Systematic review and meta-analysis of surgical suture strength according to the type, structure and geometry of suture materials

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Purpose: As a rule, wound healing is a natural and spontaneous process. However, in acute or surgical wounds, the wound edges need to be approximated and held together by artificial means. Surgery within the abdominal cavity or elsewhere almost always involves cutting through the skin, after which a medical procedure is conducted, followed by wound closure. The suture provides temporary mechanical support during the natural healing process of the affected tissues. Not only does it stimulate the primary wound healing, but also provides mechanical protection against wound dehiscence. Methods: This analysis is intended to juxtapose the basic factors that contribute to a change in suture strength and the possible failure of surgical sutures, which may affect the wound healing process and increase the risk of postoperative complications. Results: The preliminary search criteria used in the databases included keywords such as: “strength of suture materials”, “strength of surgical sutures”, “surgical knot strength”. Five key articles were ultimately selected from a pool of 336 articles first identified based on these search criteria. Next, a meta-analysis of the literature data was performed, taking into account factors such as the type of suture materials used, biological conditions and model conditions used in research, having a significant impact on the mechanical properties of surgical sutures. Conclusions: This comparison revealed considerable variations in the suture strength between different sutures of the same size, it also demonstrated that the decrease in suture strength strongly depends on the finished suture and the thread type.

Key words: meta-analysis, surgical sutures, suture strength, selection of surgical sutures

1. Introduction

Incision of the abdominal wall is an essential step of any surgical procedure within the abdominal cavity. In essence, an operating surgeon has three tasks to perform: incision of the abdominal wall to gain access to the abdominal cavity, management of the affected organ or anatomical structure, and closure of the abdominal cavity. Post-laparotomy closure is intended to approximate the layers of the abdominal wall and hold it together in place. The integrity of the abdominal wall should be restored in such a way as to reconstruct its static and dynamic function, and to support the formation of scar tissue. Also, peritoneal adhesions should be avoided [11], [29]. Correct approximation and holding of the individual layers of the abdominal wall should continue until a stable scar is formed in the course of the healing process. The integrity of the abdominal wall is vital as it serves to protect against dehiscence and evisceration. The suture should grab and hold all layers of the abdominal wall together and provide tension-free repair in order to ensure dynamic movements of the muscles [24], [29]. The ideal suture material should retain both strength and flexibility to prevent tissue slippage on the one hand and to adapt to changes in the wound environment and possible swelling on the other hand. Another important role of sutures is to minimize inflammatory reactions and limit bacterial proliferation [11], [30].

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Full patient compliance is also desired to avoid excess pressure within the wound and sutures, or abdominal wound complications. This creates favorable conditions for the proper formation of postoperative scar tissue [8], [9], [31].

In countries with highly developed healthcare, it is predicted that one of three people will undergo abdominal surgery at least once in their lifetime. The complication rates in open abdominal procedures (laparotomy involving a large surgical incision) range from 10 to 15% and if the surgical cut in the abdominal wall does not close properly, incisional hernias may follow [21]. Some researchers estimate that the risk of incisional hernias exceeds 20% [22].

Postoperative hernia deteriorates the patient’s quality of life and can be hazardous to health or even life-threatening. This complication requires a revision surgery [22]. The risk of intra-abdominal hypertension is another important aspect. Intra-abdominal hypertension is defined as a sustained or repeated IAP of over 12 mmHg. It can result in both primary and postoperative hernias, especially if the fascia structure is frail. Any type of physical impact, such as squatting, leg lifting, laughing or coughing, lifting weights, defecation, significantly increases the pressure in the abdominal cavity [20], [23]. Such activities should be deliberately avoided or even pharmacologically prevented [22].

The surgeon has a direct influence on the wound management: they choose the suture type (sewing technique) and the suture material used (the type of thread used, including its geometry).

