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Creep Behavior of Commonly Used Suture Materials in Abdominal Wall Surgery

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Background. **The incidence of incisional hernia after abdominal wall closure is high. Furthermore, recurrence is a significant complication after correction of all abdominal wall hernias. Besides surgeon- and patient-related factors, in this experimental study a third factor, i.e., creep behavior of suture materials, is introduced and evaluated.**

Materials and methods. **Creep measurements were performed on 0 and 2-0 Prolene (Ethicon, Johnson & Johnson Intl., Somerville, NJ) and 1 and 2-0 PDSII (Ethicon, Johnson & Johnson Intl.) sutures. Two different loads were used representing normal intra-abdominal pressure (IAP) and pathological IAP. A mean percentage of elongation was calculated for each type of suture material. Statistical analysis was performed using analysis of variance.**

Results. **All suture materials showed significant (3–51%) creep behavior. Prolene sutures showed more creep than PDSII sutures in both loading conditions.**

Conclusions. **As significant creep was demonstrated for commonly used suture materials, creep might be a significant influential factor with regard to the etiology of incisional hernias and recurrence after abdominal wall hernia repair.** **© 2007 Elsevier Inc. All rights reserved.**

Key Words: **suture; creep; incisional hernia; abdominal wall hernia; intra-abdominal pressure.**

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INTRODUCTION

Incisional hernia is a significant complication after abdominal surgery. Furthermore, incisional hernias and other abdominal wall hernias in general are associated with high recurrence rates. Most abdominal wall hernias are inguinal hernias, of which recurrence rates are reported ranging from 0.7% using prosthetic (tension free) repair, up to 25% using nonmesh repair [1, 2]. Incisional hernia is reported with incidences up to 20% and recurrence rates up to 45% in high-risk patients [3–7].

Many factors are considered to contribute to the development of incisional and recurrent abdominal wall hernias. In general two groups of factors can be distinguished. First, intrinsic factors, such as age, abnormalities of collagen metabolism, and conditions in which abdominal pressure is increased (obesity, constipation, abdominal compartment syndrome, ileus), are reported to be responsible [8–10]. Second, extrinsic factors such as surgical technique, the use of prosthetic biomaterial, and the characteristics of suture material (suture break, knot slip) have been reported [2, 11, 12].

Because of the great variability of patients with regard to intrinsic factors, it is difficult to investigate the precise role of extrinsic factors. Besides epidemiological studies concerning incidence and recurrence rates, most experimental studies with regard to extrinsic factors focus on the influence of surgical technique. However, as yet still a large variety of different techniques exists and there is no consensus on best practice concerning surgical technique.

Theoretically the development of incisional and re-

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current abdominal wall hernia could be initiated by early retraction of fascial edges by elongation of sutures. Research has been done concerning biomechanical properties of suture materials [13–15]. However, we could not find any report on elongation of suture materials in relation to closing abdominal fascia in laparotomies and abdominal wall hernia surgery. In this experimental study, we chose “creep” as a parameter to describe irreversible elongation of suture material under a constant load and during a strictly defined period of time. Creep testing with regard to light gauge sutures has been reported before [16-19]. However in literature we could not find any studies in which 1-, 0-, and 2-0 sutures, as commonly used in abdominal wall surgery, have been subjected to creep tests. In addition, no literature could be found concerning creep measurements with these suture materials under physiological conditions (temperature, NaCl concentration, pH, and humidity).

The purpose of the present study was to evaluate creep behavior (suture elongation) of commonly used suture materials in abdominal wall surgery under physiological conditions.

MATERIALS AND METHODS

Suture Selection

Three different suture diameters were tested, based on diameters most commonly used in abdominal wall surgery: 2-0 and 1 for polydioxanone (PDSII; Ethicon—Johnson & Johnson Intl., Somerville, NJ) sutures, 2-0 and 0 for polypropylene (Prolene; Ethicon, Johnson & Johnson Intl.). Suture samples were randomly selected from different operating rooms in two separate hospitals by an independent person. Extra care was taken by the experimenter to use sutures from at least three different batches. To prevent a conflict of interest, all test materials were purchased by the investigators. This study was not financially supported in any way. Existing facilities at the participating departments were used.

