Suture Strength and Angle of Load Application in a Suture Anchor Eyelet

Mark Deakin, M.D., David Stubbs, M.D., Warwick Bruce, M.D., Jerome Goldberg, M.D., Ronald M. Gillies, M.D., and William R. Walsh, Ph.D.

Purpose: To assess the effect of suture material, anchor orientation, and anchor eyelet design on the static loading properties of suture anchors. **Type of Study:** Biomechanical bench study. **Methods:** Two metallic suture anchors, Mitek GII (Mitek, Westwood, MA) and Corkscrew (Arthrex, Naples, FL) and a bioabsorbable anchor (Biocorkscrew; Arthrex) were tested with single strand of No. 2 Ethibond (Ethicon, Norderstedt, Germany) or No. 2 FiberWire (Arthrex) suture. Suture pull angle was varied through 0°, 45°, and 90° with the anchor rotation angle in either a sagittal or coronal plane. Constructs were tested to failure using an MTS 858 Bionix testing machine (Material Testing Systems, Eden Prairie, MN). Peak loads, stiffness, energy to peak load, and failure modes were determined for all samples. **Results:** FiberWire showed superior static mechanical properties when compared with single-strand Ethibond over all testing conditions ($P < .05$). Suture pull angle had a significant effect on load to failure with both metallic anchors but not on the bioabsorbable anchor ($P < .05$). **Conclusions:** Suture pull angle and anchor rotation angle play an important role in the failure load of suture when placed in an eyelet. The polyaxial nature of the Biocorkscrew eyelet allows for increased degrees of freedom but introduces failure of the suture eyelet as a new failure mode. **Clinical Relevance:** The loading direction and placement of the suture anchor plays a role in the performance of the suture anchor–suture complex. **Key Words:** Suture anchor—Suture material—Anchor orientation—Load to failure—Bioabsorbable.

Suture anchors have gained widespread acceptance in surgical procedures to reattach soft tissue to bone. The wide range of designs with regard to fixation, eyelet design, and the method of surgical implantation makes comparisons between designs and technique difficult. Insertion of suture anchors often results in variable placement because of anatomic and surgical limitations. Stress risers over metal edges of the anchor eyelet can contribute to early suture failure[1] along with knot failure during surgery. Clinical failure of the suture anchor complex can occur at the interfaces created as a result of the device in the bone, suture through the device, and suture through the tissue. The importance of suture breakage at the device interface as a prominent mode of failure has been shown in a number of in vivo and in vitro studies.[1-7] Although the pullout strength of suture anchors has been well reported,[8] recent studies on the influence of the eyelet design and testing orientation, the suture pull angle (SA), and the anchor rotation angle (RA),[9] have highlighted the increasing complexity when using suture anchors.[2,9,10] The introduction of new suture materials, such as polyethylene-based FiberWire suture (Arthrex, Naples, FL) adds an additional parameter that has the potential to influence clinical results. We hypothesized that the angle of load application would play an important role in the mechanical properties of these constructs. The purpose of this study was to assess the effect of suture material,

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From the Orthopaedic Research Laboratories, University of New South Wales, Prince of Wales Hospital (M.D., D.S., R.M.G., W.R.W.), Sydney; and Orthosports (W.B., J.G.), Randwick, New South Wales, Australia.

Address correspondence and reprint requests to W. R. Walsh, Ph.D., Orthopaedic Research Laboratories, University of New South Wales, Prince of Wales Hospital, Sydney 2031, Australia. E-mail: W.Walsh@unsw.edu.au

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TABLE 1. *Summary Mechanical Data for the Different Suture Anchor Devices, Suture Pull Angle (SA), Anchor Rotation Angle (RA), and Different Sutures*