The suturing procedure consists of many elements: the suturing technique, tissue handling (to limit tissue injuries) and the choice of suture material. This applies not only to operations in the abdominal organs but also to other parts of the body [6], [9]. Monofilament, non-absorbable or slowly absorbable suture materials were identified as most recommended in a number of studies [1], [5], [28]. In terms of the suturing technique or suture geometry, Hodgson et al. [13] concluded that continuous suture is the most effective suture pattern.

Technical aspects, such as the strength of surgical sutures and the type and structure of suture materials, as well as the impact on knot-tying on the suture strength, are the key factors explored in all of the identified studies. The first two aspects are particularly important as they can be easily standardized and quickly implemented in the OR. As a result, the majority of tensile strength evaluations are based on measurements of the tearing strength, while other factors such as elongation, stress, full stress–strain curves are characterized with less accuracy [2]. German engineers innovatively proposed to measure the strength and strain of thread/suture in wound in vivo [26]. The results of such in vivo measurements indicate that the tension of the suture materials changes as a function of time and is affected by the intra-abdominal pressure [14]. By analyzing data on suture materials, better models for estimating the risk of postoperative hernia and the resulting healthcare costs can be developed [27], [31].

Over the past two decades, there has been growing interest in minimally invasive surgical techniques that help reduce pain and trauma, scarring and postoperative complications [12].

The purpose of this paper is to analyze various factors that determine the tensile strength of surgical sutures.

2. Materials and methods

2.1. Inclusion and exclusion criteria

The following inclusion criteria were used in the systematic literature review and meta-analysis: articles published in 2005 and later, original studies featuring at least 5 samples with suture size ranging from 5-0 to 2-0 USP (USP Standard – United States Pharmacopoeia), or 0.10 mm to 0.30 mm in diameter. The studies were required to include strength tests of suture threads and/or knots. The search also included literature in English. Review articles and literature published before 2005, in vivo studies and those that did not analyze the tensile strength were excluded from the analysis.

In vitro studies were included in the analysis as most researchers consider them to be the most appropriate research methodology for comparative studies [3]. In addition, in vitro studies involve a lower risk of bias and offer greater control over potentially confusing variables, providing the best scientific evidence to support the effectiveness of suture materials.

2.2. Outcomes

The key keywords used to in the search included the phrase “tensile strength of the suture materials”. “Knot strength” was also used as additional search words (Fig. 1).
2.3. Protocol

The literature included in the review of research outcomes was selected in a manner appropriate for systematic reviews, in accordance with the PRISMA search criteria (Fig. 2). The review was carried out from July to August 2021, based on the PubMed database.

In the first stage, the articles included in the PubMed database and identified using the keywords were screened by title and abstract. Next, only full-text articles were qualified, from which 5 papers were selected for the final evaluation. The articles were qualified using a critical checklist. Risk of bias assessment in the qualified studies was based on the Cochrane Handbook for Systematic Reviews of Interventions, and included the assessment of:

- research method – low risk for research methods that resulted in bias (systematic error) of the research outcomes;
- evaluation of measurements – low risk for correct type of results;
- blinded participants – low risk if persons conducting the research were different from individuals who analyzed and described the results;
- data incompleteness – low risk if all information on the tested sutures and test results were disclosed;
- selective data collection – low data risk if the study protocol was available or all reported outcomes were included in the published article.

The overall risk of bias in various studies is presented in Table 1; a summary of the percentage share of the risk for each of the categories is provided in Fig. 3.

### Table 1. Risk of bias of included studies

| Manuscript                  | Research method used (selection bias) | Measurement of the result (selection bias) | Blinding of study participants (selection bias) | Incomplete output data (attrition bias) | Selective data collection (reporting bias) |
|-----------------------------|--------------------------------------|------------------------------------------|-----------------------------------------------|----------------------------------------|------------------------------------------|
| Kim J.C. et al. [20]        | +                                    | +                                        | +                                             | +                                      | +                                        |
| Abullah S.S. et al. [21]    | +                                    | +                                        | ?                                             | +                                      | +                                        |
| Alshehri M.A. et al. [22]   | +                                    | +                                        | ?                                             | +                                      | ?                                        |
| Tanaka Y. et al. [23]       | ?                                    | +                                        | -                                             | ?                                      | -                                        |
| Karabulut R. et al. [24]    | +                                    | +                                        | +                                             | -                                      | -                                        |

