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Optimizing the tissue anchoring performance of barbed sutures in skin and tendon tissues

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ABSTRACT

The focus of the current work was to study how the geometric design of a single barbed monofilament suture effects its biomechanical behavior. Different cut angles and cut depths of barbs were prepared and tested in vitro for their tensile and tissue anchoring properties by means of a novel suture/tissue pullout test. Experiments were also performed using bovine tendon and porcine skin tissues. The experimental results revealed that since tendon tissue has a higher modulus than skin it needs a more rigid barb to penetrate and anchor the surrounding tissue. A cut angle of 150° and a cut depth of 0.18 mm are therefore recommended. On the other hand, for the softer skin tissue, a cut angle of 170° and a cut depth of 0.18 mm provides a more flexible barb that gives superior skin tissue anchoring. These findings confirm that the future development of barbed suture technology requires a detailed understanding of the biomechanical properties of the tissue in which they are to be used. This will lead to the future development of a range of tissue-specific barbed sutures.

1. Introduction

The successful performance of surgical sutures have until recently depended on the ability and skill of the clinician to tie efficient and secure knots. However, in recent years knotless sutures have been developed that can provide the same level of security and command certain advantages over traditional knotted sutures.

One type of knotless suture is the ‘barbed’ suture, in which protruding barbs are placed in one or two directions along the length of a monofilament thread (Trull et al., 2004; Buncke, 1999; Villa et al., 2008; Greenberg and Einarsson, 2008; Leung et al., 2008). In vitro studies have previously reported the tissue holding capacity of a barbed suture compares with that of a knotted suture (Dattilo, 2002; Dattilo et al., 2003). The literature also contains reports describing how the tissue holding capacity (Ingle et al., 2004) and the in vivo biostability of barbed sutures (Leung, 2004) depends on the microstructure of the polymer from which they are made. Currently they are used successfully for sub-dermal wound closure and for tendon repair in human patients (O’Broin et al., 1993; McKenzie, 1967), and by cosmetic surgeons to undertake facelift and masklift procedures (Prado et al., 2008; Michael et al., 2008; Downs and Wang, 2008; Ruff, 2006).

Recently there have been suggestions in the literature that the optimal barb design may not be the same for all surgical applications, and that variables such as the geometric shape, frequency, alignment and sequence of barbs may need to change for use with different types of tissues like skin, tendon and fatty tissue (Einarsson, 2008; Sasaki et al., 2008). The primary objective of this study was to determine the effect of barb cut angle and barb cut depth on the tensile and tissue anchoring properties of a single barbed suture in skin and tendon tissues. Single barbed suture samples were prepared from a polypropylene monofilament with three different levels of cut angle and three different levels of cut depth. They were then evaluated for their tensile and suture/tissue pullout performance so as to determine the optimal barb geometry.

2. Materials and methods

2.1. Material selection

The suture used was blue polypropylene monofilament of size ‘0’ (zero), diameter 0.400 ± 0.001 mm, provided by Covidien Inc., in a continuous length. This suture differed from that used clinically in that it was not cut, swaged to needles, folded, packaged and sterilized as commercial sutures are.

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2.2. Design of experiment

This study involved three nominal levels of barb cut angle and three nominal levels of barb cut depth. A complete factorial nine block design is shown in Table 1. In addition, two tissue types, skin and tendon, were selected for performing suture/tissue pullout tests.

2.3. Barbed suture preparation and image analysis

The single barbed specimens were prototyped to the desired specifications using an innovative cutting method developed in the Biomedical Textiles Laboratory at North Carolina State University (Ingle, 2008). A Nikon optical (Model: Labophot-Pol) microscope was used for viewing and capturing the image at a magnification of 100x. The images were subsequently analyzed using Image J software (Dattilo et al., 2003; Ingle, 2008). The measured cut angle and cut depth (Fig. 1) were then used to validate the prototyping process.

2.4. Tensile testing of unbarbed and barbed sutures

Uniaxial tensile loading to failure (10–15 specimens) was performed at a constant rate of displacement on an MTS ReNew tensile tester (Model No. 1122). A 250 N load cell was used with capstan clamps and a time to break of 20 ± 3 s. Testing parameters were: gauge length: 12 mm (barbed), 35 mm (unbarbed), cross-head speed: 2.0 mm/s, clamps: capstan effect.

Table 1
Design of experiment for barbed sutures with different geometries

Nominal Cut Depth (mm)	Nominal cut angle		
	150°	160°	170°
0.07	x	x	x
0.12	x	x	x
0.18	x	x	x

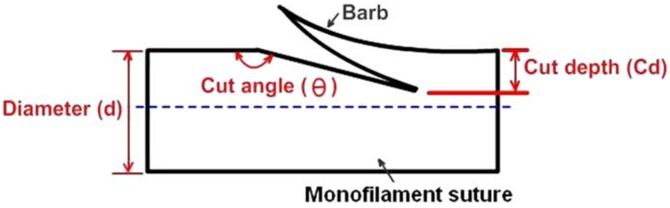

Fig. 1. Geometry of a single barb.

