Finite Element Analysis of a Single Barbed Suture Using Beam Theory

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Statement of Purpose: Since being approved by the US Food and Drug Administration in 2004, barbed surgical sutures have attracted attention from both researchers and surgeons all around the world. The major applications of barbed sutures are in cosmetic surgery and soft tissue wound closure [1]. Studies in orthopedic surgery have also been performed on tendon repair since the use of barbed sutures can significantly reduced the site area compared with conventional sutures [2]. However, these studies have not been performed *in vivo* because of a lack of knowledge of the anchoring ability of barbed sutures, which is directly related to barb geometry, such as the cut depth and cut angle (Figure 1). The objective of the current study is to simulate barb behavior in terms of the maximum deflection and stress on a single barb with four different geometries using 2D finite element analysis.

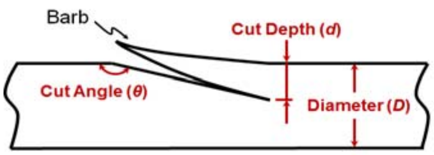

Figure 1: Barb geometry.

Methods: A suture with a single barb was approximated to be a 2D structure using plane42 elements in ANSYS. The suture was assumed to be fixed in cross section and at the bottom surface. The model (Figure 2) was created by defining seven major nodes, and meshing the space between these nodes. A uniform pressure load was applied perpendicular to the inner cut surface of the barb so as to mimic the force applied by trapped tissue located *in vivo* underneath the barb.

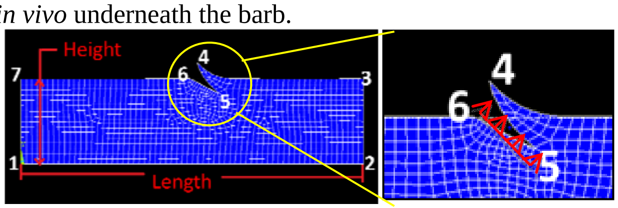

Figure 2: Finite element model of a single barbed suture.

Two cut depths and two cut angles were used to define the barb geometry, resulting in four barb models (Table 1) [3]. The maximum stress was found by creating a Von-Mises stess contour of each model.

Table 1: Four barb geometry models

Model No.	Model 1	Model 2	Model 3	Model 4
Cut depth (mm)	0.18	0.07	0.18	0.07
Cut angle (°)	150	150	170	170

Results: The maximum deflection occurred at the barb tip. The applied pressure caused the barb to lift and penetrate the surrounding tissue, which would be expected to improve the barb's anchoring ability. The maximum stress (red in Figure 3) occurred at the base of the cut line for all 4 barb geometries (Figure 3). In addition, the maximum compressive stress occurred at the back of the barb for Model 2. When the maximum stress occurs at the base of the cut line, the barbs are more likely to fail by peeling and losing their anchoring ability. When the maximum stress is located at the back of the barb, barb failure is more likely to occur due to the barb bending backwards. Given the same cut angle, the barb with a deeper cut has a more extensive stress contour area, which lowers the entire suture strength. Given the same cut depth, the barb with the greater cut angle has a larger deflection at the barb tip. The applied load was fixed and kept uniform in the current analysis. However, in the real world, it depends on tissue properties and location along the barb. For example, flexible skin tissue may achieve a higher anchoring ability using long and thin barbs, while short and deep barbs may work well for stiff tendon tissue.

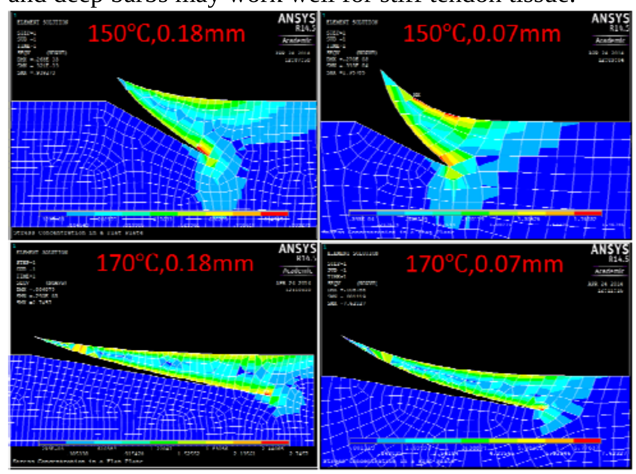

Figure 3: Stress contours of a single barb with four different barb geometries.

Conclusions: 2D finite element analysis has successfully modeled the barb behavior of single barbed sutures under uniform applied pressure conditions. The barbs with different geometries behave differently to the applied pressure load. The optimized anchoring performance depends on both the barb geometry and the tissue type. Barb failure, namely barb bending and barb peeling occur depending on the position of the maximum stress. The limitations of this finite element analysis model include the 2D assumption, the constant triangle elements at the barb tip, and the direction and uniformity of the applied pressure along the barb inner surface. Ongoing *in vitro* experiments of barb movement in transparent gelatin and future *in vivo* physiological studies in animals will provide verification of this finite element analysis model.

References:

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