Model for Estimating the Threshold Mechanical Stability of Structural Cartilage Grafts Used in Rhinoplasty

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ABSTRACT

Objectives: Stiffness values of grafts used in rhinoplasty are currently unknown; characterizing the mechanical properties of columellar, alar, and L-strut replacements is valuable because softer engineered tissues are more time- and cost-efficient to manufacture. The aim of this study is to quantitatively identify the threshold mechanical stability (e.g. Young’s Modulus) of structural cartilage grafts used in rhinoplasty.

Methods: Ten urethane “mechanical phantoms” of identical size (5x20x2.3mm) and varying stiffness (0.360 to 0.85 MPa in 0.05 MPa) were made. A focus group of rhinoplasty surgeons (n=12, 5-40 years in practice) were asked to arrange the phantoms in order of increasing stiffness. Then, they were asked to identify the minimum acceptable stiffness for three clinical applications: lateral crural, columellar, and L-strut grafts. The surgeons were tested twice after one week to evaluate intra-rater consistency.

Results: Each surgeon, the threshold stiffness for each clinical application differed from the threshold values derived by logistic regression by no more than 0.05 MPa (accuracy to within 10%). Specific thresholds were 0.446, 0.551, and 0.590 MPa for columellar, alar, and L-struts respectively. For comparison, human nasal septal cartilage is approximately 0.8 MPa [1].

Conclusions: There was little inter- and intra-rater variation of the identified threshold values for adequate graft stiffness. The threshold values will be useful for designing tissue-engineered or semi-cartilaginous grafts for use structural nasal surgery.

INTRODUCTION

Surgeons traditionally use autologous cartilage as a source of tissue grafts. Harvesting cartilage from patients has disadvantages such as donor site morbidity, inadequate or non-uniform stiffness of the harvested tissue, and a limited amount of harvestable tissue. These disadvantages drive the motivation of research labs to develop engineered cartilage tissues [2]. However, the quantitative threshold for grafts is unknown because surgeons qualitatively determine whether donor tissue is structurally suitable.

MATERIALS AND METHODS

Ten urethane specimens were made with varying stiffness from 0.36 to 0.85 MPa in 0.05 MPa increments. Polyurethane prepolymer, polyol-plasticizer, and a white urethane dye were combined allowed to set for 24 hours. The stiffness of the rubber was controlled by adding a phthalic acid, benzyl butyl ester softerner in different proportions. The rubber sheets were then cut into 20mm x 5mm rectangles, so each specimen was nearly identical in color, sheen and size (20mm x 5mm x 2.3mm). It is important to emphasize that the urethane specimens were only used as “mechanical phantoms” and were not used, or intended to be used, as actual grafts. The elastic modulus of each mechanical phantom was determined with a force transducer (Bose-ELF). The softest and hardest specimens were made to have an identical pair, to act as controls. The specimens were then labeled with colored dots to ensure blind-testing of the surgeons.

The focus group consisted of experienced head and neck surgeons affiliated with the UC Irvine Medical Center (n=12, 5-40 years in practice). Each surgeon was presented with all ten specimens and was asked to arrange the mechanical phantoms in order of increasing stiffness. Then, they were asked to identify the minimum acceptable stiffness for three clinical applications: lateral crural, columellar, and L-strut grafts. The surgeons were tested again after one week to evaluate intra-rater consistency.

RESULTS

Rater Accuracy: Each surgeon was given an accuracy rating which was determined by how many mechanical phantoms he or she correctly arranged in order of increasing stiffness.

Rater Consistency: Intra-rater reliability was determined by comparing the two responses collected during different testing sessions for each surgeon.

Logistic Regression: The threshold stiffness values for alar, columellar and L-strut grafts were determined with a binary logistic regression between the mechanical acceptability and non-acceptability. The data collected from the surgeons were fit to equations of the form f(z) = 1/(1+e-(a+bx)) using Matlab. The accuracy of the model was evaluated with the Hosmer-Lemeshow test. The p-values for all three data sets ranged from 0.07 to 0.1, indicating no statistical evidence for lack of fit, or that there is no statistical significance between the expected values calculated with model and the actual data collected.

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CONCLUSION

The calculated thresholds, 0.446 MPa for columellar grafts, 0.551 MPa for alar grafts, and 0.590 MPa for L-struts is consistent with the qualitative description of the grafts. Columellar grafts require minimum strength because they are used composite structures, alar grafts require intermediate stiffness because they are more subject to deformation than columellar grafts, and L-struts require high mechanical strength because they provide the most structural support of the three grafts. The threshold data also gives insight to the mechanical stability of the nose. Future work consists of collecting more data from other surgeons.

REFERENCES