+ – low risk, ? some concerns, – high risk.
### 2.4. Statistical analysis

The results were statistically analyzed using the Statistica 13 software. Qualitative data was rendered as arithmetic mean and standard deviation (Mean ± SD). If no standard deviation was available, it was replaced by mean confidence interval (Mean ± SE). The results are graphically displayed as forest plots (blooggograms). The whiskers on the plot represent the confidence interval for the research outcomes (–95% CL and +95% CL), the blue square is the standard error of the mean (SE), and the mean value (Mean) is in the center of this distractor.
Statistical heterogeneity was calculated using the \( \chi^2 \) test. The analysis included test results along with results corrected for \( p \)-value. The groups modeled in the meta-analysis were compared with the ANOVA test.

The share of a given study in the overall analysis was determined using a weighted index, defined as the percentage share of the weight of an individual study in relation to the total weight of all studies included in the analysis.

Heterogeneity of the reported literature data on the suture strength was investigated using the I-squared (I\(^2\)) statistic. The following thresholds for the interpretation of statistics I\(^2\) were adopted:
- 0 to 40%: no heterogeneity;
- 30 to 60%: moderate heterogeneity;
- 50 to 90%: significant heterogeneity;
- 75 to 100%: very high heterogeneity.

The quantitative data were formally summarized using a two-step frequency approach to a panoramic meta-analysis. This method provided a single cumulative estimate of the odds ratio for mean differences across all articles included in the analysis, along with the estimates of the degree of heterogeneity between different articles. Thus, the variability between studies and between articles could be assessed.

### 3. Results

In Table 2, literature data on the mechanical strength of various suture materials are summarised. The collected literature data was supplemented with the results of the author’s own research, which had not been published before. The data on suture strength are presented as mean and standard deviation.

In Table 3, the results of meta-analysis assessing the impact of a decrease in suture strength attributed to knot-tying are presented; abbreviated codification was used to label the suture materials. The results listed in Table 3 and Fig. 4 represent mean differences between the strength of suture tied in a knot and the decrease in strength attributed to knot-tying (\( \Delta \text{Mean} \)). The confidence interval for the obtained data (\(-95\% \text{ CL and } +95\% \text{ CL} – \text{whiskers}\)) as well as the standard error of mean (SE – width of the rectangle) were also included.

| Suture material – codification | No. of sample | \( \Delta \text{Mean} \) | SE | -95% CL | +95% CL | Z-test | \( P \)-value | Part |
|-------------------------------|---------------|------------------------|----|---------|---------|--------|-------------|------|
| **Group: Absorbable**         |               |                        |    |         |         |        |             |      |
| CC                            | 10            | 2.70                   | 0.70| 1.34    | 4.06    | 3.88   | <0.001     | 20.17% |
| PC                            | 10            | 4.20                   | 0.24| 3.73    | 4.67    | 17.44  | <0.001     | 27.54% |
| PGA                           | 10            | 3.50                   | 0.69| 2.14    | 4.86    | 5.04   | <0.001     | 20.19% |
| PGA*                          | 14            | 1.40                   | 0.91| -0.39   | 3.19    | 1.53   | 0.126      | 16.50% |
| VC*                           | 14            | 2.00                   | 0.98| 0.09    | 3.91    | 2.05   | 0.040      | 15.59% |
| Total                         | 58            | 2.95                   | 0.57| 1.84    | 4.06    | 5.21   | <0.001     |      |
| **Group: Non absorbable**     |               |                        |    |         |         |        |             |      |
| NL                            | 10            | 2.40                   | 1.01| 0.42    | 4.38    | 2.37   | 0.018      | 8.81% |
| NL*                           | 14            | 2.80                   | 0.40| 2.01    | 3.59    | 6.93   | <0.001     | 14.69% |
| PE                            | 10            | 0.70                   | 0.63| -0.54   | 1.94    | 1.11   | 0.268      | 12.41% |
| PE*                           | 14            | 0.50                   | 0.54| -0.55   | 1.55    | 0.93   | 0.352      | 13.39% |
| PP                            | 10            | 2.00                   | 0.58| 0.86    | 3.14    | 3.44   | 0.001      | 12.94% |
| PP*                           | 14            | 1.60                   | 0.60| 0.43    | 2.77    | 2.68   | 0.007      | 12.77% |
| SL                            | 10            | -0.40                  | 0.58| -1.54   | 0.74    | -0.69  | 0.491      | 12.94% |
| SL*                           | 14            | 0.40                   | 0.67| -0.91   | 1.71    | 0.60   | 0.550      | 12.04% |
| Total                         | 96            | 1.24                   | 0.44| 0.38    | 2.09    | 2.84   | 0.005      |      |