Device	SA	RA	Suture	Stiffness (N/mm) Mean ± SD	Load (N) Mean ± SD	Energy (Nmm) Mean ± SD
Biocorkscrew	0°	—	Ethibond	12.36 ± 0.51	193.90 ± 4.75	1,670.59 ± 96.47
Biocorkscrew	0°	—	FiberWire	62.17 ± 10.23	270.64 ± 11.87	686.58 ± 142.74
Corkscrew	0°	—	Ethibond	11.67 ± 0.84	204.66 ± 8.63	799.02 ± 159.24
Corkscrew	0°	—	FiberWire	103.52 ± 15.88	352.19 ± 41.93	349.42 ± 126.58
Mitek	0°	—	Ethibond	10.94 ± 0.83	179.09 ± 19.75	703.09 ± 199.42
Mitek	0°	—	FiberWire	69.37 ± 2.46	418.21 ± 15.92	611.99 ± 119.73
Biocorkscrew	45°	—	Ethibond	12.47 ± 1.10	175.75 ± 13.05	1,534.60 ± 159.19
Biocorkscrew	45°	—	FiberWire	54.55 ± 7.67	249.69 ± 11.07	753.59 ± 170.08
Corkscrew	45°	Coronal	Ethibond	12.49 ± 0.87	187.16 ± 4.94	614.23 ± 77.12
Corkscrew	45°	Coronal	FiberWire	71.68 ± 1.97	353.44 ± 28.93	399.76 ± 86.50
Mitek	45°	Coronal	Ethibond	10.23 ± 0.64	145.97 ± 3.83	395.82 ± 82.05
Mitek	45°	Coronal	FiberWire	64.66 ± 3.32	336.42 ± 32.03	423.59 ± 84.75
Corkscrew	45°	Sagittal	Ethibond	12.18 ± 0.68	171.01 ± 8.61	570.85 ± 68.39
Corkscrew	45°	Sagittal	FiberWire	65.44 ± 2.17	339.34 ± 13.79	450.75 ± 90.82
Mitek	45°	Sagittal	Ethibond	10.22 ± 0.44	155.38 ± 5.27	540.41 ± 73.18
Mitek	45°	Sagittal	FiberWire	61.59 ± 7.18	303.64 ± 68.59	369.02 ± 98.17
Biocorkscrew	90°	—	Ethibond	13.22 ± 1.63	184.41 ± 9.81	1,690.78 ± 227.74
Biocorkscrew	90°	—	FiberWire	27.37 ± 6.71	214.17 ± 16.12	1,346.89 ± 455.03
Corkscrew	90°	Coronal	Ethibond	17.26 ± 1.84	124.96 ± 6.08	911.19 ± 98.81
Corkscrew	90°	Coronal	FiberWire	61.34 ± 4.93	268.60 ± 17.51	768.39 ± 192.81
Corkscrew	90°	Sagittal	Ethibond	13.16 ± 2.73	180.00 ± 7.43	1,547.30 ± 100.80
Corkscrew	90°	Sagittal	FiberWire	52.68 ± 6.97	300.19 ± 47.53	974.00 ± 355.57
Mitek	90°	Coronal	Ethibond	13.05 ± 1.33	87.84 ± 20.06	870.57 ± 38.86
Mitek	90°	Sagittal	FiberWire	52.52 ± 4.68	206.84 ± 23.57	429.91 ± 118.63
Mitek	90°	Sagittal	Ethibond	17.69 ± 0.64	124.53 ± 3.36	411.55 ± 67.44
Mitek	90°	Coronal	FiberWire	45.89 ± 3.28	169.07 ± 16.10	553.20 ± 218.28

anchor orientation, and anchor eyelet design on the static mechanical properties sutures.

METHODS

In this study, the Mitek GII (Mitek, Westwood, MA), Corkscrew, and Biocorkscrew 5.0 anchors (Arthrex) were tested using 1 loop of No. 2 Ethibond (Ethicon, Norderstedt, Germany) or No. 2 FiberWire suture as described below. A new metal anchor was used for each new experimental condition where the RA or SA was examined with a new loop of suture for each experiment. A total of 10 Mitek GII and 10 Corkscrew anchors were required for the 10 orientations tested as outline in Table 1. A new Biocorkscrew anchor was used for each experimental condition and resulted in a total of 48 Biocorkscrews for this study. A new Biocorkscrew was used for each experiment, considering the potential damage to the suture anchor eyelet, which is embedded in the polymer itself. The mechanical properties of a new loop of each suture type within the anchor eyelets were tested to failure in tension using an MTS 858 Bionix testing machine (Material Testing Systems, Eden Prairie, MN) with a 1-kN load cell. All testing was performed in phosphate-buffered saline at room temperature, similar to the conditions of Meyer et al.,[2] with a constant gauge length of 60 mm and a displacement rate of 60 mm per minute. This resulted in all testing performed with a deformation rate of 100% per minute. The anchors were rigidly fixed distally in a custom vice grip so that anchor pullout would not occur, and the properties of the suture in the eyelet were examined (Fig 1). The sutures were proximally fixed by winding 3 times over a 10-mm highly polished stainless steel bar and clamped superiorly, thus avoiding the use of knots, which may act as a stress riser as well as introduce an additional variable. This clamping technique allowed the suture that was tested to be loaded in tension without any compressive force due to the clamping. The static tensile properties of the suture in the eyelets were evaluated in the best-case scenario of 0° SA and RA with a single loop of No. 2 Ethibond or FiberWire for all 3 anchor designs. In addition, the metal anchors

