# MATERIAL PROPERTIES OF COMMON SUTURE MATERIALS IN ORTHOPAEDIC SURGERY

S. Najibi,[*,†] R. Banglmeier,[†] J.M. Matta,[*] M. Tannast[*]


## ABSTRACT

**Suture materials in orthopaedic surgery are used for closure of wounds, repair of fascia, muscles, tendons, ligaments, joint capsules, and cerclage or tension band of certain fractures. The purpose of this study was to compare the biomechanical properties of eleven commonly used sutures in orthopaedic surgery. Three types of braided non-absorbable and one type of braided absorbable suture material with different calibers (n=77) underwent biomechanical testing for maximum load to failure, strain, and stiffness. All samples were tied by one surgeon with a single SMC (Seoul Medical Center) knot and three square knots. The maximum load to failure and strain were highest for #5 FiberWire and lowest for #0 Ethibond Excel (p<0.001). The stiffness was highest for #5 FiberWire and lowest for #2-0 Vicryl (p<0.001). In all samples, the failure of the suture material occurred at the knot. There was no slippage of the knot in any of the samples tested. This data will assist the orthopaedic surgeon in selection and application of appropriate suture materials and calibers to specific tasks.**


## INTRODUCTION

Suture materials have multiple applications in orthopaedic surgery ranging from closure of surgical wounds, repair of fascia, muscles, tendons, ligaments, joint capsules, and cerclage or tension band of certain fractures. The quality of tissue repair is dependent on multiple variables including tissue characteristics, material properties of the suture, and surgical technique. The choice of suture material has important implications in tissue repair. Adverse surgical outcomes can be avoided by selection of the suitable suture materials for appropriate indication.[4,9,11,12,15,16,19,20,21]

Surgical complications associated with failure of tissue repair include wound dehiscence, re-rupture of muscle, tendon and ligaments, incisional hernia, failure of repair of capsulolabral structures, and loss of reduction of fractures.[4,9,11,12,15,16,19,20,21] Different knots and anchor materials have been studied extensively.[2,3] However, manufacturer-independent information on the biomechanical properties of commonly used suture materials with varying calibers in orthopaedic surgery is not available.

We raised the following four questions: what is (1) the maximum load to failure, (2) the strain, (3) the stiffness, and (4) the location of material failure for each of the selected suture types?

## MATERIALS AND METHODS

An experimental, comparative study of commonly used suture materials in orthopaedic surgery was performed. Three types of braided non-absorbable and one type of braided absorbable suture material with various calibers were tested. The braided non-absorbable suture materials included Numbers 2 and 5 FiberWire (Arthrex, Naples, FL); Numbers 0, 1, 2, and 5 Ethibond Excel (Ethicon, Somerville, NJ); and Numbers 2 and 5 TiCron (Sherwood-Davis & Geck, St. Louis, MI). The braided absorbable suture material included Numbers 2-0, 0, and 1 Vicryl (Ethicon, Somerville, NJ). This yielded a total of eleven suture materials for testing.

FiberWire is made with a core of several small individual strands of biocompatible polyethylene covered with braided polyester suture material. Ethibond suture is made from braided polyester and coated with polybutylate for easier tying. TiCron is made of braided polyethylene coated with silicone. Vicryl is a braided suture material made by copolymerization of lactide and glycolide.

A pilot study was performed on a set of four randomly selected suture types from the aforementioned eleven varieties. This was done in order to have a manufacturer-independent data for a power analysis and calculation of the adequate sample sizes. With an alpha level of 0.05 and a test power of 0.8, the calculated sample size (i.e., the minimum number of samples of each suture type


[*]The Hip & Pelvis Institute, St. John's Health Center, Santa Monica, CA

[†]Department of Orthopaedic Surgery, Henry Ford Health Systems, Detroit, MI

Corresponding author: Soheil Najibi MD.,Ph.D,
The Hip & Pelvis Institute,
St. John's Health Center,
2001 Santa Monica Blvd #1090,
Santa Monica, CA, 90404.
Phone 310-582-7475
Fax 310-582-7481.
Email: snajibi@pol.net

**TABLE 1. Overview on analyzed braided suture materials and calibers**

| Type of suture | Bioabsorbability | Material | Cross-section area [mm2} | Diameter [mm] |
|---|---|---|---|---|
| Number 5 FiberWire | Non-absorbable | polyethylene covered with braided polyester | 0.75 | 0.98 |
| Number 2 FiberWire | Non-absorbable | polyethylene covered with braided polyester | 0.37 | 0.69 |
| Number 5 Ethibond Excel | Non-absorbable | braided polyester and coated with polybutylate | 0.61 | 0.88 |
| Number 2 Ethibond Excel | Non-absorbable | braided polyester and coated with polybutylate | 0.27 | 0.58 |
| Number 1 Ethibond Excel | Non-absorbable | braided polyester and coated with polybutylate | 0.23 | 0.54 |
| Number 0 Ethibond Excel | Non-absorbable | braided polyester and coated with polybutylate | 0.16 | 0.44 |
| Number 5 TiCron | Non-absorbable | braided polyethylene coated with silicone | 0.5 | 0.79 |
| Number 2 TiCron | Non-absorbable | braided polyethylene coated with silicone | 0.25 | 0.56 |
| Number 1 Vicryl | Absorbable | braided clpolymerized lactide and glycolide | 0.21 | 0.51 |
| Number 0 Vicryl | Absorbable | braided copolymerized lactide and glycolide | 0.14 | 0.42 |
| Number 2-0 Vicryl | Absorbable | braided copolymerized lactide and glycolide | 0.09 | 0.33 |

tested) was 4 for each suture. An n of 7 of each group was selected to minimize alpha and beta errors.

