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Torsion of monofilament and polyfilament sutures under tension decreases suture strength and increases risk of suture fracture

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Abstract

Background: A continuous running suture is the preferential method for abdominal closure. In this technique the suture is secured with an initial knot and successive tissue bites are taken. At each tissue bite, the needle is rotated through the tissue; in doing so, the suture can twist around the knot which acts as an anchor.

Objective: To determine the effect of axial torsional forces on sutures used in abdominal closure.

Methods: The effect of axial twisting on polydioxanone (PDS*II), polyglactin (Vicryl), polypropylene (Prolene) and nylon (Ethilion) sutures was investigated using a uniaxial testing device.

Results: The maximum tensile force withstood for untwisted sutures was determined: polydioxanone failed at a tensile force of 116.4±0.84 N, polyglactin failed at 113.9±2.4 N, polypropylene failed at 71.1±1.5 N and nylon failed at 61.8±0.5 N. Twisting decreased the maximum tensile force of all sutures; one complete twist per 10mm (i.e. 15 twists) decreased the tensile strength of polydioxanone by 21%, polyglactin by 23%, polypropylene by 16% and nylon by 13%, p <0.001. Excessive twisting caused a non linear decrease in suture strength, with one twist per 75mm (i.e. 20 twists) of polydioxanone decreasing strength by 39%, P <0.001.

Conclusion: The effect of excessive twisting on the mechanical properties of sutures is a previously unrecognised phenomenon. Surgeons should be aware that this can result in a

decrease in suture strength and reduce the elasticity of the material, and therefore need to adapt their practice to reduce the torsional force placed on sutures.

Torsion of monofilament and polyfilament sutures under tension decreases suture strength and increases risk of suture fracture

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1. Introduction

Despite advances in wound closure techniques and materials, the complication rate post midline laparotomy remains high, with 1.3% of patients suffering a wound dehiscence, 16% of patients developing a surgical site infection (SSI) and up to 26% of patients developing an incisional hernia [1 2]. The pathogenesis of wound complications is complex and multi-factorial; both systemic and local factors are involved. However the role of surgical error and poor technique are increasingly becoming recognised as fundamental factors in the development of wound complications [3 4]. Accordingly the area of wound closure research is of particular interest, as these factors are related to wound complications and are directly modifiable by the surgeon [5 6 7]. The mass closure of a laparotomy incision, incorporating all of the layers of the abdominal wall, in a continuous running technique, using gauge 1 or 2 absorbable monofilament suture, with a suture length to wound length ratio of 4 to 1 is the current recommended abdominal closure method. However recent publications have identified shortcomings in regard to conventional wound closure methods [8 9]. Furthermore these studies have also highlighted the relative dearth of information regarding wound closure and the scientific basis of wound closure.

The influence of suture handling and placement on suture strength is a poorly understood area of surgical practice. Reports to date have demonstrated that chronic loading, stray knots and excess manipulation decrease the maximal tensile strength of sutures [10 11]. Additionally it has been shown that twisting a suture up to 4 times had no affect on the mechanical failure load of sutures. However we propose that sutures can become twisted more than 4 times during an abdominal closure. This will occur when the initial knot acts like an anchor, around which the suture twists as the needle is passed through the fascia at each successive tissue bite. This axial twisting wound and have the effect to induce a shear stress on the suture, which would act as a preload that could decrease the maximal tensile strength of the suture and can increase the risk of suture failure.

The aim of this study is to compare the maximum tensile force at failure of untwisted sutures to sutures that have been axially twisted and placed under torsional strain that could be experienced during a continuous abdominal closure. Four commonly used sutures were analysed, namely polydioxanone, polyglactin, polypropylene and nylon. These sutures were chosen as they are commonly used and have proven applicability in continuous abdominal closure [1,12 13]. Firstly, the failure force of the four different materials was investigated untwisted. Secondly, the failure force of sutures twisted 1 complete revolution per 10mm (i.e. 15 twists) was tested and compared untwisted sutures were compared. Finally, for polydioxanone the influence of the extent of twisting on suture strength was examined.

