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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).

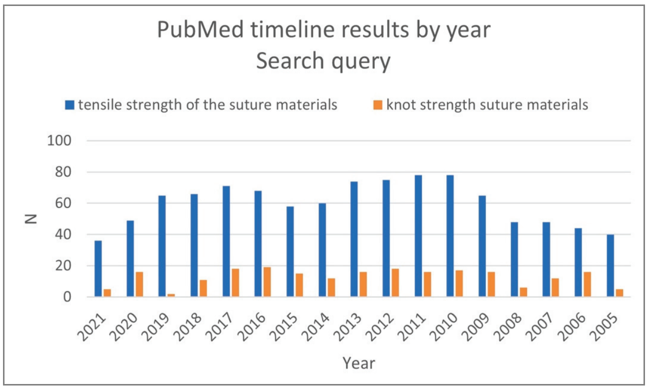

Fig. 1. Number of articles identified with the search words: tensile strength of the suture materials and knot strength

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.

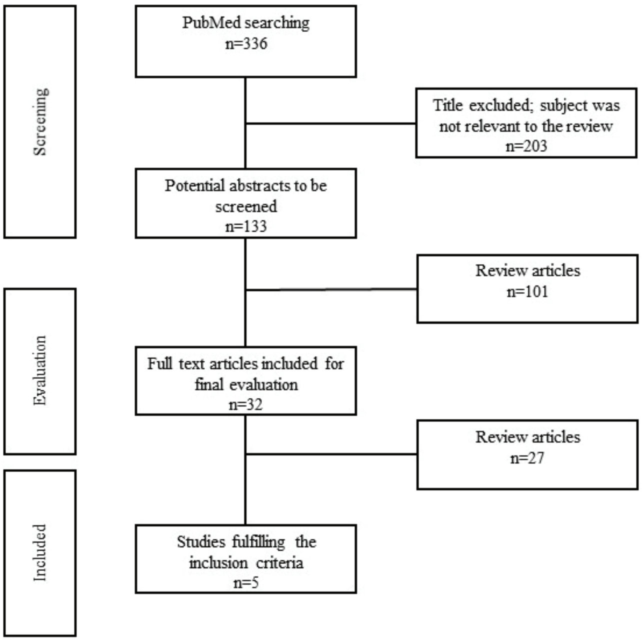

Fig. 2. Literature selection for systematic review

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]	+	+	+	+	+
Abullais 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.

