Changing the Convexity and Concavity of Nasal Cartilages and Cartilage Grafts with Horizontal Mattress Sutures: Part I. Experimental Results

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Prior studies indicated that horizontal mattress sutures can control the curvature of a convex lateral crus. This study undertook to ascertain the ideal spacing for mattress sutures, determine what effect they have on the subsequent strength of the cartilage, and compare that to the resultant strength after scoring procedures used to control curvature. Curved fresh cadaver septa of various thicknesses (0.5, 1, and 1.5 mm) were used. The ideal spacing (gap between suture purchases) for the mattress suture was sought in 15 specimens. The consequent change in stiffness (modulus) of the cartilage was measured in nine other specimens before and after suture placement and after scoring. If the spacing was too large, instability resulted. If it was too small, curvature correction could not be obtained. An ideal mattress spacing (6 to 8 mm for 0.5-mm specimens and 8 to 10 mm for 1.5-mm specimens) removed most curvature and provided stability. The mattress suture increased the stiffness (modulus) above normal and far above that when the curvature was removed by scoring. The mean composite modulus before suturing was 4.6 MPa. After ideally spaced sutures, it was 6.2 MPa, a 35 percent increase in stiffness. After scoring to improve curvature, it was 2.4 MPa, a 48 percent reduction in stiffness ($p = 0.02$, Wilcoxon signed rank test). The horizontal mattress suture technique corrects cartilage curvature if the appropriate spacing is used. The corrected cartilage is stiffer/stronger than normal cartilage and much stiffer/stronger than if scored. (*Plast. Reconstr. Surg.* 115: 589, 2005.)

One of the most frustrating aspects of rhinoplasty has been the difficulty in controlling the curvature (e.g., convexity and/or concavity) of nasal cartilages. The use of mattress sutures to control cartilage shape is not new. Mustardé[1] and Tardy et al.[2] used various mattress suture techniques to modify the shape of ear cartilage, particularly that of the prominent ear. Byrd et al.[3] used a vertical mattress suture to successfully control the curvature of the nasal septum. Previous studies involving aesthetic rhinoplasty have also shown that suture techniques can be extremely helpful. The most conspicuous example is the use of the lateral crural mattress suture[4] for removing the convexity of the lateral crus and therefore allowing correction of virtually all bulbous or broad tip noses.

One of the problems with horizontal mattress suture techniques, however, is the potential difficulty of execution (particularly for the first-time user). If the spacing between mattress bites is too small, the convexity is incompletely corrected. If the spacing between needle purchases is large, the cartilage may collapse. In our previous study,[4] we noted that there was an

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ideal spacing between needle purchases (bites) to remove the convexity when tightening the knot. That study involved the lateral crura, which is typically 0.5 mm thick. One purpose of this study, therefore, was to find the optimum spacing when applying a mattress suture to cartilage of various thicknesses. A second purpose was to note whether the mattress suture has any beneficial effect on cartilage in terms of the resultant strength or stiffness. The third purpose was to compare the results of suture techniques to that of scoring procedures that have always been associated with an unfavorable reduction in the stiffness of cartilage.

Materials and Methods

Our pilot study revealed that the two parallel suture strands on the convex side of a piece of cartilage act as a brace for the cartilage and provide stability (Fig. 1). As the knot is tied, the length of those two braces shortens and consequently the cartilage on the longer convex side shortens as well. It also indicated that when the spacing is too small, the convexity of the cartilage is not sufficiently corrected but the specimen does not lose stability (i.e., no effect) (Fig. 2, *above*). If the spacing is too large, the convexity is corrected but the cartilage buckles and stability is lost (i.e., buckled) (Fig. 2, *center*). If the spacing is ideal, the convexity is essentially eliminated and the specimen remains stable (i.e., curvature corrected) (Fig. 2, *below*).