2. Experimental Section

2.1. Materials

Suture material**:** All sutures tested were Gauge 1 (diameter = 0.4mm). Non-absorbable monofilament nylon (Ethilion) and polypropylene (Prolene), along with absorbable monofilament polydioxanone (PDS*II) and braided polyglactin (Vicryl) sutures were obtained from *Ethicon* (Sommerville, NJ, USA). Table 1 lists the type, material, absorbability and use of all four sutures used in this study.

2.2. Methods

Suture loading**:** Sutures were removed from their packages and loaded into a Zwick /Z005 uniaxial testing device (*Zwick/Roell Group*, Leominister, Herefordshire, HR6OQH, England). The lengths of suture were secured in place by being wound over threaded cylinders 150mm apart (see Supporting Material, Figure 1). This method utilized friction between the suture and the threaded bar to hold the suture in place without the need for a knot which would act as a stress concentration. In this way, failure of sutures was always achieved away from the grips. Nonetheless suture slippage did occur and the results of these tests were nullified. The experiments were carried out at room temperature and were repeated 3 times for statistical significance.

Tensile strength testing**:** The tensile failure force of untwisted sutures and sutures twisted one complete revolution clockwise per 10mm (i.e. a total of 15 twists) was determined by performing uniaxial tensile strength tests. The effect of the number of twists on polydioxanone sutures was also examined, where sutures were also twisted one complete turn per 15mm (i.e., 10 twists) and 7.5mm (i.e., 20 twists). Using a 5kN load cell, sutures were preloaded to 1kN and stretched quasi-statically at a rate of 20mm/min. The maximum tensile force $F_{t,max}$ was defined as the force required for the suture to fail. Data interpretation and analysis was performed by testXpert version 11.0 (*Zwick GmbH& Co*, August-Nagel Strasse 11, 99079 Ulm, Germany). Data is represented in graph form consistent with already published experimental models of mechanical behaviour of biomedical materials [14 15 16].

Statistical analysis: Data analysis was carried out using SigmaPlot version 11.0 (*Systat Software Inc*, San Jose, California, USA). Mean values were compared using an unpaired two-tailed *t* test and P-values of less than 0.05 were accepted as significant.

3. Results

3.1. Tensile strength of untwisted suture materials.

The tensile strength of untwisted sutures was determined by uniaxial tests for polydioxanone, polyglactin, polypropylene and nylon sutures. Figure 1 depicts tensile force F_t against change in suture length/extension (ε) for all four materials. The maximum tensile force $F_{t,max}$ and maximum extension (ε_{max}) have been extracted from Figure 1 and are represented in Table 2. Polydioxanone sutures were the strongest suture, failure occurred at a tensile force of 116.4±0.8 N. This suture also had the largest extension failure of 92.4±0.1 mm. Polyglactin sutures were the second strongest suture, with a failure force of 113.9±2.4 N, but were the least elastic suture tested an extension at failure of 47.0±3.2 mm. Polypropylene sutures were the second weakest sutures tested and failed at a force of approximately 71.1±1.5 N, but polypropylene sutures had similar extension at failure as polydioxanone sutures. Nylon sutures were the weakest suture tested, and fractured at 61.8±0.5 N; this makes this suture less than half as strong as polydioxanone sutures.