**Summary – Group comparison**

\( Q \)-test: 5.60; Df = 1; \( P \)-value = 0.016

Literature sources are marked with symbols: * own research.
A higher mean loss of strength after knot-tying (Mean 2.95 SE 0.57) was shown for biodegradable sutures compared to non-biodegradable sutures. (Mean 1.24 SE 0.44). Importantly, no significant decrease in strength was reported for polyester or silk sutures ($p > 0.05$).

The $I^2$ index of 74.5% and 76.7% determines the mean heterogeneity of biodegradable sutures versus non-biodegradable sutures, respectively. This indicates high heterogeneity in either case.

An inter-group analysis revealed a significant difference in the decrease in strength of biodegradable and non-biodegradable sutures after knot-tying. The decrease is significantly greater for biodegradable sutures ($p = 0.016$), as summarized in Table 3.

In Table 4, the results of strength measurements for sutures tied a knot are shown. A strong heterogeneity of the results (over 90% $I^2$) was revealed for groups of size 3-0, 4-0, and 5-0 sutures. Nevertheless, for size 3-0 and size 5-0 sutures, no significant intra-group differences in the results were observed. The intra-group results were significant for suture size 4-0.

On average, the results are as follows for size 3-0 sutures: Mean 20.39, SE: 1.32. The data for size 4-0 sutures are significantly lower and are as follows: Mean 10.88; SE: 0.44, but are the lowest for size 5-0 sutures: Mean 6.08; SE: 1.22.

The significant differences in strength between the compared groups are apparent, and can be attributed to the suture diameter (Fig. 5).

Internal data consistency was also estimated, broken down into the type of suture materials. Data were obtained for seven (7) size 4-0 suture materials, except for size 3-0 PDS sutures. Heterogeneity statistics reveal differences in literature data for CC, PDS, and PGA suture materials. On the other hand, literature data was shown to be consistent for other suture materials, including NL, PE, PP and SL – here, no significant differences were identified in inter-group comparisons. The results of the analysis are presented in Table 5 and Fig. 6.

### Table 4. Descriptive and statistical analysis of literature data included in the meta-analysis, according to suture size