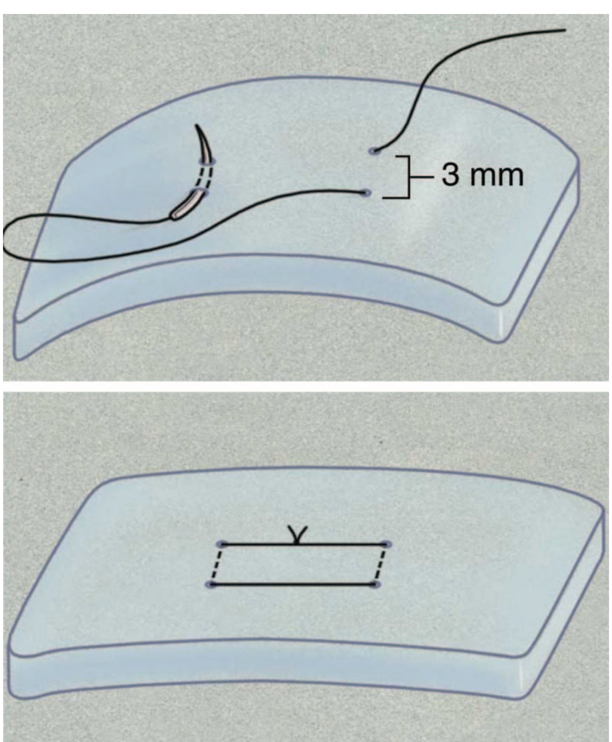

FIG. 1. The convexity of cartilage (*above*) can be largely removed by a mattress suture (*below*). The two parallel suture strands on the convex side of the cartilage act as a brace for the cartilage and provide stability. As the knot is tied, the length of those two braces shortens and consequently the convex side shortens to match that of the concave side.

Six cadavers rendered three specimens (30 × 6 mm) each and three cadavers rendered two specimens (30 × 6 mm) each, for a total of 24 specimens (to be used for both experiments). Six millimeters was chosen as the width for these specimens because that is the recommended width of the lateral crus following cephalic trim to maintain sufficient integrity for manipulation by sutures. The specimens were then allocated into three groups on the basis of their approximate thickness in the centralmost portion (0.5, 1, or 1.5 mm) where sutures would later be placed. If the cartilage did not already possess an intrinsic curvature, it was shaved or scored lightly on one side to produce one.

Experiment 1

Fifteen specimens were used for this experiment. Five specimens were used to test nine spacings at each of three thicknesses (0.5, 1, and 1.5 mm). We needed to test the spacing between the two suture purchases at every 1-mm interval from 4 to 12 mm (nine spacings). Because multiple suture holes are known to weaken cartilage, each specimen was tested with no more than two suture spacings. Thus, we needed five specimens to test nine spacings. To reduce the risk of needle holes overlapping and weakening the cartilage, the second suture spacing for any one specimen differed by 4 mm from the first suture spacing. The pattern for suture placement in the five specimens was as follows: 4 and 8 mm; 5 and 9 mm; 6 and 10 mm; 7 and 11 mm; and 8 and 12 mm (Fig. 3). This resulted in two values for the 8-mm spacing and one value for each of the other spacings. To test all three thicknesses, we needed a total of 15 specimens. To create these spacings, horizontal mattress sutures (5-0 nylon) were inserted (Fig. 1). The needle was passed perpendicular to the length of the cartilage specimen. The purchase size for all horizontal mattress sutures was approximately 3 mm.

Experiment 2

Nine cartilage specimens were tested for their strength or stiffness. From a mechanical

