Biomechanical evaluation of suture materials used for abdominal fascial closure

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Abstract

Background. While there are clear recommendations for the technique and suture material for abdominal fascial closure, surgeons may have personal preferences arising from previous experiences or influenced during training. The decision of which suture material to use should not influence the outcome of fascial closure. The objective of this study is to analyze the influence of time and tension on the mechanical properties of sutures used for abdominal fascial closure.

Methods. Polyglactin 910, polypropylene, and polydioxanone sutures were exposed to 8 and 10 newtons of constant tensile strain during a period of 7 and 14 days. They were then mechanically tested to assess changes in their properties regarding strength and deformation.

Results. No significant changes were observed in maximum tensile force or extension within the different suture groups. Regarding deformation, polypropylene and polydioxanone did not exhibit alterations in their curve behavior, while polyglactin 910 did exhibit changes compared to the control group, as seen by the elevation in its Young modulus when manipulated.

Conclusions. Our study finds that while different sutures behave differently, neither time nor tension have a negative effect on their biomechanical resilience and can withstand tensile strengths well above any physiological or pathological condition.

Introduction

The European Hernia Society recently published an updated clinical guideline on abdominal wall closure. Their main recommendations are to use a slow absorbable monofilament suture, to close in a continuous fashion, taking a bite 5 millimeters away from the wound edge, and skipping 5 millimeters between stitches (small bite technique). This closure is to be done in a single layer, having a 4:1 ratio between the suture and wound length [1]. This clinical guideline intends to standardize abdominal fascial closure, given the current variability in the type of suture used and the surgeon’s technique.

The literature describes different techniques and materials used for abdominal fascial closure. Usually, surgeons learn to suture the fascia from a vertical teaching method, learned from generation to generation. Most surgeons choose the material that they will use for abdominal fascial closure based on their personal training, geographical trends, and personal preference [2]. The importance of proper closure of the abdominal fascia is a priority since doing it incorrectly may lead to serious consequences, such as dehiscence [3], incisional hernia [4, 5], surgical site infection [6], tissue strangulation, among others.

The incidence of fascial dehiscence is 0.4%–3.5% depending on the type of surgery, occurring either in the early or late postoperative period [3]. In a laparotomy approach, the incidence of an incisional hernia varies between 4%–20%. Furthermore, recurrence of an incisional hernia occurs in 5% to 20% of patients [4, 5].
Evisceration is a surgical emergency with high morbidity and mortality [3–5, 7, 8]. Abdominal dehiscence increases morbidity, mortality, hospital stay, and total costs.

There are multiple risk factors for the development of an incisional hernia, and they can be divided into those dependent on the surgeon (closure material and technique) and those patient dependent such as chronic degenerative diseases, obesity, infection, smoking, to mention a few [2, 9, 10]. The materials used for closure of the abdominal wall have different measurable characteristics, including degradation (absorbable and non-absorbable), composition (synthetic or natural), structure (monofilament or multifilament), among others [11, 12]. The tension exerted by the abdominal wall on the sutures can have different effects on them and therefore the material used for closure can directly affect the results and complications in patients.

We set to analyze the change in biomechanical properties of the sutures after being subjected to tensions comparable to those exerted by the abdominal wall after seven and fourteen days.

**Materials and methods**

We did an experimental study with the three types of sutures most commonly used for abdominal wall closure, Vicryl Plus (Polyglactin 910) -1®, PDS II (Polydioxanone) -0® and Prolene (Polypropylene)-0® (Ethicon Inc., Cincinnati, OH). Sutures were exposed to a constant tension similar to that exerted by the abdominal wall in post-operative patients (laparotomy). Sutures were fixed in place with a quadruple square knot and passed through a straight segment to a final loop holding the weight, fixed in the same manner, as illustrated in figure 1. All sutures (n = 75) were knotted by the same surgeon to account for any effect of suture manipulation.

The post-surgical intra-abdominal pressure to which the sutures are exposed is constantly changing. It has been described that the immediate intra-abdominal pressure is about 12.3 mm Hg at 24 hours the intra-abdominal pressure is about 11.44 mm Hg and at 48 hours is at 10.66 mm Hg [13]. Given an abdominal wound of 30 cm in length and 2 cm in width, calculations for the total force were as follows:

\[
\text{Surface area: } 0.3 \times 0.02 = 0.06 \text{ m}^2
\]

**Formula 1.** The total surface area of the wound.

\[
\text{Tension: } (10 \times 133.322)0.006 = 7.99 \text{ N}
\]

\[
\text{Tension: } (12 \times 133.322)0.006 = 9.81 \text{ N}
\]

**Formula 2.** Total tension dependent on intra-abdominal pressure (10 and 12 mmHg converted to pascals [133.322 factor]).