| Suture material – codification | No. of sample | Mean   | SE    | -95%CI | +95%CI | Z-test | P-value | Part |
|-------------------------------|---------------|--------|-------|--------|--------|--------|---------|------|
| Group: UPS 3-0                |               |        |       |        |        |        |         |      |
| PDS*                         | 7             | 21.90  | 0.39  | 21.19  | 22.71  | 12.74% |         |      |
| PGA*                         | 7             | 19.90  | 0.57  | 18.78  | 21.02  | 12.58% |         |      |
| PP*                          | 7             | 13.80  | 0.49  | 12.84  | 14.76  | 12.66% |         |      |
| PP*                          | 7             | 18.08  | 0.48  | 17.13  | 19.03  | 12.66% |         |      |
| SL*                          | 7             | 17.20  | 0.53  | 16.16  | 18.24  | 12.62% |         |      |
| VC*                          | 7             | 19.50  | 0.76  | 18.02  | 20.98  | 12.36% |         |      |
| Total                        | 56            | 20.39  | 1.32  | 17.81  | 22.98  | 12.073 | 0.098   |      |
| Group: UPS 4-0                |               |        |       |        |        |        |         |      |
| CC*                          | 7             | 9.70   | 0.42  | 8.89   | 10.51  | 6.23%  |         |      |
| NL1                          | 7             | 8.60   | 0.32  | 7.98   | 9.22   | 6.38%  |         |      |
| NL*                          | 7             | 11.90  | 0.60  | 10.71  | 13.09  | 5.87%  |         |      |
| PE1                          | 7             | 11.30  | 0.79  | 9.74   | 12.86  | 5.44%  |         |      |
| PC*                          | 7             | 8.70   | 0.76  | 7.22   | 10.18  | 5.53%  |         |      |
| PE*                          | 7             | 10.10  | 0.38  | 9.36   | 10.84  | 6.29%  |         |      |
| PGA*                         | 7             | 9.20   | 1.51  | 6.24   | 12.16  | 6.23%  |         |      |

Fig. 4. Distribution of the difference in means between biodegradable and non-biodegradable sutures, with the confidence interval for the literature data – forest diagram.
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Table 4 continued

|        | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| PGA^2  | 7   | 14.50 | 0.48 | 13.56 | 15.44 | 6.12% |
| PGA*   | 7   | 11.30 | 0.72 | 9.89  | 12.71 | 5.62% |
| PP^1   | 7   | 9.70  | 0.45 | 8.81  | 10.59 | 6.17% |
| PP*    | 7   | 10.20 | 0.48 | 9.27  | 11.13 | 6.13% |
| PP     | 7   | 9.50  | 0.49 | 8.54  | 10.46 | 6.10% |
| SL^1   | 7   | 10.40 | 0.19 | 10.03 | 10.77 | 6.52% |
| SL*    | 7   | 10.60 | 0.48 | 9.67  | 11.53 | 6.13% |
| SL     | 7   | 10.70 | 0.49 | 9.74  | 11.66 | 6.10% |
| VC*    | 7   | 19.20 | 0.79 | 17.64 | 20.76 | 5.44% |
| Total  | 119 | 10.88 | 0.44 | 10.02 | 11.75 | 29.684 0.019 |

Group: UPS 5-0

|        | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| NL*    | 7   | 6.70 | 0.30 | 6.11 | 7.29 | 11.12% |
| PC5    | 7   | 2.55 | 0.22 | 2.12 | 2.98 | 11.16% |
| PGA^3  | 7   | 12.80 | 0.26 | 12.28 | 13.32 | 11.14% |
| PGA*   | 7   | 7.50  | 0.60 | 6.31  | 8.69  | 10.90% |
| PP*    | 7   | 1.25  | 0.09 | 1.06  | 1.44  | 11.19% |
| SL^2   | 7   | 9.40  | 0.23 | 8.96  | 9.84  | 11.16% |
| SL*    | 7   | 2.37  | 0.12 | 2.13  | 2.61  | 11.19% |
| SL     | 7   | 6.90  | 0.53 | 5.86  | 7.94  | 10.97% |
| VC*    | 7   | 5.30  | 0.17 | 4.97  | 5.63  | 11.17% |
| Total  | 63  | 6.08  | 1.22 | 3.68  | 8.47  | 8.150 0.418 |