3.2. Tensile failure force for untwisted and twisted suture materials.

Sutures were stressed prior to uniaxial tests by twisting the suture one complete revolution clockwise per 10mm of material. Figure 2 compares F_t (ε)-curves for untwisted and twisted sutures for all four materials, namely (A) polydioxanone, (B) polyglactin, (C) polypropylene and (D) nylon. The maximum tensile force $F_{t,max}$ and maximum nominal extension ε_{max} have been extracted from Figure 2 and are represented in Table 2. This induced stress via twisting decreased the failure load and extension of all sutures tested. Table 2 shows that twisting polydioxanone sutures decreased the tensile failure force from 116.4±0.8 N to 91.3±1.3 N, this represents a 21% decrease in force required to cause suture failure. This was a statistically significant reduction, *t* test P <0.0001. Twisting also decreased the elasticity of polydioxanone sutures by 6.7%, *t* test P =0.0024. In the case of polyglactin sutures, twisting reduced the tensile failure force from 113.9±2.4 N to 86.9±0.4 N, representing a 23% decrease in tensile force, *t* test P < 0.0001. Axially twisting also reduced the nominal strain of polyglactin sutures by 17.1%, *t* test P < 0.0001.Twisting also affected the maximal tensile force and extension of polypropylene and nylon sutures. Axial twisting polypropylene and nylon sutures reduced the maximal tensile force by 16% and 13% respectively, *t* test P <0.0001. It also reduced the nominal strain of polypropylene by 35%, t test P < 0.0001and nylon by 7.5%, *t* test P <0.001.

3.3.Influence of the number of twists on Polydioxanone sutures.

Polydioxanone sutures were selected for further testing as numerous studies and meta-analyses have recommended its use for abdominal closure [1 13 17]. This material has demonstrated comparable wound strength to non-absorbable sutures and is associated with a significantly lower incidence of wound complications [13 17 18]. Furthermore in our experiments, polydioxanone also demonstrated the greatest maximum tensile force of the four different materials studied (see Section 3.1). Sutures were twisted one complete turn per 15mm (i.e. 10 twists in total), one turn per 10mm (i.e. 15 twists) and 7.5mm (i.e. 20 twists) , and compared with untwisted suture results given in Section 3.1. Figure 3 compares F_t (ε)-curves for untwisted and twisted (i.e. 10, 15 and 20 twists respectively) for polydioxanone sutures. Successive twisting led to a continuous decrease in the strength of the suture. Twisting the suture 10 times decreased its failure load by

10.3%, 15 twists decreased the failure load by 21% and 20 twists by 47%, *t* test P <0.0001 (see Figure 4). The elastic properties of polydioxanone were also affected by axial twisting, with the material becoming stiffer extension at failure reduced by 4.1% for 10 twists, by 6.7% for 15 twists and 20.8% for 20 twists, *t* test P =0.0002

4. Discussion

Surgeons must have a scientific basis for wound closure and must stay informed about the most up-to-date findings concerning all types of wound closure techniques. Previously the continuous running closure of an abdominal wound with a absorbable monofilament suture with a length to wound length ratio of 4:1 has been recommended [12 19 20 21]. The initial anchoring knot should be a loop knot, and each tissue bite should be taken greater than 10 mm from the cut edge, and the final knot should either be an Aberdeen knot or surgeons knot [4]. However recent studies have identified that excessive tissue bites are associated with unacceptable increased rates of wound complications, and as such it is recommended to reduce tissue bites to less than 1 mm, additionally the length to wound length ratio will need to be altered to facilitate this [9]. Equally other aspects of wound closure need investigation; one such area is the effect of axial twisting forces on sutures. While performing a continuous abdominal closure, the initial loop knot can act as an anchor which around a suture can twist. When taking a tissue bite, the suture needle is passed at a 90° angle through one side of the wound; it is then picked up in the needle holder and passed at a 90° angle through the opposite side. In doing this, the suture will twist axially. With each advancing subsequent tissue bite, the twisting will develop a shear stress on the suture (see Supporting Material, Figure 2). The effect of excessive axial twisting on suture strength has previously been undetermined.

In this paper we initially determined the maximum tensile force of polydioxanone, polyglactin, polypropylene and nylon sutures. Polydioxanone is the strongest suture material and failed only after a force of 116.4±0.8 N was applied. The braided absorbable material polyglactin was the second strongest material and failed at 113.9±2.5 N, interestingly polyglactin demonstrated the least elastic properties of all sutures tested, and this is attributed to its multi filament arrangement. Polypropylene and nylon were the weakest material tested and failed at 71.1±1.5 N and 61.8±0.5 N respectively; they also had similar extension at failure forces. These findings are in line with other studies which demonstrated that polyglactin was stronger than polypropylene and nylon [22 23]. Our results have demonstrated that polydioxanone has a superior tensile failure force compared to polypropylene and nylon, and has superior extension at failure properties compared to the other polyglactin; confirming polydioxanone as the suture of choice of abdominal closure.