Thus, the conversion resulted in 8 N (815 grams) and 10 N (978 grams) of weight to be applied to the sutures.
The tension was maintained constant for 7 or 14 days. Afterwards, the sutures were cut adjacent to the knot, and the straight portions of the sutures under tension were subjected to a longitudinal stress test to measure the Maximum Tensile Force (MaxTF) and extension. Measurements were made using the Instron 3365 equipment (Instron Corporation, Nordstrom, MA), with a 5 kN load cell for mechanical tests, which were analyzed with the Bluehill software and the parameters previously reported by our group [10]. Two flat pneumatic jaws hold the sutures in position, which were placed 10 cm apart (supplementary figure 1 available online at stacks.iop.org/MRX/8/115401/mmedia). A continuous speed of 100 millimeters/minute was applied to the sutures until rupture as done in previous similar experiments [10, 14–18]. MaxTF and extension were measured. New sutures were used as controls. Tests and positioning of the sutures were performed by the same user. Sutures were secured to avoid any slipping.

All statistical analysis was performed by a two-way ANOVA using GraphPad Prism version 6.04 (Windows, GraphPad Software, La Jolla, CA).

Results

Seventy-five stress tests were performed. During the tests there were no premature breaks, all the sutures were broken two centimeters away from the jaws, and none were loosened without breaking.

As previously reported by our group, the 3 different sutures (Prolene-0®, Vicryl Plus-1®, PDS II®) behaved as expected with regards to elasticity and tensile strength. Panel a in figure 2 depicts the average extension before suture failure. No statistical differences between the study groups were found. Panel b shows the average force required for the rupture to occur, which as well did not exhibit significant changes.

This was followed by comparing the different sutures with each other and we found that Vicryl showed the highest maximum tensile strength, and PDS II showed the greatest extension with a significant statistical difference when compared to the different suturing materials. These characteristics were present in the control groups and remained in the experimental groups with no changes when modifying the weight exerted or time exposed.

Regarding changes in the plasticity of the material, the plotting of force versus deformation (figure 3) revealed a significant change in the control group of Vicryl, while all test groups exhibited a similar curve. As for PDS and Prolene, no significant changes were found in the behavior of the deformation curve.

Young's modulus measures stiffness by associating stress and deformity with the linear elasticity of any material. As found in figure 4, all test groups of Vicryl exhibited a significant increase compared to the control group, with a tendency to increase in a time-dependent fashion. Statistical significance was also found between the group corresponding to the lowest tension (8 N) and shortest time (7 days) when compared to the same tension and longer time as well as the group subjected to the highest tension (10 N) for 14 days. Regarding PDS and Prolene, no significant changes were found among control and test groups.
Discussion

Multiple patient-related risk factors are known to increase abdominal wound dehiscence, such as male sex, chronic diseases, high intraabdominal pressure (ascites), blood alterations (anemia), emergency surgery, and surgical site infection. In a Swedish study, surgical site infection and body mass index above 25 kg m\(^{-2}\) were associated with dehiscence of the surgical wound and incisional hernia \([19, 20]\). Technical factors associated with dehiscence of the abdominal wall have been described, such as the type of surgical incision and the surgical technique used to close the abdominal wall. The ideal suture is one that maintains its high tensile strength without losing its elasticity, easy to manipulate, is biologically inert, and does not generate tissue inflammation or promote infections. No suture meets all of these characteristics \([21]\). In 95% of patients with facial dehiscence, the suture and knot are intact. This is usually the result of stitching very close to the edge of the fascia or with a lot of tension that induces ischemia and disrupts the fascia \([3, 4, 8, 11]\). This has been further studied by Horeman and co-workers, which after developing a tension sensor, demonstrated that the force applied to a continuous suture after the knot remains constant for more than 3 stitches. This emphasizes the importance of bite size, force distribution, and tension along the whole wound \([22]\).

Non-absorbable suture failure is usually secondary to the knot unraveling and absorbable sutures tend to rupture first before the knot is undone \([19, 21]\). The clinical guidelines recommend using slow absorbable
material, however many centers continue to use non-absorbable material (Prolene), and apparently, the results are the same [1].