Creep

The magnitude of creep behavior was assessed as a function of three constant physiological forces. The forces, physiologically acting on the abdominal wall and hence on abdominal wall sutures, were calculated by using Laplace’s equation, which states that pressure into a cylinder is directly proportional to its wall tension and inversely proportional to its radius. This can be described by the formula: $T_{\text{cyl wall tension}}$ (N/m) = P_{cyl} (Pa) * r_{cyl} (m). When we consider the abdominal cavity as a cylinder, this formula can be applied to the abdominal wall as follows: $T_{\text{abd wall}} = P_{\text{IAP}} * r$. Thus according to Laplace’s law, intra-abdominal pressure (IAP) is directly proportional to abdominal wall tension and inversely proportional to the radius of the abdomen. IAP normally ranges between 5 and 10 mmHg [20-23]. Ten millimeters of mercury was chosen to represent IAP in a static rest phase to serve as control value. A wide spectrum of pathologically increased IAPs, ranging from 17 cm H_2O up to 40 mm Hg, have been reported [24-26]. Moreover even higher intermittent physiological IAPs are reported representing coughing, defecating, palpation of the abdomen, Valsalva maneuvers, etc. [20, 27, 28]. In our study a value between 17 cm H_2O and 40 mmHg was chosen, using 32 mmHg representing pathological increased IAP.

Assuming a mean radius of 0.15 m and an IAP of 10 cm H_2O (7 mmHg) at rest, a $T_{\text{abd wall}}$ of 150 N per linear meter was calculated using the above formula. With an interstitch distance of 1.5 cm, this was calculated to equal a force of 2.3 N per single suture. The force that has to be guided through the tissue (wound length) is not dependent upon whether the surgeon decided for an interrupted or running configuration and remains the same. For practical reasons in this experiment a constant load of 2.5 N was chosen to equal the force exerted on a single suture in patients with a normal IAP of 6.4 mmHg. In the same way $T_{\text{abd wall}}$ was calculated representing a pathological increased IAP which resulted in a $T_{\text{abd wall}}$ of 666 N per linear meter, which equals a force of 10 N per single suture.

To determine creep, 100-mm suture specimens were subjected to constant loads of 2.5 and 10 N in a medium of saline-phosphate buffer with a constant pH of 7.4. Temperature was kept constant at 37°C. Percentage of elongation was measured as a function of time for 24 h. Measurements were recorded by means of a customized experimental setup (Fig. 1), using both a linear variable displacement transducer (LVDT; Sangamo, Schlumberger, Berlin Erlensee, Germany) and an ultrasonic sensor (P47, Pil Ultraschall-Sensorik, Berlin Erlensee, Germany) for registration in each recording session. Because of its associated high resolution, the LVDT was used for measuring elongation less than 15 mm; the ultrasonic sensor was used when elongation exceeded this distance. Data were recorded with a sample frequency of 1 Hz and stored electronically. A best fit was calculated afterward by using mathematical software to describe the curve and in this way determine elongation at 24 h for each suture sample. Each test was performed eight times using samples from separate sutures and an average percentage of elongation was calculated for each type of suture.

The effect of the load (10 N *versus* 2.5 N) and type of suture was evaluated with analysis of variance (ANOVA). Interaction effects were analyzed to investigate whether the difference in elongations between the various types of suture depended on the applied load. All elongations had to be transformed logarithmically to obtain approximate normal distributions with homogeneous variances. $P < 0.05$ was considered the limit of significance.

RESULTS

Elongation started immediately at the beginning of the recording (Fig. 2). A hyperbolic shape was observed in the measured curves, while creep was most significant within the first few hours of recordings. No breaking of sutures was observed.

Fig. 3 graphs elongations according to type of suture and applied load. Each combination of suture and load resulted in a statistically significant elongation (the lower limits of the 95% confidence intervals were 2% at least). Analysis by ANOVA showed that the difference between the various types of suture depended on the applied load ($P < 0.001$). Further analysis showed that that there were no significant differences between the four types of suture in case the load was 2.5 N ($P = 0.23$). In contrast, highly significant differences were found between sutures at a load of 10 N ($P < 0.001$). At this load pairwise comparison between sutures revealed significant differences between Prolene 2-0 *versus* all others (all $P < 0.006$) and between Prolene 0 *versus* all others (all $P < 0.006$). PDSII 2-0 and PDSII 0 did not significantly differ from each other ($P = 0.19$). Although the difference between the loads of 2.5 N and 10 N was smallest for PDSII 1, the difference was still