To simulate the twisting sutures may undergo during a continuous abdominal closure, sutures were then twisted axially one complete revolution per 1cm of material. Tensile tests of the twisted sutures showed that the tensile force of all sutures was decreased significantly. Axially twisting polydioxanone decreased the maximum suture strength from 116.4±0.8 N to 91.3±1.3 N, representing a 21% decrease in suture strength, $P < 0.001$. Similarly we found that axial twisting polyglactin decreased suture strength 23%, while polypropylene and nylon sutures were decreased 16% and 13% respectively, $P < 0.001$. Axial twisting also affected the elastic properties of sutures tested; in all cases there was a statistically significant reduction in the sutures ability to resist a change in length under tension. This suggests that axially twisted sutures are less likely to elongate and conform to a wound than untwisted sutures. This property would increase the risk of suture failure and wound complications. To examine if the decrease in suture strength was proportional to the number of twists, polydioxanone sutures were twisted further; one complete turn per 15mm (i.e. 10 twists) and 1 turn per 7.5mm of material (i.e. 20 twists). Axial twisting by one complete turn per 1.5cm decreased the tensile strength 10.3%, while one complete turn per 0.75cm decreased the strength by 39%. This is in contrast to a previous study that demonstrated that axial twisting a suture 4 times had no effect on suture tensile strength [11]. This data suggests that between 4 and 10 twists a critical level of twist is achieved in which the induced shear stress in the sutures leads to a quantifiable reduction in tensile failure force. Furthermore excessive axial twisting of a suture decreases the tensile failure force in a nonlinear manner, as 10 twists decreased the tensile failure force by 10.3% but 20 twists decreased the failure force by nearly 40%.

The effect of axial twisting and torsional forces on sutures has previously been unknown, for the first time it had been identified that axial twisting a suture excessively can decrease the suture strength and reduce the elastic properties in a non-linear manner that risks suture failure and post-operative wound complications. Hence surgeons need to be aware that excessive axial twisting significantly decreases the maximum tensile force of suture strength and the ability of a suture to resist a change length. While performing a continuous running closure of the abdomen, extra care should be taken to prevent axial twisting. The authors additionally recommend that the suture should be removed from the needle holder and be left to untwist after every 10 successive tissue bites, in doing so surgeons will adhere to the emerging scientific basis for abdominal wound closure.

5. Acknowledgements

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6. Tables and Figure legends

6.1. Table 1: Suture materials

The commercial name of suture tested type of suture, the method of absorption and indicated use.

6.2. Table 2: Summarised results from Figure 2.

Change in suture length/extension ε, maximum tensile force $F_{t,max}$ and P-value with unpaired two-tailed *t* test for polydioxanone (PDS*II), polyglactin (Vicryl), polypropylene (Prolene) and nylon (Ethilion). Values are given for both untwisted (i.e. 0 twists) and twisted (i.e. 15 twists) measurements and are extracted from Figures 1 and 2.

6.3. Figure 1: Tensile strength of untwisted suture materials.

Tensile force F_t as a function extension ε for four untwisted suture materials tested, namely polydioxanone (PDS*II), polyglactin (Vicryl), polypropylene (Prolene) and nylon (Ethilion) sutures. The maximum tensile force $F_{t,max}$ are extracted and represented in Table 2.

6.4. Figure 2: Tensile strength of untwisted and twisted suture materials.

Tensile force F_t as a function of extension ε for four different suture material, which are untwisted (i.e. 0 twists) and twisted (i.e. 15 twists, twisted one complete revolution clockwise per 10mm). The four different suture materials are (A) polydioxanone (PDS*II), (B) polyglactin

(Vicryl), (C) polypropylene (Prolene) and (C) nylon (Ethilion) sutures. Maximum tensile force $F_{t,max}$ are extracted and represented in Table 2.