There are studies in the literature that show no statistically significant difference in the incidence of incisional hernia depending on the surgical technique used or the suture used [19]. However, these studies are retrospective, and some show selection bias [19]. In a meta-analysis of the Cochrane database, they analyzed the surgeon’s technique and material used to close the abdominal fascia in laparotomies in 55 studies. They found that for the incidence of hernias there is no significant difference when using absorbable (fast or slow) or non-absorbable material, layered or mass closure, continuous suture, or interrupted stitches. When comparing the risk of infection, they also found no significant difference when using absorbable (fast or slow) or non-absorbable sutures, closing in bulk or layers, using continuous or interrupted suturing technique, using monofilament or multifilament. Finally, they compared the incidence of dehiscence without finding differences in the use of absorbable or non-absorbable sutures, mass or layered closure, using continuous or interrupted suturing technique, monofilament or multifilament sutures. They did find a lower incidence of incisional hernia when using monofilament versus multifilament sutures. They found that the slow absorption suture may be linked to a higher incidence of dehiscence and explained that this phenomenon may be a result of suture management (higher difficulty for PDS II than Vicryl) [2].

Desire Abellán et al analyzed multiple types of sutures in a controlled in vitro environment for biomechanical properties. In this study, the sutures were subjected to one and two weeks in environments with different concentrations of pH and temperature and subsequently subjected to tension tests. They concluded that physical conditions such as pH and temperature do not influence the mechanical properties of the sutures [11]. Furthermore, sutures have been also exposed to cultures of E. coli and increased pH. In these studies, they found out that there is greater degradation of the sutures but there is no difference when performing biomechanical tests [23–27].

In-vitro studies usually expose the sutures to external stress for the first period (pH, temperature, tension) and are subsequently carried out to biomechanical testing. When the sutures are used in the abdominal fascia, all factors are present at the same time: change in pH, temperature, and continuous tension. In our study we decided to keep the sutures under continuous tension, hypothesizing that continuous stress on the suture would change the biomechanical characteristics of the material when testing. In the end, our results were similar to those described in the literature, there is no difference when exposing the sutures to continuous tension (10 N and 12 N) for one or two weeks.

Muller and his group compared 5 different sutures (Vicryl, Maxon, Monocryl, PDS II, Vicryl Rapide, and Ethibond) for 56 days in an in vitro setting at a temperature of 37 degrees and pH 7.40. They found out that absorbable sutures can support larger loads during the first two weeks. Furthermore, they found that Maxon and PDS II maintain their elastic properties despite their degradation and loss of tensile strength [23–27]. Diaz-Elizondo et al described a similar pattern [10].

Regarding surgical technique and manipulation, in the study carried out by Diaz-Elizondo et al they compared new sutures (no biomechanical stress) with sutures that were used for closure of a porcine fascia by general surgery residents. They found no difference when subjecting the sutures to the same tests herein performed [10].

In our study, we found that the three sutures behave similarly to the control groups regardless of the time and weight to which they were exposed. Vicryl continues to be the suture with the highest maximum tensile force and PDS II with the greatest deformity in all groups. Factors that arise from their composition, Vicryl® is prepared from polyglactin 910 as a multifilament, while PDS II® is a suture prepared from polydioxanone as a monofilament, thus allowing a greater elasticity. This phenomenon can as well explain the changes in Vicryl’s Young modulus, that by being a multifilament, any manipulation or stress leads to a rapid increase towards a plastic deformation (figure 4).

By subjecting any material to a force, deformation occurs. In general, materials have an elastic deformation that is reversible and not permanent. If we continue to apply a force, materials enter a plastic deformation phase which is no longer reversible and subsequently fail under stress. In figure 3, we show force versus deformation graphs. Note that the elastic limit of Vicryl is approximately 20 N, whereas for PDS II and Prolene it is much higher. Intra-abdominal pressure exerts forces less than 20 N. This means that intra-abdominal pressures can cause elastic deformity on the sutures, but not enough to generate plastic deformation. It can be seen that the elastic limit and the fracture point of the materials are well above any pressure that can physiologically be found in the abdomen and subject to the sutures and therefore, these sutures withstand well above the strength and are safe for the closure of the abdominal fascia.

Despite our findings, it is important to acknowledge the limitations of the present study, we have not included other variables, such as pH, or temperature. While it has been well established that both, alkaline and acidic environments enhance hydrolysis, our main objective was to determine the effects of uninterrupted tension on the mechanical properties of the material. Another limitation is that intraabdominal pressure is not
constant, thus tensile changes could play a role in the plasticity and consequently the mechanical behavior of sutures.

Conclusions

We conclude that there is no difference in tensile strength or elongation between control groups and sample groups regardless of the material used. Vicryl is the suture that shows the greatest MaxTF and PDS is the suture that shows the greatest deformity. All sutures have MaxTF and elastic limits well above a high intra-abdominal pressure, which makes them very safe to close the abdominal fascia. Further work will be performed to elucidate the effects of other variables such as humidity, pH, and temperature on the mechanical integrity of suturing material.

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Data availability statement

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

Conflicts of interest/competing interests

The authors declare that they have no competing interests.

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Declarations of interest

None.

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