosphere, 155° humeral neck angle, and a 0.250 humeral liner constraint. The next largest improvements in ROM (from 51.75° to 95.25°) can be achieved by distally offsetting the glenosphere (from 0mm to 6mm) while decreasing humeral liner constraint (from 0.300 to 0.250); assuming a Grammont reverse shoulder design with a 36mm glenosphere, 155° humeral neck angle, and a 0.250 humeral liner constraint. The next largest improvements in ROM (from 51.75° to 95.25°) can be achieved by distally offsetting the glenosphere (from 0mm to 6mm) while decreasing humeral liner constraint (from 0.300 to 0.250); assuming a Grammont reverse shoulder design with a 36mm glenosphere, 155° humeral neck angle, and a 0.250 humeral liner constraint. The next largest improvements in ROM (from 51.75° to 95.25°) can be achieved by distally offsetting the glenosphere (from 0mm to 6mm) while decreasing humeral liner constraint (from 0.300 to 0.250); assuming a Grammont reverse shoulder design with a 36mm glenosphere, 155° humeral neck angle, and a 0.250 humeral liner constraint.

Discussion and Conclusions
This study quantified the linear relationships between several reverse shoulder design parameters and functional measurements during simulated humeral abduction/adduction in the scapular plane using the Grammont reverse shoulder. Additionally, this study coupled and ordered those design parameters that produce the greatest successes in ROM. Specifically, inferior impingement can be minimized by decreasing humeral neck angle, decreasing humeral liner constraint, increasing glenosphere thickness, and/or distally offsetting the glenosphere. ROM can be increased by decreasing the humeral liner constraint, increasing the glenosphere thickness, and/or distally offsetting the glenosphere. Jump distance can be increased by increasing the humeral liner constraint and/or increasing the glenosphere diameter. The authors contend that these elucidated relationships are useful for designing a reverse shoulder prosthesis that minimizes inferior impingement and maximizes ROM and stability; however, we recommend that these relationships be applied in concert to minimize lateralization of the center of rotation in order that Dr. Paul Grammont’s successes can be reproduced.

References