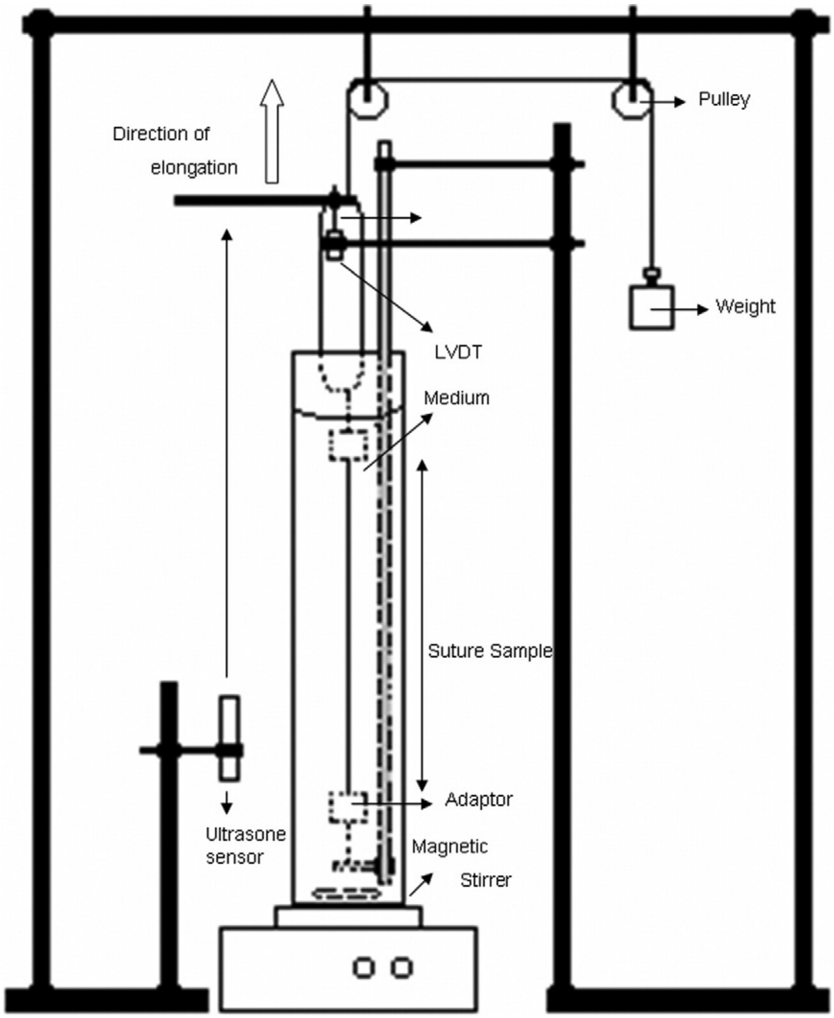

FIG. 1. Measurements were recorded by means of a customized experimental setup, using a Linear Variable Displacement Transducer (LVDT; Sangamo, Schlumberger, Germany) measuring elongation less than 15 mm and an ultrasonic sensor (P47; Pil Ultraschall-Sensorik, Berlin Erlensee, Germany) measuring elongation exceeding this distance.

statistically significant as can be seen from the non-overlapping 95% confidence intervals.

DISCUSSION

Leaper *et al.* stated that suture break, knot slip, and tissue tear are the main reasons for failure of abdominal wounds to heal [12]. Despite the fact that creep measurements have been reported with respect to lighter gauge suture materials before, we could not find any reports in which creep measurements were related to wound failure [16]. In addition, no literature was found about creep measurements on heavier suture materials used for closing abdominal fascia in laparatomies.

Creep is a process, representing a plastic altering of shape of a certain object in time as a result of a constant static pulling force (weight). In the case of suture material, creep behavior is observed as an irreversible

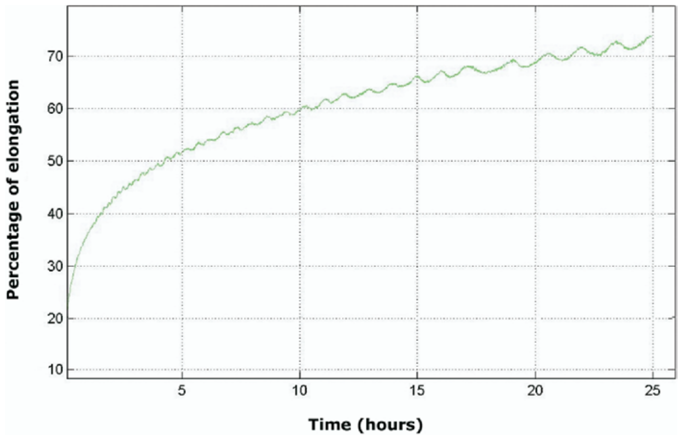

FIG. 2. The percentage of elongation of Prolene 2-0 at a load of 10 N as function of time for 25 h, measured by an ultrasonic sensor. With an offset value of 18, the percentage of elongations amounts up to 54% after 24 h. A hyperbolic shape was observed in the measured curves, while creep was most significant within the first few hours of recordings. (Color version of figure is available online.)