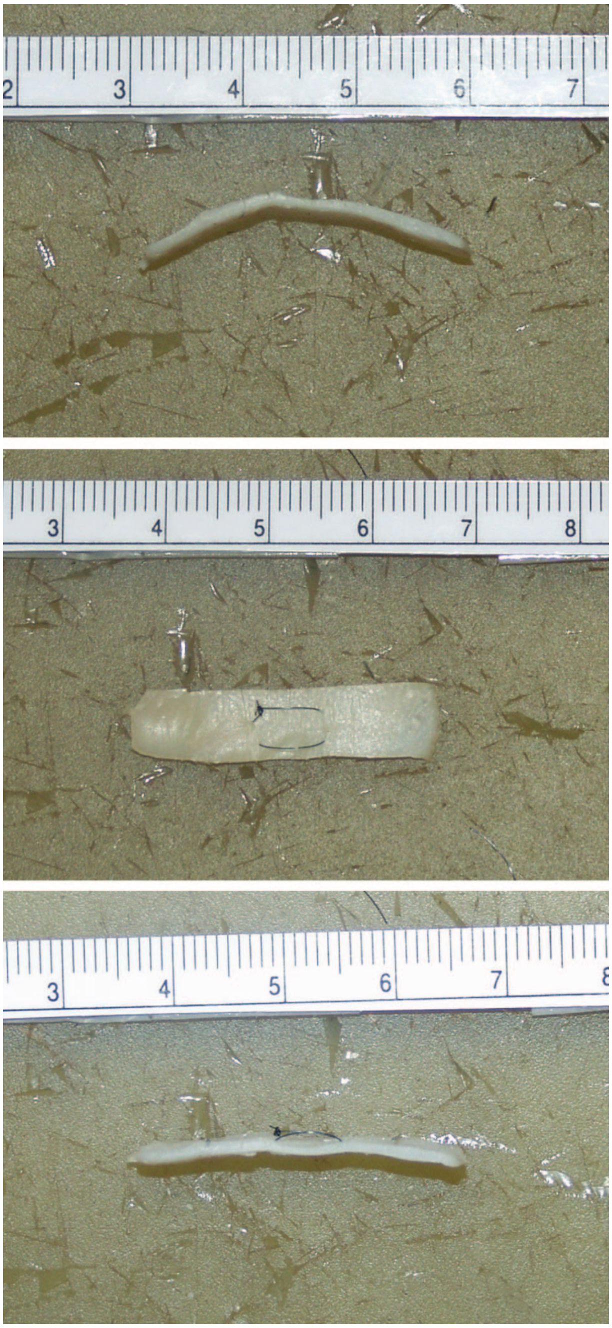

FIG. 2. If a curved piece of cartilage (*above*) receives a horitzontal mattress suture on its convex side (*center*), the curvature will be largely corrected (*below*).

engineering point of view,[5] the property that best reflects the strength or stiffness of cartilage to support weight is known as the elastic modulus. The elastic modulus can be thought of as the load (weight) that is required to effect a fixed displacement (distortion) of one dimension of a homogenous, geometrically symmetrical specimen. For example, the elastic modulus of a longitudinal piece of cartilage (such as the lateral crus) is calculated by noting the number of grams required to cause the lateral crus to displace a fixed distance. In the experiments performed here, however, the specimens were not necessarily homogeneous (e.g., when containing a mattress suture) and were not geometrically symmetrical (when scored on only one side). The weight necessary to cause a fixed displacement would be different on the two sides of such a biplanar specimen. To appreciate the overall modulus of the nonhomogenous or geometrically asymmetrical specimen, one needs to average the modulus observed for both sides of the cartilage specimen. The average value for both sides of the specimen is referred to here as the "biplanar modulus." The biplanar modulus of unsutured, unscored cartilage corresponds to the traditional "elastic modulus."

The biplanar modulus was measured by an apparatus (Fig. 4) consisting of a two-post cartilage holder, weights that can be attached to the cartilage, and a laser light with a beam width of 2.5 mm. Sufficient weights could be attached to the specimen to cause it to be displaced from one side of the beam width to the other.