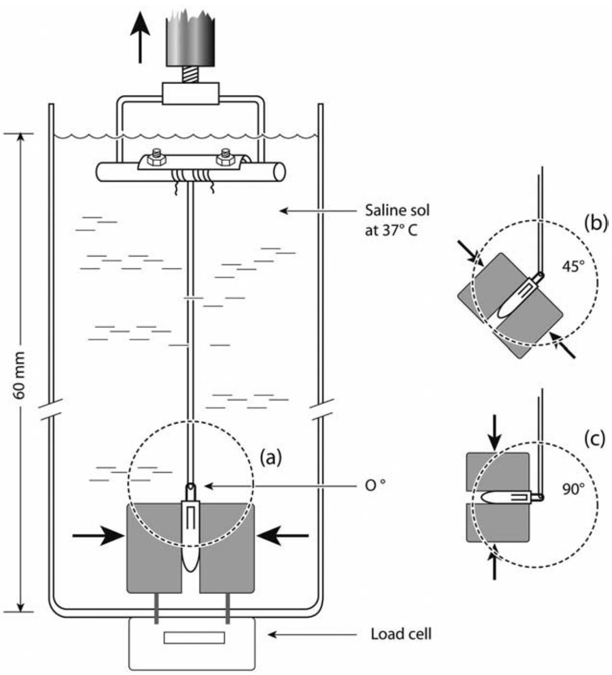

FIGURE 1. The testing setup. The gauge between the suture eyelet and the gripping mechanism proximally was 60 mm. All testing was performed submerged in a phosphate-buffered saline bath. Anchors were tested at 0° (a), 45° (b), and 90° (c) to the applied tensile load.

were tested at an SA 45° or 90° and RA in either a sagittal or coronal plane with 1 loop of No. 2 Ethibond or FiberWire suture. Considering that the Biocorkscrew eyelet is made of suture, the coronal and sagittal testing orientations were not performed with this anchor. The peak load, stiffness, energy to peak load, and failure mode were analyzed with a 1-way analysis of variance using SPSS for Windows (SPSS Inc, Chicago, IL) followed by a Tukey HSD post hoc test.

RESULTS

Table 1 presents the summary of the descriptive statistical data from the current study. These data result in an enormous number of potential post hoc comparisons which will be considered below.

Failure Modes

Ethibond suture failed in the eyelet in all cases when used with the metal and Biocorkscrew designs. In contrast, FiberWire failed in the eyelet in all cases with metal anchors whereas the No. 5 loop of the Biocorkscrew failed when used in combination with FiberWire. No discernable damage to the metal anchor eyelets was noted on macroscopic inspection after testing. In the case of the Biocorkscrew, testing with Ethibond did not damage the suture eyelet of this design but the FiberWire did cut through the No. 5 suture eyelet.

Suture Type at 0°

The type of suture (Ethibond *v* FiberWire) at 0° had a statistically significant effect on the properties for all anchor designs tested ($P < .05$). The use of No. 2 FiberWire resulted in load, energy, and stiffness superior to No. 2 Ethibond ($P < .05$). FiberWire and Ethibond failed during testing when used with a metal anchor design at 0°. In contrast, No. 2 Ethibond failed when used with the Biocorkscrew and the Biocorkscrew eyelet suture failed when used in combination with No. 2 FiberWire. The stiffness of the suture–suture anchor constructs were dependent on the suture type when tested with the metal anchor designs (Mitek and Corkscrew). Suture–suture anchor constructs tested with FiberWire were stiffer than Ethibond. SA and RA did not influence the stiffness for either suture type but did influence the ultimate failure loads. Anchors tested with FiberWire were significantly stiffer than Ethibond with all anchor designs ($P < .05$). The suture stiffness when using Biocorkscrew anchor with Ethibond was similar to that with the metal anchors. In contrast, the stiffness of the suture when using Biocorkscrew with FiberWire was significantly less stiff than the metal anchors when tested with FiberWire ($P < .05$).