6.5. Figure 3: Effect of decreasing and increasing the number of twists on Polydioxanone.

Effect of varying the number of axial twists on polydioxanone (PDS*II) sutures. Tensile force F_t as a function of extension ε for polydioxanone sutures, which are untwisted (i.e. 0 twists) and twisted (twist = 10, 15 and 0). Twisting was achieved by one complete turn per 15mm (i.e. 10 twists), 10mm (i.e. 15 twists) and 7.5mm (i.e. 20 twists). Maximum tensile force $F_{t,max}$ are 116.4±0.8 N (i.e. 0 twists), 104.1±0.6 N (i.e. 10 twists), 91.3±1.3 N (i.e. 15 twists) and 70.9±1.8 N (i.e. 20 twists).

6.6. Figure 4: Continuous decrease in maximal tensile strength with increasing axial twists

Excessive axial twisting of polydioxanone caused a continuous decrease in suture strength shown in. Twisting polydioxanone sutures one complete turn per 15mm (i.e. 10 twists) decreased suture strength 11%, twisting the suture one turn per 10mm (i.e. 15 twists) decreased the strength 21%. Whereas one turn per 7.5mm (i.e. 20 twists) decreased the suture strength by 39%.

7. Reference

1 L. A. Israelsson and T. Jonsson, "Closure of midline laparotomy incisions with polydioxanone and nylon: the importance of suture technique," Br J Surg 81 (11), 1606-1608 (1994).

2 L. Heller, S. L. Levin, and C. E. Butler, "Management of abdominal wound dehiscence using vacuum assisted closure in patients with compromised healing," Am J Surg 191 (2), 165-172 (2006).

3 E. J. van Rijssel, J. B. Trimbos, and M. H. Booster, "Mechanical performance of square knots and sliding knots in surgery: comparative study," Am J Obstet Gynecol 162 (1), 93-97 (1990).

4 E. D. Fong, A. S. Bartlett, S. Malak, and I. A. Anderson, "Tensile strength of surgical knots in abdominal wound closure," ANZ J Surg 78 (3), 164-166 (2008).

5 M. Mudge and L. E. Hughes, "Incisional hernia: a 10 year prospective study of incidence and attitudes," Br J Surg 72 (1), 70-71 (1985).

6 H. J. Sugerman, J. M. Kellum, Jr., H. D. Reines, E. J. DeMaria, H. H. Newsome, and J. W. Lowry, "Greater risk of incisional hernia with morbidly obese than steroid-dependent patients and low recurrence with prefascial polypropylene mesh," Am J Surg 171 (1), 80-84 (1996).

7 T. E. Pavlidis, I. N. Galatianos, B. T. Papaziogas, C. N. Lazaridis, K. S. Atmatzidis, J. G. Makris, and T. B. Papaziogas, "Complete dehiscence of the abdominal wound and incriminating factors," Eur J Surg 167 (5), 351-354; discussion 355 (2001).

8 Y. Cengiz, P. Blomquist, and L. A. Israelsson, "Small tissue bites and wound strength: an experimental study," Arch Surg 136 (3), 272-275 (2001).

9 Cengiz Y Millbourn D, Israelsson LA., "Effect of stitch length on wound complications after closure of midline incisions," Arch Surg 144 (11), 1056-1059 (2009).

10 P. B. Dobrin, "Chronic loading of polypropylene sutures: implications for breakage after carotid endarterectomy," J Surg Res 61 (1), 4-10 (1996).

11 P. B. Dobrin, "Surgical manipulation and the tensile strength of polypropylene sutures," Arch Surg 124 (6), 665-668 (1989).

12 J. Wissing, T. J. van Vroonhoven, M. E. Schattenkerk, H. F. Veen, R. J. Ponsen, and J. Jeekel, "Fascia closure after midline laparotomy: results of a randomized trial," Br J Surg 74 (8), 738-741 (1987).

13 N. C. Hodgson, R. A. Malthaner, and T. Ostbye, "The search for an ideal method of abdominal fascial closure: a meta-analysis," Ann Surg 231 (3), 436-442 (2000).