Literature sources are marked with the following symbols: 1 – Kim J.C. et al. (2007), 2 – Abullais S.S. et al. (2020), 3 – Alshehri M.A. et al. (2015), 4 – Tanaka Y. et al. (2012), 5 – Karabulut R. et al. (2010), * own research.
Sutures are an essential component of wound healing and the choice of suture type and material plays a key role in surgical procedures [32]. With advanced surgical techniques available today, surgeons are constantly reviewing the existing options to find the perfect suture material and knot configuration. However, the suture strength has only been determined based on suture diameters and there is a scarcity of readily available comparisons of the base material. The primary purpose of all sutures is to keep the knot secure and to stimulate wound healing, but there is a lack of standardization of knots and wound suturing [15], [25], [34]. As a result, the suturing technique, the patient’s condition, and individual approach to suturing can make the assessment of suture materials very complex [19], [33]. In addition, abdominal surgery is characterized by a unique biological environment as it can present a major challenge as it requires precision in wound closure to allow proper healing.

This review revealed significant differences in the tensile strength of suture materials using standardized and comparable experimental methods. However, it does not address all issues associated with in vivo tests, including the potential impact of comorbidities, eating habits, smoking, and the patient’s health status, which may also alter the relevant underlying physiological and mechanical conditions [3], [4], [10], [11], [31].

4. Conclusions

Despite thousands of years of experience with biomaterials used for wound closure, no study or surgeon has yet identified the best all-purpose suture. When selecting the optimum suture, the tissue characteristics as well as the suture tensile strength, reactivity, absorption rate and performance properties need to be accounted for [11].

This comparison reveals considerable variations in the suture strength between different sutures of the same size (Table 4, Fig. 5); it was also demonstrated that the decrease in suture strength strongly depends on the finished suture and the thread type (Figs. 3, 4). Importantly, when examining suture materials of the same size, variations in the obtained results may occur to the extent that the data become heterogeneous (Table 5, Fig. 6).

Suture materials are broadly classified based on their degradation pattern, tensile strength, reduction of inflammation/infection, and tissue traumatization. Natural vs. synthetic and monofilament vs. multi-filament threads are considered secondary suture characteristics. In terms of mechanical parameters, braided sutures were shown to have better tensile strength than monofilament ones. Chemical factors such as changes in the pH value (alkaline for pancreas or duodenum, or acidic for stomach sutures) have a greater impact on absorbable sutures than non-absorbable ones [7], [11], [18]. Non-absorbable silk seams are still most commonly used suture materials, despite their increased sensitivity to pH changes and suboptimal mechanical properties. This preference is often attributed to their ease of use, reliability and increased strength compared to other natural monofilament and non-absorbable sutures [11], [16], [17].

Sutures are an essential component of wound healing and the choice of suture type and material plays a key role in surgical procedures [32]. With advanced surgical techniques available today, surgeons are constantly reviewing the existing options to find the perfect suture material and knot configuration. However, the suture strength has only been determined based on suture diameters and there is a scarcity of readily available comparisons of the base material. The primary purpose of all sutures is to keep the knot secure and to stimulate wound healing, but there is a lack of standardization of knots and wound suturing [15], [25], [34]. As a result, the suturing technique, the patient’s condition, and individual approach to suturing can make the assessment of suture materials very complex [19], [33]. In addition, abdominal surgery is characterized by a unique biological environment as it can present a major challenge as it requires precision in wound closure to allow proper healing.

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References

[1] ALBERTSMEIER M., SEILER C.M., FISCHER L., BAUMANN P., HUSING J., SEIDLMAYER C., FRANCK A., JAUCH K.W., KNAEBEL H.P., BUCHLER M.W., Evaluation of the safety and efficacy of MonoMax(R) suture material for abdominal wall closure after primary midline laparotomy – a controlled prospective multicentre trial: I.S.S.A.A.C [NCT005725079], Langenbecks Arch. Surg., 2012, 397 (3), 363–371, DOI: 10.1007/s00423-011-0884-6.

[2] ASHER R., CHACARTCHI T., TANDLICH M., SHAPIRA L., POLAK D., Microbial accumulation on different suture materials following oral surgery: a randomized controlled study, Clin. Oral Investig., 2019, 23 (2), 559–565, DOI: 10.1007/s00784-018-2476-0.