Failure loads of the sutures were significantly reduced with the Mitek GII with an SA 45° or 90° ($P < .05$) (Figs 2 and 3), whereas RA alone was not a significant factor for both suture types with this anchor. Failure loads for the Corkscrew only became significant with an SA of 90° (Figs 2 and 3). In contrast, SA did not affect the ultimate tensile loads for the Biocorkscrew, which has a loop of No. 5 suture as the eyelet, when using Ethibond, which was the weakest link in the system and failed in all cases. The failure mode in this in vitro experiment switched to the No. 5 suture eyelet of the Biocorkscrew when FiberWire was used and at lower loads compared with the metal Corkscrew anchor ($P < .05$) (Fig 1).

DISCUSSION

The goal of soft tissue to bone reattachment, as in the case of a rotator cuff tear, is to provide a secure method of fixation to allow tissue healing. Moreover, after most musculoskeletal surgery, early mobilization is advantageous,

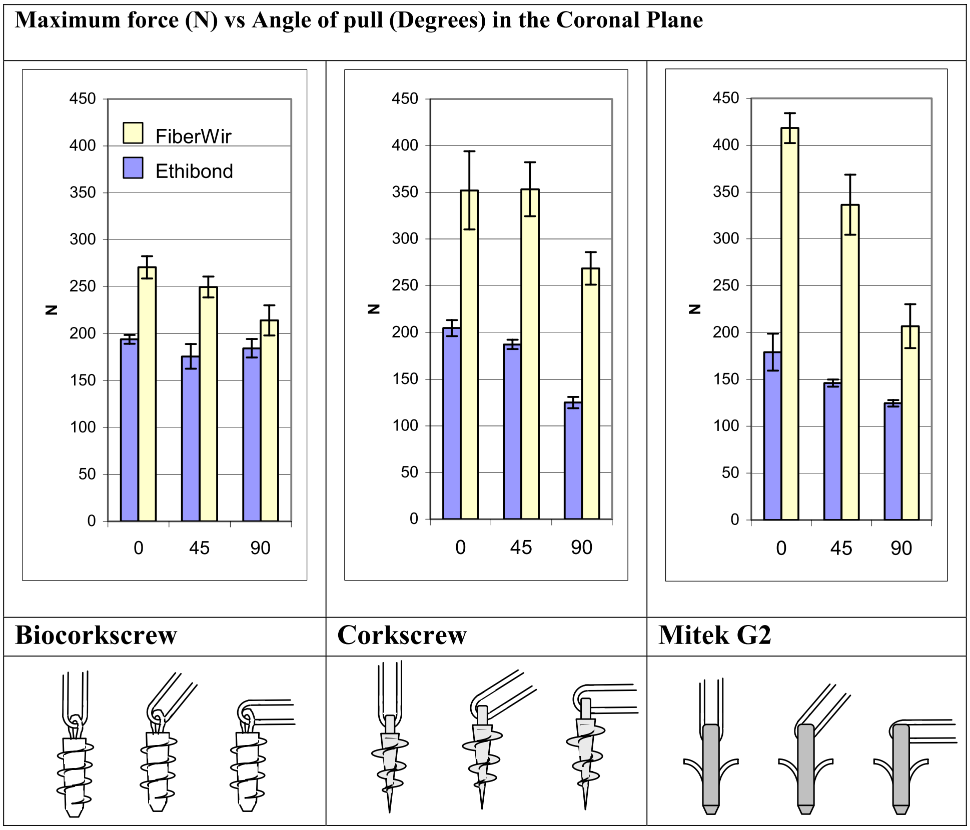

FIGURE 2. Maximum force (N) versus angle of pull (degrees) in the coronal plane are shown for the Biocorkscrew, Corkscrew, and Mitek anchors with 1 strand of No. 2 Ethibond or FiberWire.

placing more rigorous demands on the strength of the surgical construct. Some surgeons believe that the strength of a suture anchor repair is inadequate to sustain early mobilization[3] and, therefore, it is important to study the weak link(s) in current repair systems. Previous research indicates that suture breakage at the anchor eyelet is often this weak link.[1,3,5]

Suture anchors are often used in situations in which the loading axis differs from that of the anchor insertion angle.[8] In view of its more limited access, arthroscopic use of anchors has the potential to further complicate SA and RA. The current study incorporated these concepts introduced by Bardana et al.[9] and shows that the eyelet design of metal anchors becomes important with respect to the orientation of loading. Factors such as the radius of curvature and the presence of any sharp edges become important aspects of the design. Suture in a metal anchor design will be loaded over a different portion of the eyelet depending on the final placement of the anchor. Interestingly, the Biocorkscrew anchor, which has a suture serving as the eyelet, is not influenced by SA and by design has no RA to consider. The use of a suture as the eyelet results in a polyaxial suture anchor that allows the eyelet to be pulled in any direction without the introduction of a potential stress riser over a metal eyelet. However, the use of FiberWire with a suture eyelet showed the weak point to be the suture eyelet itself when tested under these conditions. In addition, having No. 5 suture as the eyelet had no effect on stiffness of the construct when using No. 2 Ethibond, whereas the stiffness of the construct was reduced compared with a metal anchor when No. 2 FiberWire was used.