14 A. Yildirim and Y. Cherruault, "Analytical approximate solution of a SIR epidemic model with constant vaccination strategy by homotopy perturbation method," Kybernetes 38 (9), 1566 - 1575 (2009).

15 M. Merdana, A. Gökdoğanb, and A. Yildirim, "On the numerical solution of the model for HIV infection of CD4+ T cells," Computers & Mathematics with Applications 62 (1), 118–123 (2011).

16 A. Yildirim and H. Koçak, "An analytical approach to transmission dynamics of infectious diseases with waning immunity," Journal of Mechanics in Medicine and Biology 11 (4) (2011).

17 P. M. McNeil and H. J. Sugerman, "Continuous absorbable vs interrupted nonabsorbable fascial closure. A prospective, randomized comparison," Arch Surg 121 (7), 821-823 (1986).

18 J. Rucinski, M. Margolis, G. Panagopoulos, and L. Wise, "Closure of the abdominal midline fascia: meta-analysis delineates the optimal technique," Am Surg 67 (5), 421-426 (2001).

19 T. P. Jenkins, "The burst abdominal wound: a mechanical approach," Br J Surg 63 (11), 873-876 (1976).

20 M. van 't Riet, E. W. Steyerberg, J. Nellensteyn, H. J. Bonjer, and J. Jeekel, "Meta-analysis of techniques for closure of midline abdominal incisions," Br J Surg 89 (11), 1350-1356 (2002).

21 H. Gislason, J. E. Gronbech, and O. Soreide, "Burst abdomen and incisional hernia after major gastrointestinal operations--comparison of three closure techniques," Eur J Surg 161 (5), 349-354 (1995).

22 L. Nobile, L. Checchi, and G. Monaco, "Experimental analysis of tensile properties of some suturing materials," J Mater Sci Mater Med 8 (1), 53-56 (1997).

23 J. C. Kim, Y. K. Lee, B. S. Lim, S. H. Rhee, and H. C. Yang, "Comparison of tensile and knot security properties of surgical sutures," J Mater Sci Mater Med 18 (12), 2363-2369 (2007).