The diameter of all suture samples were measured and recorded with a digital caliper (E-Base Measuring Tools Co., Taiwan, Table 1) prior to biomechanical testing. The suture samples were looped over two stainless steel hooks which were placed at a distance of 50mm from one another. The free ends of the sutures were tied with a single SMC (Seoul Medical Center) knot with three half-hitches over reversed posts.[13] The SMC knot was chosen because of its superior characteristics in regards to strength and slippage.[1,8,18] Three half-hitches could be shown to be optimal for the knot-holding capacity.[14] All the knots were tied by one experienced surgeon (SN). This was done in a nonaqueous environment under direct visualization. The free ends of the sutures were secured with a surgical clamp 5mm distal to the knot. This was performed to assess any knot slippage. The suture material was marked at the knot to detect any slippage. The completed suture loops were loaded onto a model 8501M Instron servo hydraulic machine (Instron, Canton, MA), pre-tensioned to 10 N and loaded to failure at 1mm per second.

The following variables were recorded for each suture sample (n=77): (1) the load to failure, (2) the strain at maximum load to failure, (3) the stiffness as the ratio of load to displacement on the linear portion of the stress strain curve, and (4) the location of material failure. The experimental reproducibility of the first three variables was detected with the intraclass correlation coefficient (ICC). A very good reproducibility was found for all three continuous variables with an ICC of 0.99 (95% confidence interval 0.99 – 0.99) for load to failure, 0.88 (0.73 – 0.96) for strain, and 0.97 (0.95 – 0.99) for stiffness, respectively. The Kappa coefficient was used for assessment of the reproducibility of the location of material failure. A Kappa of 1.0 was found for failure at the knot.

We used the Kolmogorov-Smirnov test to assess the normal distribution for load of failure, strain, and stiffness. We used one-way ANOVA to assess differences among the eleven different suture materials for these three key variables. When a difference between groups was identified with ANOVA, we compared group means using an unpaired Student's t-test. The level of significance was set at 0.05.

## RESULTS

There was a statistically significant difference for the average maximum load to failure among the eleven different suture types ($p < 0.001$, Table 2). The highest load of failure was found in Number 5 FiberWire followed by Number 2 FiberWire. The lowest load to failure was found in Number 0 Ethibond Excel.

There was a statistically significant difference for the average strain among the eleven different suture types ($p < 0.001$, Table 2). The highest strain occurred in Number 5 FiberWire followed by Number 5 TiCron. The lowest occurred in Number 0 Ethibond Excel.

There was a statistically significant difference for the average stiffness among the eleven different suture types ($p < 0.001$, Table 2). The highest stiffness was calculated for Number 5 FiberWire followed by Number 2 FiberWire. The lowest stiffness occurred in 2-0 Vicryl.

Of the 77 tested suture samples, all the failures occurred at the knot where the suture broke. There was no knot slippage in any of the samples.

**TABLE 2. Results**

| Type of suture (n=77) | Max. load to failure [N] | Strain [%] | Stiffness [N/mm] |
|---|---|---|---|
| Number 5 FiberWire | 620 ± 29 | 23 ± 7 | 62 ± 18 |
| Number 2 FiberWire | 282 ± 30 | 16 ± 3 | 35 ± 6 |
| Number 5 Ethibond Excel | 247 ± 10 | 18 ± 2 | 25 ± 2 |
| Number 2 Ethibond Excel | 134 ± 9 | 18 ± 2 | 13 ± 2 |
| Number 1 Ethibond Excel | 118 ± 7 | 15 ± 1 | 12 ± 1 |
| Number 0 Ethibond Excel | 73 ± 5 | 13 ± 1 | 12 ± 1 |
| Number 5 TiCron | 226 ± 12 | 22 ± 4 | 19 ± 5 |
| Number 2 TiCron | 136 ± 3 | 16 ± 1 | 14 ± 1 |
| Number 1 Vicryl | 130 ± 9 | 16 ± 1 | 15 ± 1 |
| Number 0 Vicryl | 105 ± 6 | 16 ± 1 | 12 ± 1 |
| Number 2-0 Vicryl | 76 ± 3 | 15 ± 1 | 10 ± 1 |

## DISCUSSION

Choice of suture material for tissue repair in orthopaedics is influenced by multiple factors. These include the caliber of the suture, material properties of the specific tissues being repaired (fascia, tendon, or bone), balance between rigid and elastic fixation (e.g., fracture fixation versus tendon repair), location of the repair (superficial versus deep), and bioabsorbability. The purpose of this study was to assess the material properties of the most common suture materials of various calibers used in orthopaedics. This data will assist the orthopaedic surgeon in selection and application of appropriate suture materials and calibers to specific tasks.