[3] BERGER R.L., LI L.T., HICKS S.C., DAVILA J.A., KAO L.S., LIANG M.K., Development and validation of a risk-stratification score for surgical site occurrence and surgical site infection after open ventral hernia repair, J. Am. Coll. Surg., 2013, 217 (6), 974–982, DOI: 10.1016/j.jamcollsurg.2013.08.003.

[4] BOSANQUET D.C., ANSELL J., ABDELRAHMAN T., CORNHISH, HARRIES R., STIMPSON A., DAVIES L., GLASBEY J.C., FREWER K.A., FREWER N.C., RUSSELL D., RUSSELL I., TORKINGTON J., Systematic Review and Meta-Regression of Factors Affecting Midline Incisional Hernia Rates: Analysis of 14,618 Patients, PLoS One, 2015, 10 (9), e0138745, DOI: 10.1371/journal.pone.0138745.

[5] CEYDELI A., RUCINSKI J., WISE L., Finding the best abdominal closure: an evidence-based review of the literature, Curr. Surg., 2005, 62 (2), 220–225, DOI: 10.1016/j.cursur.2004.08.014.

[6] CHEN Z., WANG J., WEI J.S., HOU Z.Y., LI M., CHEN Q.X., Biomechanical evaluation of tendon connection with novel
suture techniques, Acta Bioeng. Biomech., 2018, 20 (1), 135–141.

[7] CHUNG E., MCPHERSON N., GRANT A., Tensile strength of absorbable suture materials: in vitro analysis of the effects of pH and bacteria, J. Surg. Educ., 2009, 66 (4), 208–211, DOI: 10.1016/j.jsurg.2009.06.007.

[8] FISCHER J.P., BASTA M.N., MIRZABEIGI M.N., BAUDER A.R., FOX J.P., DREBIN J.A., SERLETTI J.M., KOVACH J.S., A Risk Model and Cost Analysis of Incisional Hernia After Elective, Abdominal Surgery Based Upon 12,373 Cases: The Case for Targeted Prophylactic Intervention, Ann. Surg., 2016, 263 (5), 1010–1017, DOI: 10.1097/SLA.0000000000001394.

[9] GABLER C., GERSCHNER S., TISCHER T., BADER R., Comparison of different suture techniques for Achilles tendon repair in rat model using collagen scaffolds, Acta Bioeng. Biomech., 2018, 20 (2), 73–77.

[10] GOODENOUGH C.J., KO T.C., KAO L.S., NGUYEN M.T., Intra-Abdominal Pressure – A case report and review of literature, J. Surg. Educ., 2009, 66 (4), 208–211, DOI: 10.1016/j.jsurg.2009.06.007.

[11] KUTEESA J., KITUUKA O., NAMUGUZI D., NDIKUNO C., KIRUNDA S., MUKUNYA D., GALUKANDE M., Intra-abdominal hypertension; prevalence, incidence and outcomes in a low resource setting: a prospective observational study, World J. Emerg. Surg., 2015, 10, 57, DOI: 10.1186/s13017-015-0051-4.

[12] LE HUU NGO R., MEDE G., OUASSI M., SIELENNST I., SASTRE B., Incidence and prevention of ventral incisional hernia, J. Visc. Surg., 2012, 149 (Suppl. 5), e3-14, DOI: 10.1016/j.jviscsurg.2012.05.004.

[13] LI L.T., JAFRANI R.J., BECKER N.S., BERGER R.L., HICKS S.C., DAVILA J.A., LIANG M.K., Outcomes of acute versus elective primary ventral hernia repair, J. Trauma Acute Care Surg., 2014, 76 (2), 523–528, DOI: 10.1097/TA.0b013e3182ab0743.

[14] MUFFLY T.M., BOYCE J., KIEWEG S.L., BONHAM A.J., Tensile strength of a surgeon’s or a square knot, J. Surg. Educ., 2010, 67 (4), 222–226, DOI: 10.1016/j.jsurg.2010.06.007.