Nine curved specimens were evaluated (three at 0.5 mm, three at 1 mm, and three at 1.5 mm). Before receiving a horizontal mattress suture, each specimen was tested by placing it on the cartilage holder. The initial position was noted, after which weights were added to effect a 2.5-mm defection (as indicated by a break in the laser beam). A mattress suture (of appropriate spacing to correct the curvature) was applied that removed much of the curvature and the experiment was repeated, noting

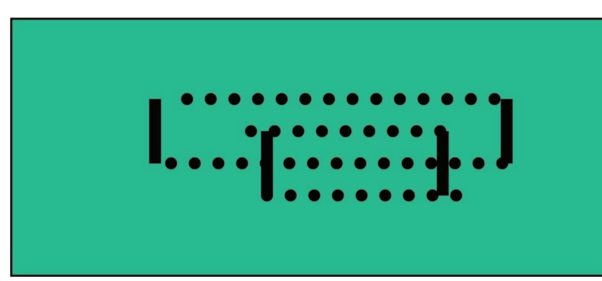

FIG. 3. Schematic example of how one cartilage specimen (30 × 6 mm) is tested with two spacings. Five specimens were required to test all nine spacings. To be able to use each specimen for two spacings and avoid needles from being too close to one another, the pattern for suture placement in these five specimens was as follows: 4 and 8 mm; 5 and 9 mm; 6 and 10 mm; 7 and 11 mm; and 8 and 12 mm. This resulted in two values for the 8-mm spacing and one value for all of the others. Each of three thicknesses (0.5, 1, and 1.5 mm) was tested in this fashion.

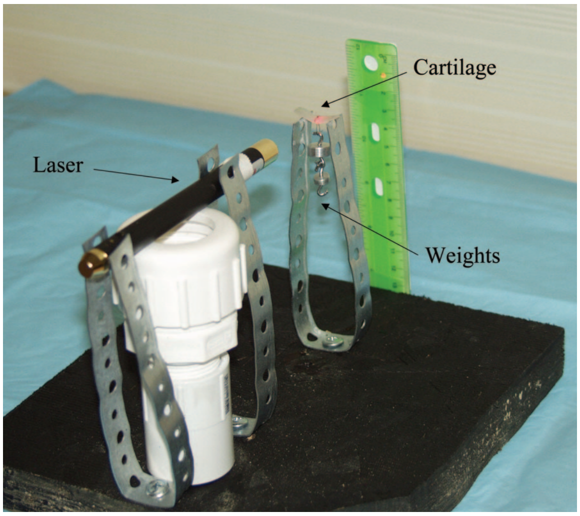

FIG. 4. The modulus was measured by an apparatus consisting of a cartilage holder, a weighing pan (with weights) that can be attached to the cartilage, and a laser light that can ascertain the displacement of the cartilage when weights are added.

the weight necessary to effect the same displacement. Lastly, the suture was removed, the specimen was scored in multiple places on its concave side (just enough to flatten it out), and the experiment was repeated for a third time noting the weight necessary to effect a 2.5-mm deflection. Scoring depth was limited to 50 percent of the cartilage thickness. The specimens were incrementally scored until they achieved a flatness similar to that of sutured specimens. Each set of measurements was performed three times on both sides of the specimens.

Having calculated the weight (m_x) necessary to cause a specimen of given width (b) thickness (h) on a holder of beam length (L) between the posts, to endure a displacement (y) of 2.5 mm, the modulus on each side (M_x) and the biplanar modulus (BM) was calculated using the following equations[4]:

$$M_x = m_x G(L/b)^3/4yh \quad (1)$$

$$BM = (M_1 + M_2)/2 \quad (2)$$

where G = Newton's constant, x = 1 on side 1, and x = 2 on side 2.

RESULTS

Experiment 1

Our quantitative measurements indicated that the ideal spacing for curvature correction of 0.5-mm specimens occurred at 6 to 8 mm. Spacing less than 6 mm tended to have no effect and spacing greater than 8 mm tended to cause buckling of the specimen. For 1-mm specimens, curvature correction occurred at 7 to 9 mm. For 1.5-mm specimens, it occurred at 8 to 10 mm. In general, spacing that was too small did not correct the curvature and spacing that was too large caused buckling. Spacing that was just right, however, corrected the curvature (Fig. 5). As cartilage thickness increased, the spacing had to be wider to correct curvature without causing buckling.