Figure

Figures

Figure 1: Tensile failure force of untwisted suture materials

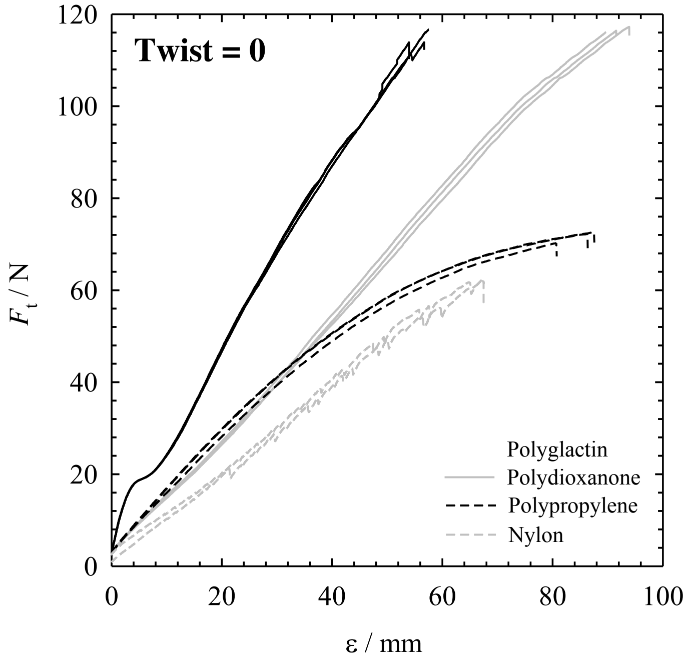
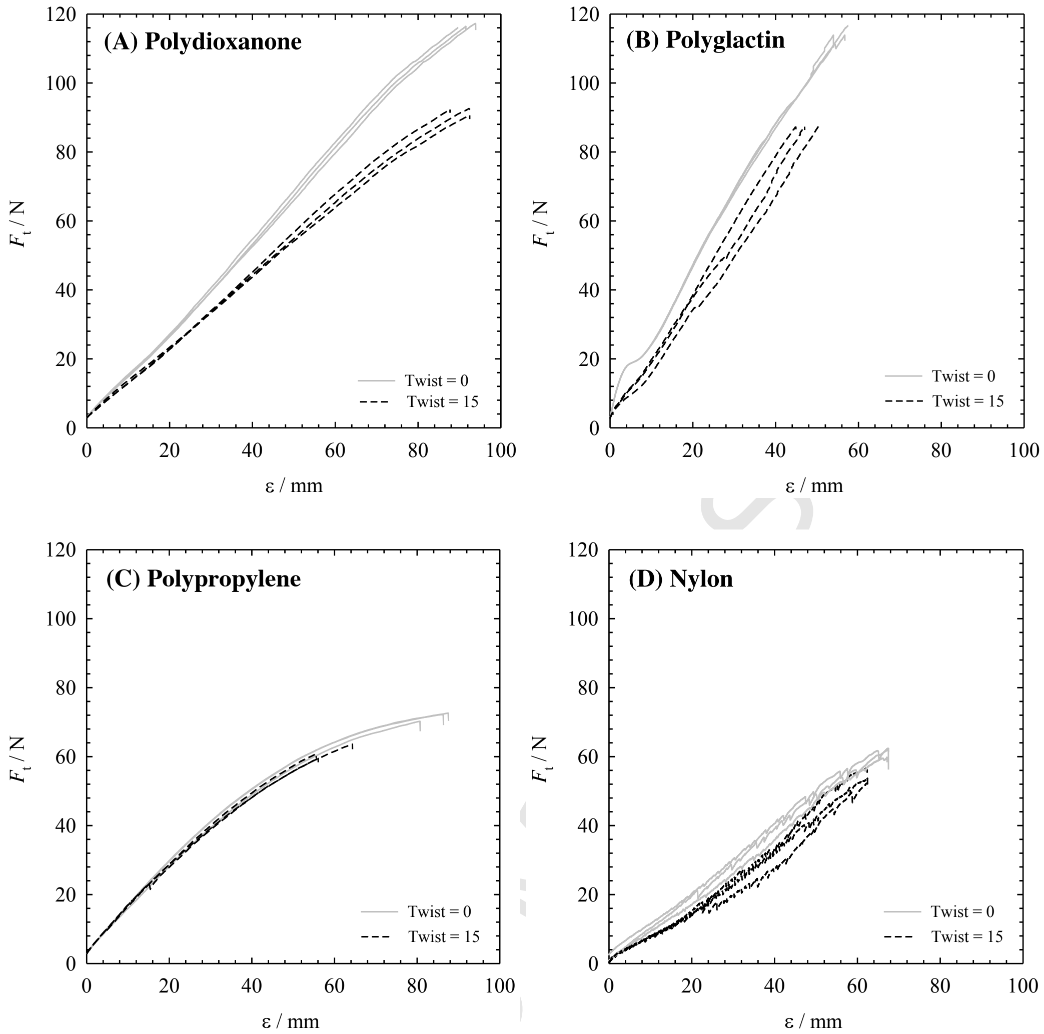


Figure 2: Tensile strength of untwisted and twisted suture materials.



(A) Polydioxanone
(B) Polyglactin
(C) Polypropylene
(D) Nylon
F_t / N
ε / mm
Twist = 0
Twist = 15
0
20
40
60
80
100
120

Figure 3: Influence of the number of twists on polydioxanone sutures.