[15] PETERSSON P., PETERSSON U., Dynamic Fascial Closure With Vacuum-Assisted Wound Closure and Mesh-Mediated Fascial Traction (VAWCM) Treatment of the Open Abdomen: An Updated Systematic Review, Front Surg., 2020, 7, 577104, DOI: 10.3389/fsurg.2020.577104.

[16] ROMEO A., ROCHA C.I., FERNANDES L.F., ASENSIO F.A., ZOMER M.T., FUJIMOTO C., USSIA A., WATTIEZ A., KONINCKX P.R., KONDO W., What is the Best Surgeon’s Knot? Evaluation of the Security of the Different Laparoscopic Knot Combinations, J. Minim. Invasive Gynecol., 2018, 25 (5), 902–911, DOI: 10.1016/j.jmig.2018.01.032.

[17] SCHACHTRUPP A., WETTER O., HOER J., An implantable sensor device measuring suture tension dynamics: results of developmental and experimental work, Hernia, 2016, 20 (4), 601–606, DOI: 10.1007/s10029-015-1433-y.

[18] SCHACHTRUPP A., WETTER O., HOER J., Influence of Intra-abdominal Pressure on Suture Tension Dynamics in a Porcine Model, J. Surg. Res., 2019, 233, 207–212, DOI: 10.1016/j.jss.2018.07.043.

[19] SEILER C.M., BRUCKNER T., DIENER M.K., PAPPAN A., GOLCHER H., SEIDLMAYER C., FRANCK A., KIESER M., BUCHLER M.W., KNAEBEL H.P., Interrupted or continuous slowly absorbable sutures for closure of primary elective midline abdominal incisions: a multicenter randomized trial (INSECT: ISRCTN24023541), Ann. Surg., 2009, 249 (4), 567–582, DOI: 10.1097/SLA.0b013e3181e6ce68.

[20] SU J.S., HOY N.Y., FAFAJ A., TASTALDI L., STRONG A., What is the Best Surgeon’s Knot? Evaluation of the Security of the Different Laparoscopic Knot Combinations, J. Minim. Invasive Gynecol., 2013, 20 (2), 73–78, DOI: 10.1016/j.jmig.2012.10.008.

[21] TAJRIAN A.L., GOLDBERG D.J., A review of sutures and other skin closure materials, J. Cosmet. Laser Ther., 2010, 12 (6), 296–302, DOI: 10.1177/147641721038413.

[22] TECC E.M., BASTA M.N., SHUBINETS V., LANNI M.A., MIRZABEIGI M.N., COONEY L., SENAPATI S., HAGGERTY A.F., WEISSER J.M., HERNANDEZ J.A., FISCHER J.P., A risk model and cost analysis of post-operative incisional hernia following 2,145 open hysterectomies – Defining indications and opportunities for risk reduction, Am. J. Surg., 2017, 213 (6), 1083–1090, DOI: 10.1016/j.amjsurg.2016.09.047.

[23] TOLBIAS K.M., KIDD C.E., MULON P.Y., ZHU X., Tensile properties of synthetic, absorbable monofilament suture materials before and after incubation in phosphate-buffered saline, Vet. Surg., 2020, 49 (3), 550–560, DOI: 10.1111/vsu.13326.
[33] van’t Riet M., Steyerberg E.W., Nellensteyn J., Bonjer H.J., Jeekel J., Meta-analysis of techniques for closure of midline abdominal incisions, Br. J. Surg., 2002, 89 (11), 1350–1356, DOI: 10.1046/j.1365-2168.2002.02258.x.

[34] von Trotha K.T., Grommes J., Butz N., Lambertz A., Klink C.D., Neumann U.P., Jacobs M., Binnebosel M., Surgical sutures: coincidence or experience?, Hernia, 2017, 21 (4), 505–508, DOI: 10.1007/s10029-017-1597-8.