Although the tension placed on a suture can be an important variable, we did not attempt to objectively measure it. However, we did note that when the spacing was too small, excessive tension had little impact on creating curvature. Decreasing the tension when the spacing was

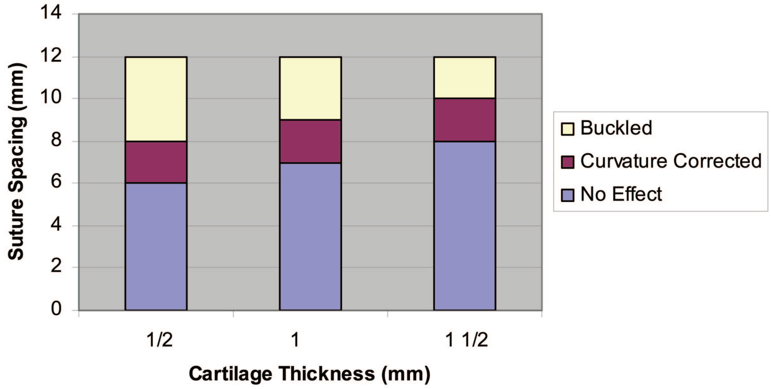

FIG. 5. The effect on curvature is recorded at each width of suture spacing at each of the three thicknesses of cartilage (*red*, curvature corrected; *blue*, no effect; *yellow*, buckled). For 0.5-mm specimens, curvature correction occurred at 6 to 8 mm. For 1-mm specimens, it occurred at 7 to 9 mm. For 1.5-mm specimens, it occurred at 8 to 10 mm.

too wide helped avoid immediate buckling but did not prevent the cartilage from subsequently buckling if a slight additional force (e.g., finger palpation) was applied.

Experiment 2

The mean and range of the biplanar modulus values are plotted in Figure 6 as a function of the type of treatment rendered. The mean biplanar modulus before receiving horizontal mattress sutures was 4.6 MPa. This result is similar to other studies[6,7] that have measured the elastic modulus in septal cartilage. After horizontal mattress sutures, the biplanar modulus was 6.2 MPa (35 percent increase in stiffness). After scoring to improve the curvature, however, the biplanar modulus was 2.4 MPa (48 percent reduction in stiffness). Statistical analysis of the data revealed that the modulus is strongly correlated with the method of curvature control, with sutures being superior to no sutures and scoring being inferior to the other two methods ($p = 0.02$, Wilcoxon signed rank test) (Table I).

DISCUSSION

Execution of the horizontal mattress suture can be difficult at first because the surgeon has to decide how wide to space the mattress. The required spacing increases in proportion to cartilage thickness. In this experiment, the specimen width was arbitrarily chosen to be 6 mm. As a result, we obtained ideal spacings for a particular width. Had we chosen narrower specimens (<6 mm), the spacing would probably not need to be as wide to achieve curvature control. Had we chosen wider specimens (>6 mm), the spacing would likely need to be wider to achieve curvature control. Our data provide a starting point for cartilage widths that are commonly used. After conservative trim of the cephalic portion of the lateral crus, which is commonly recommnended,[8,9] we find that a 6-mm-wide lateral crus remains and is our most common location for the horizontal mattress suture.

We must acknowledge that there are a few factors that can potentially lead to variability of results. Different cartilages possess different degrees of curvature and may respond differently to a given suture spacing. The curvature change may also be affected by how much the suture is tightened (i.e., the tension). These two factors alone may well be why there is a range of suture spacing to maximally improve the curvature of cartilage. This study did not attempt to deal with the factor of the radius of curvature of the cartilage or the tension of the suture following knot placement. Additional studies would be needed to assess these variables. However, the suture spacing estimates provide a first-order estimate for the most important factor: cartilage thickness. One other potential factor that can affect curvature control is the width of the purchase. We attempted to use a consistent 3-mm purchase because it is the minimum width necessary to obtain a purchase. Larger purchases were not used because a curvature change would then result in a direction orthogonal to that which was desired.