This study is limited in that we used static tensile failure rather than cyclical loading to failure. We also did not test the anchors in a bony bed that could introduce other modes of failure such as anchor pullout from the bone at different orientations. Therefore, the results should be extrapolated with care. Our testing procedure was designed to isolate the variables of eyelet design, orientation, and suture type rather than adding additional variables such as bone density and quality. Other properties such as knot security and potential suture cut-through of the soft tissue as well as biocompatibility

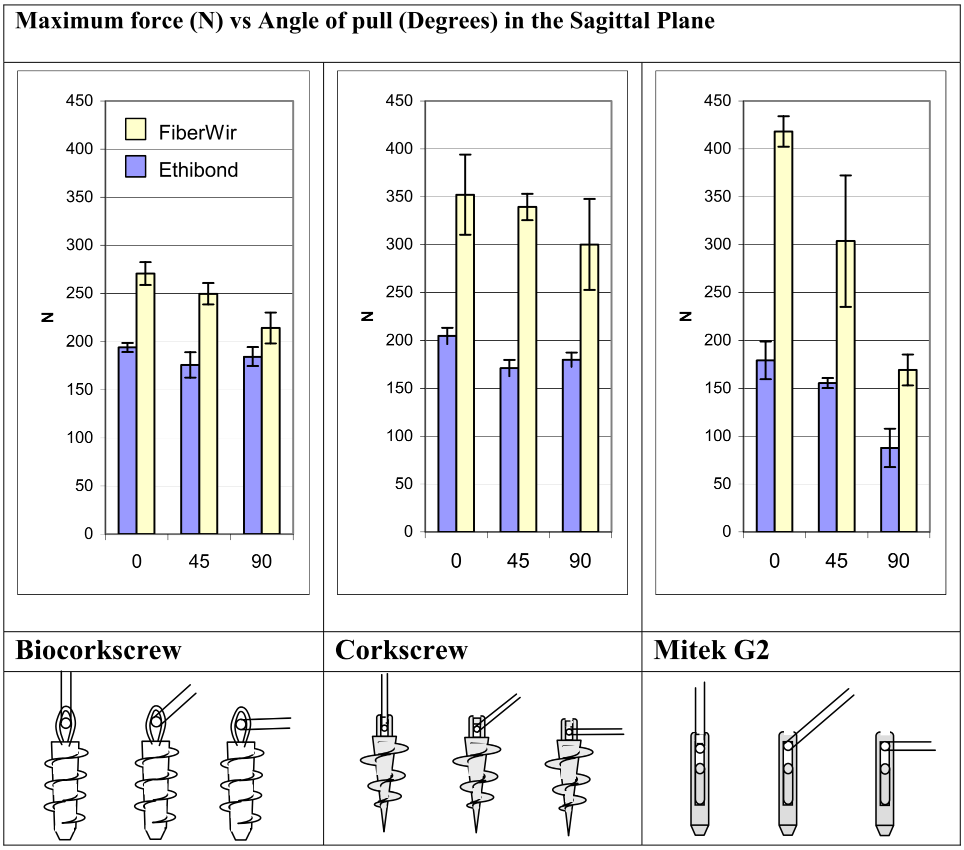

FIGURE 3. Maximum force (N) versus angle of pull (degrees) in the sagittal plane are presented for the Biocorkscrew, Corkscrew, and Mitek anchors with 1 strand of No. 2 Ethibond or FiberWire.

are important concerns that were not examined in the current study.

CONCLUSIONS

This study showed superior in vitro mechanical properties of a polyethylene-based suture (FiberWire) over a braided polyester suture (Ethibond) of the same gauge commonly used clinically. This was the case over all testing conditions examined. Suture pull angle and anchor rotation angle play an important role in the failure load of suture when placed in an eyelet. The polyaxial nature of the Biocorkscrew eyelet allows for increased degrees of freedom but introduces failure of the suture eyelet as a new failure mode.

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