2.5. Suture/tissue specimen preparation and pullout tests

Fresh porcine skin and bovine tendon tissues were purchased locally. The specimens were kept in a cold water bath to avoid dehydration, and all tests were performed within 12 h of procurement. A surgical skin graft blade (Swann-Morton Limited) was used for tissue specimen preparation. The skin tissue was approximately 2 mm thick. It was cut into approximately 10 mm wide and 50 mm long specimens (Fig. 2). For the tendon, after dissection and removal of surrounding tissue, the specimens had an oval cross-section with diameters varying from 7 to 12 mm. They were cut into 50 mm lengths with a rectangular shaped end for clamping in the lower jaw of the tensile tester (Fig. 2).

A new method was developed to insert the needle-less suture into the tissue. A syringe needle (21G1 PrecisionGlide), with 'inner' diameter marginally greater than that of the suture, was used for threading (Fig. 2). It was assumed that the surrounding tissue collapsed back against the suture after needle was retracted, thus ensuring good barb/tissue mechanical anchoring. Six single barbed suture/tissue pullout test specimens were tested for each suture and tissue combination on the same MTS tensile tester using a 10 N load cell, a cross-head speed of 0.75 mm/s and a 10 mm anchoring distance.

2.6. Statistical analysis

A Student *t*-test was used at a 95% confidence interval to determine significant, differences between sample means.

3. Results

3.1. Images of barbed sutures

Fig. 3 shows the images of a single barbed suture samples. Barbs on polypropylene suture material have a tendency flare out for good anchoring.

3.2. Barbed suture geometry measurements by image analysis

The means and standard deviations for the measured cut angles for the prototype samples were: nominal 150°: 150.00 ± 0.30; nominal 160°: 160.00 ± 0.13; nominal 170°: 170.00 ± 0.23. Likewise the measured cut depths were: nominal 0.18 mm: 0.180 ± 0.001; nominal 0.12 mm: 0.120 ± 0.001; nominal 0.07 mm: 0.070 ± 0.001.

3.3. Tensile testing

The means and standard errors of the peak tensile loads are shown in Fig. 4 together with a 9 point significance chart. The values for cut depths 0.07, 0.12 and 0.18 mm when averaged over all 3 cut angles, were 33.65 ± 0.77, 30.82 ± 0.90 and

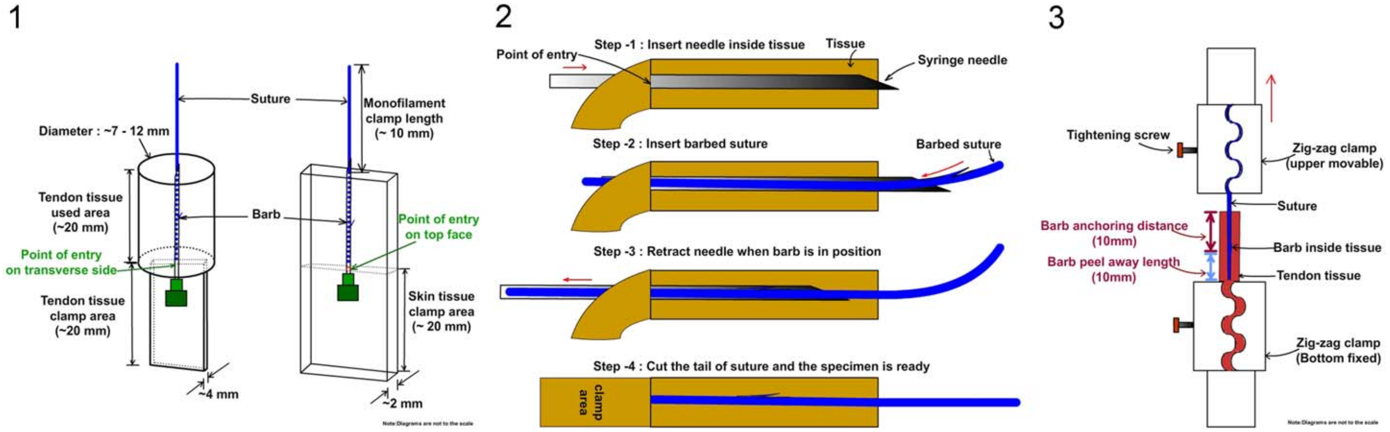

Fig. 2. (1) Specimen preparation for skin and tendon tissue pullout test; (2) Threading the barbed suture into the tissue for preparing the pullout specimen; (3) Specimen mounted ready for skin tissue or tendon tissue pullout test.