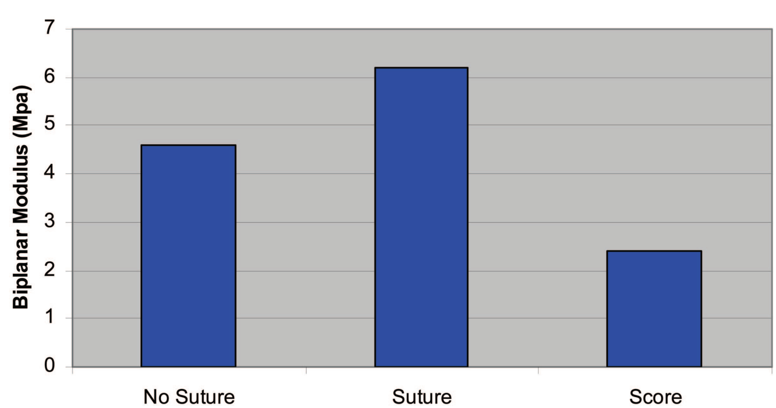

FIG. 6. The mean composite modulus (stiffness) of the specimens is plotted as a function of the manner in which the curvature was corrected (horizontal mattress suture, scoring, or no treatment). The mean composite modulus before receiving ideally spaced sutures was 4.6 MPa. After ideally spaced sutures, it was 6.2 MPa (a 35 percent increase in stiffness). After scoring to improve the curvature, it was 2.4 MPa (a 48 percent reduction in stiffness).

TABLE I
Data Analysis*

Modulus Measurement Pairing	Mean Difference	Sum of Ranks (T)	*p*†
Before suture–after suture	1.5	45 (positive)	0.002
After suture–after scoring	–3.7	45 (negative)	0.002
Before suture–after scoring	–2.2	45 (negative)	0.002

* The specimens had a mean modulus of 4.6 MPa before the suture, 6.2 MPa after the suture, and 2.4 MPa after scoring the cartilage. Results of the Wilcoxon signed rank test are as given. With *p* values of 0.002, we can reject the null hypotheses that the difference between the sets of measurements is zero, and accept the alternative hypotheses that there is a difference between them: modulus measurements taken before the suture and after the suture; modulus measurements taken after the suture and after scoring the cartilage; and modulus measurements taken before the suture and after scoring the cartilage.

† The *p* values are identical because in all three pairings the differences all had the same sign, whether positive or negative.

Experimentation is required on the part of the surgeon when first applying sutures to cartilage specimens of different widths and thicknesses. As shown by this experiment, a difference of 2 mm makes a significant difference in controlling the curvature. Exactness is required. Fortunately, suture placement is reversible. If the curvature is not fully corrected after tying the knot or if the cartilage buckles (demonstrates instability), the mattress suture can always be repeated with a different spacing.

Fortunately, the learning curve for this simple technique is short. Once experience is gained in using mattress sutures to reduce if not eliminate unwanted cartilage curvatures, its application to control nasal cartilage should be limitless. It should be possible to save both operative time (by reducing the need for cartilage grafts) and graft donor sites (for purposes where they are essential, e.g., tip grafts and columellar struts).

Conclusions

Traditionally, scoring has been a successful means of controlling the curvature of cartilage.[10,11] Unfortunately, it is associated with cartilage instability. Moreover, if the scoring is overzealous, the cartilage may completely collapse and prove worthless. Our quantitative results with cadaver cartilage confirmed this concept. The stiffness (biplanar modulus) of sutured cartilage is, in fact, even greater than that of unsutured cartilage. The suture acts to reinforce the cartilage much as rebar does in concrete. The stiffness (biplanar modulus) of normal cartilage became a fraction of its normal value when it was scored for the purposes of curvature control. The simplicity of the horizontal mattress suture along with its potential to minimize the need for scoring and cartilage grafts justifies, in our experience, its continued use.

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