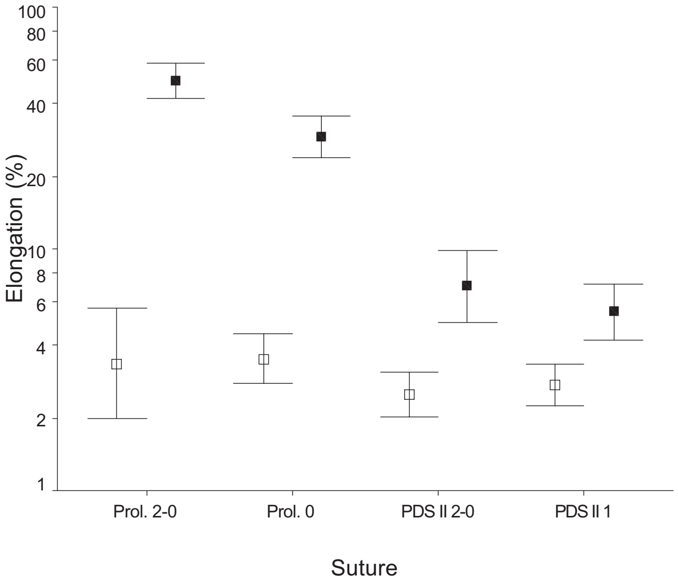

FIG. 3. Plot of geometric mean elongations (%), with 95% confidence limits, according to suture type and applied load. The open and closed symbols represent loads of 2.5 N and 10 N, respectively.

increase of length as a function of time expressed as percent elongation. Unlike elasticity, suture elongation is an undesirable phenomenon in the complex process of wound healing. After all, for wound healing it is essential that wound edges are approximated closely, especially during the first 3 days postoperatively [29]. As significant creep was measured during the first 24 h, it is likely that suture elongation as a result of creep could thus prevent lasting contact of wound edges and impair wound healing.

In our study all sutures showed creep when exposed to a constant load of 10 N as well as to 2.5 N. Increasing the load resulted in increased creep values for both suture materials. However this was more pronounced with Prolene sutures. In addition, higher percentages of creep were observed with Prolene than with PDSII sutures at a load of 10 N. As expected, an increase of diameter of the suture material resulted in a decrease of creep at a load of 10 N. Again this was more pronounced in Prolene than in PDSII sutures. At a load of 2.5 N this was less pronounced: when mutually compared, both suture materials showed no significant differences. These results indicate that in both load situations PDSII sutures exhibit less creep, rendering them more suitable for closing wounds in situations where substantial force is needed to approximate both wound edges. This makes PDSII in relation to Prolene the preferred material for closing the abdominal wall fascia.

From our results it is hypothesized that creep of suture materials, as commonly used in abdominal wall surgery, even under conditions of normal IAP, could contribute to wound-failure and hernia development. This phenomenon might occur even more distinctively when IAP is increased (permanently or incidentally). IAP often increases in patients undergoing laparatomies as forced abdominal closure increases IAP by means of formation of visceral edema as a result of shock, ischemia, or capillary leakage during operation [22, 30]. In addition increased postoperative IAP is reported in patients undergoing major surgery [24]. Also, patients anesthetized with fentanyl showed large increases in IAP [25].

In this experiment we assumed a mean abdominal cavity radius of 0.15 m. As the abdominal wall tension is dependent on IAP as well as abdominal cavity radius according to Laplace's law, it is imaginable that in obese persons abdominal cavity radius can be much higher than our initial assumption. This leads to an even higher force on each suture than we calculated. Because of this, more creep can be expected in these persons, possibly impairing wound healing, thus making them even more susceptible for developing (recurrent) abdominal wall hernias. Moreover in obese persons higher incidences and recurrence rates of incisional hernias have been reported [10]. As stated before the development of incisional and recurrent abdominal wall hernias seems to be a complex multifactorial process. Until now no attention has been paid to the influence of suture material in this respect.

Although a direct relation between creep of suture materials and wound failure has not as yet been clinically proven, the observation of high percentages of irreversible elongation even at physiological IAP is worrisome and needs further (prospective) study in clinical situations.

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