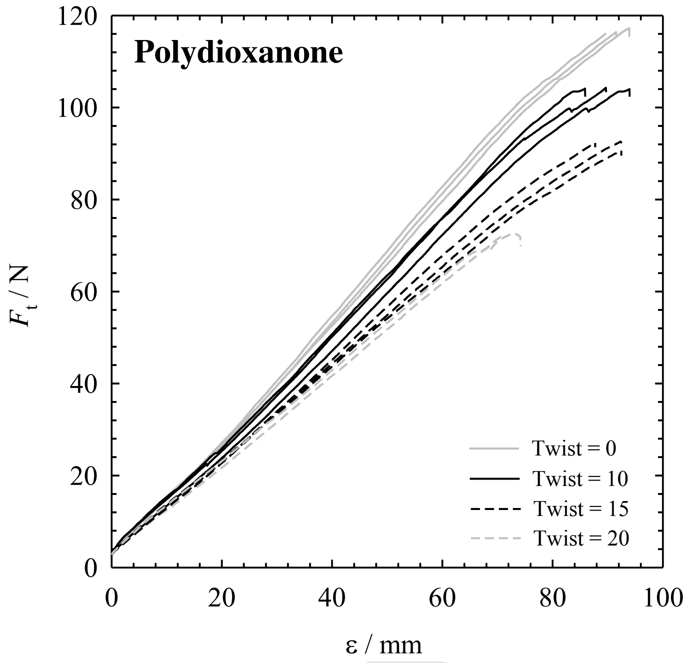
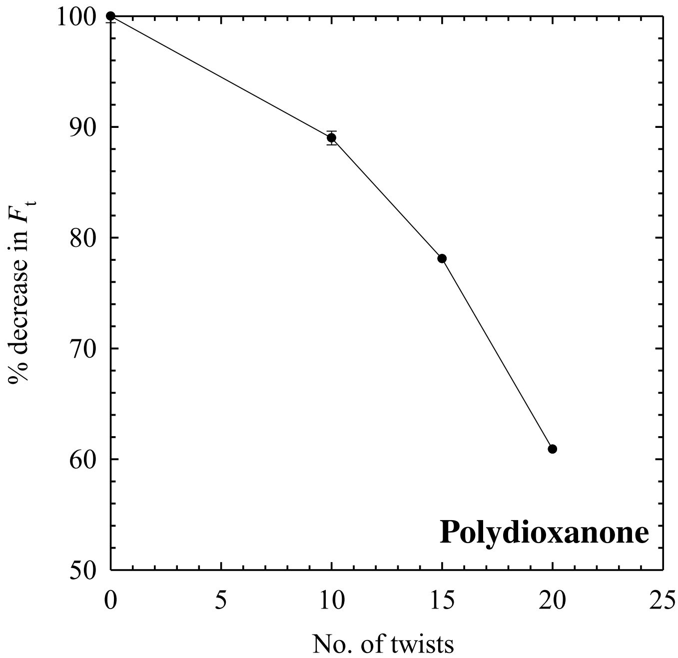


Figure 4: Continuous decrease in maximal tensile strength with increasing axial twists


100
90
80
70
60
50
% decrease in F_t
Polydioxanone
0
5
10
15
20
25
No. of twists

Table

Tables

2.1. Table 1: Suture materials

Material	Suture	Type	Absorbable/Non absorbable	Use
Polydioxanone	PDS*II	Monofilament	Absorbable	All tissues except where approximation is required indefinitely
Polyglactin 910	Vicryl	Braided	Absorbable	Ligating, suturing all tissues except where extended approximation is required
Polypropylene	Prolene	Monofilament	Non-absorbable	Fascia, skin, blood vessels, cardiac
Nylon	Ethilion	Monofilament	Non-absorbable	Fascia, skin, blood vessels, nerves

2.2. Table 2: Summarised results from Figure 2

	Extension ε (mm)			**$F_{t,max}$ (N)**		
Material	Twist = 0	Twist =15	*P value	Twist = 0	Twist =15	*P value
Polydioxanone	91.5 ±2.4	87.4±1.0	0.0024	116.4±0.8	91.3±1.3	< 0.0001
Polyglactin 910	56.7±0.8	47.1±3.2	< 0.0001	113.8±2.4	86.9±0.4	< 0.0001
Polypropylene	86.3±1.2	56.1±8.2	< 0.0001	71.0±1.6	59.5±2.6	< 0.0001
Nylon	67.5±0.3	62.4±0.1	< 0.0001	61.8±0.5	53.7±1.4	< 0.0001