One limitations of this study was in vitro testing of the materials. FiberWire, Ethibond and TiCron are not bioabsorbable and the material properties do not change in vivo.[6] Vicryl, however, is bioabsorbable and the in vitro data is representation of the initial suture strength. Another limitation of the study was that only a single load to failure as opposed to cyclic loading was performed. It is possible that the suture materials may undergo dynamic creep with cyclic loading. However, in order for the results to be applicable to a clinical worst-case scenario, a single load to failure test was performed. This was to assess the tolerance and material properties of the suture materials at their yield point.

Clinical application of different suture materials is influenced by multiple factors. These factors include the material properties of the suture and the tissues being repaired, the desired stiffness of the construct, and the potential for bioabsorbability. For example, in the case of the four-part proximal humerus fracture where the greater and lesser tuberosities need to be repaired but rigid fixation with screws is not possible, non-absorbable suture materials with a high-load to failure and caliber are ideal (i.e., Number 5 FiberWire in conjunction with Number 5 Ethibond).

Other examples are repair of subcutaneous fascia layers and tendons such as reattachment of the abdominal muscles to the iliac crest, repair of fascia lata, or repair of the Achilles tendon. In these applications, an absorbable suture material is more desirable compared to a non-absorbable suture material of equivalent strength and stiffness. The non-absorbable suture materials and knots can be palpable, irritating, and a nidus for infection. An unexpected finding of this study was that Number 1 Vicryl has equivalent strength to Number 2 Ethibond and Number 2 TiCron. The bioabsorbability of Vicryl is an advantage in the aforementioned applications. Moreover, selection of appropriate suture material and caliber is important in avoiding potential complications. In one study, abdominal hernias were reported after reattachment of the abdominal muscles to the iliac crest with 2-0 Vicryl.[4] This could potentially be avoided with utilization of Number 1 Vicryl for this task.

In comparison of Number 5 caliber FiberWire, Ethibond and TiCron, the highest load to failure and stiffness were recorded in Number 5 FiberWire. In comparison to 18 gauge stainless steel wire (load to failure 910 N, stiffness of 320 N/mm),[7] single loop Number 5

**TABLE 3. Selected literature for comparison of maximum load to failure in Newtons for the different suture materials**

| Type of suture | Present study | Barber et al [1] | Wright et al [21] | Ilahi et al [10] | Barber et al [2] | Hassinger et al [8] |
|---|---|---|---|---|---|---|
| Loading | Single | Cyclic | Single | Cyclic | Cyclic | Single |
| Knot | SMC | SMC | No knot | SMC | No knot | SMC |
| Year | 2009 | 2009 | 2006 | 2008 | 2006 | 2006 |
| Environment | nonaqueous | nonaqueous | nonaqueous | saline | nonaqueous | nonaqueous |
| Number 5 FiberWire | 620 ± 29 | – | – | – | 482 ± 23 | – |
| Number 2 FiberWire | 282 ± 30 | 259 ± 85 | 255 ± 10 | 369 ± 23 | 188 ± 12 | – |
| Number 5 Ethibond Excel | 247 ± 10 | – | – | – | 193 ± 14 | – |
| Number 2 Ethibond Excel | 134 ± 9 | 144 ± 17 | 114 ± 2 | 160 ± 7 | 91 ± 5 | 135 ± 4 |
| Number 1 Ethibond Excel | 118 ± 7 | – | – | – | – | – |
| Number 0 Ethibond Excel | 73 ± 5 | – | – | – | – | – |
| Number 5 TiCron | 226 ± 12 | – | – | – | – | – |
| Number 2 TiCron | 136 ± 3 | – | – | – | – | – |
| Number 1 Vicryl | 130 ± 9 | – | – | – | – | – |
| Number 0 Vicryl | 105 ± 6 | – | – | – | – | – |
| Number 2-0 Vicryl | 76 ± 3 | – | – | – | – | – |

FiberWire is the suture material which has the closest material properties. It can be utilized for tension band fixation of subcutaneous fractures such as olecranon or patellar fracture without the need for future hardware removal. In addition, Number 5 FiberWire has the advantage of being less irritating to subcutaneous tissues than stainless steel wire.

There are several studies in the literature which assess the biomechanical properties of sutures. Most of these studies assess material properties of specific suture knots,[1,8,10] pull out strength of anchors,[2,17] or comparison of one type of suture versus stainless steel wire.[5,7] Some of the data in these studies is comparable and supportive of our data (Table 3). However, none of these studies assesses the material properties of the various calibers of most common suture materials.

In summary, the choice for application of suture material is guided by matching the material properties of the tissues being repaired to that of the suture material.

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