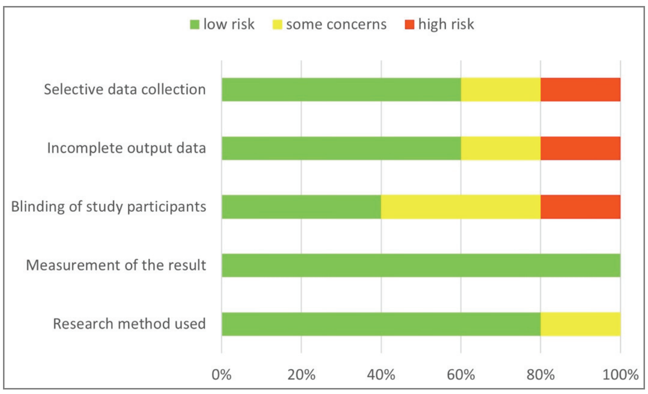

Fig. 3. Presentation of potential risks of bias

Table. 2. Pooled data used in the meta-analysis

Manuscript	Saturate material	Codification	USP (caliber)	The strength of the thread without knots (Mean ± SD)	The strength of the thread with a knot (Mean ± SD)	Composition	Material structure	Degradation
Kim J.C. et al. [20]	Chromic catgut	CC	4-0	12.4 (1.1)	9.7 (1.1)	Natural enriched	Monofilament	+
	Nylon	NL	4-0	14.3 (1.6)	11.9 (1.6)	Synthetic	Monofilament	–
	Plain catgut	PC	4-0	12.9 (0.5)	8.7 (2.0)	Natural	Monofilament	+
	Polyester	PE	4-0	10.8 (1.0)	10.1 (1.0)	Synthetic	Silicone-coated braided polyesther	–
	Polyglycolic acid	PGA	4-0	12.7 (1.5)	9.2 (4.0)	Synthetic	Braided fibre	+
	Polypropylen	PP	4-0	11.7 (0.5)	9.7 (1.2)	Synthetic	Monofilament	–
	Silk	SL	4-0	10.0 (1.2)	10.4 (0.5)	Natural	Silicone-coated braided fibre	–
Abullais S.S. et al. [21]	Chromic catgut	CC	4-0	–	8.6 (0.84)	Natural enriched	Monofilament	+
	Polyglycolic acid	PGA	4-0	–	14.5 (1.27)	Synthetic	Braided	+
	Polypropylen	PP	4-0	–	10.2 (1.26)	Synthetic	Monofilament	–
	Silk	SL	4-0	–	10.6 (1.26)	Natural	Silicone-coated braided fibre	–
Alshehri M.A. et al. [22]	Polyglycolic acid	PGA	5-0		12.8 (0.7)	Synthetic	Braided fibre	+
	Silk	SL	5-0		9.4 (0.6)	Natural	Silicone-coated braided polyesther	–
Tanaka Y. et al. [23]	Polidioksanon	PDS	3-0		21.95 (1.02)	Synthetic	Monofilament	+
	Poliglaktyna	Vicryl	3-0		22.8 (0.98)	Synthetic	Braided fibre	+
	Polypropylen	PP	3-0		18.08 (1.28)	Synthetic	Monofilament	–
Karabulut R. et al. [24]	Plain catgut	PC	5-0		2.55 (0.58)	Natural	Monofilament	+
	Silk	SL	5-0		2.37 (0.33)	Synthetic	Braided fibre	+
	Poliglaktyna	Vicryl	5-0		5.30 (0.45)	Synthetic	Monofilament	–
	Polypropylen	PP	5-0		1.25 (0.25)	Natural	Braided	–
Own research	Nylon	NL	4-0	14.1 (1.9)	11.3 (2.1)	Synthetic	Monofilament	–
	Nylon	NL	5-0	9.1 (1.0)	6.7 (0.8)	Synthetic	Monofilament	–
	Polidioksanon	PDS	3-0		19.9 (1.51)	Synthetic	Monofilament	+
	Poliglaktyna	VC	3-0	38.2 (3.3)	30.7 (3.2)	Synthetic	Braided fibre	+
	Poliglaktyna	VC	4-0	21.2 (1.5)	19.2 (2.1)	Synthetic	Braided fibre	+
	Polyester	PE	4-0	10.3 (0.9)	9.8 (1.1)	Synthetic	Silicone-coated braided fibre	–
	Polyglycolic acid	PGA	3-0	16.1 (0.9)	13.8 (1.3)	Synthetic	Braided fibre	+
	Polyglycolic acid	PGA	4-0	12.7 (1.5)	11.3 (1.9)	Synthetic	Braided fibre	+
	Polyglycolic acid	PGA	5-0	9.1 (0.8)	7.5 (1.6)	Synthetic	Braided fibre	+
	Polypropylen	PP	3-0	20.3 (1.1)	17.2 (1.4)	Synthetic	Monofilament	–
	Polypropylen	PP	4-0	11.1 (0.9)	9.5 (1.3)	Synthetic	Monofilament	–
	Silk	SL	3-0	23.1 (2.1)	19.5 (2.0)	Natural	Silicone-coated braided fibre	–
	Silk	SL	4-0	11.1 (1.2)	10.7 (1.3)	Natural	Silicone-coated braided fibre	–
	Silk	SL	5-0	9.5 (1.5)	6.9 (1.4)	Natural	Silicone-coated braided fibre	–

Degradation: + (Absorbable) or – (Non-absorbable).

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 (blobbograms). 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 χ^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 from continuous values 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 (*d*Mean). The confidence interval for the obtained data (–95% CL and + 95% CL – whiskers) as well as the standard error of mean (SE – width of the rectangle) were also included.

Table. 3. Descriptive and statistical analysis of the results obtained in the meta-analysis – differences in the strength of biodegradable and non-biodegradable sutures after knot-tying

Saturate material – codification	No. of sample	*d*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.

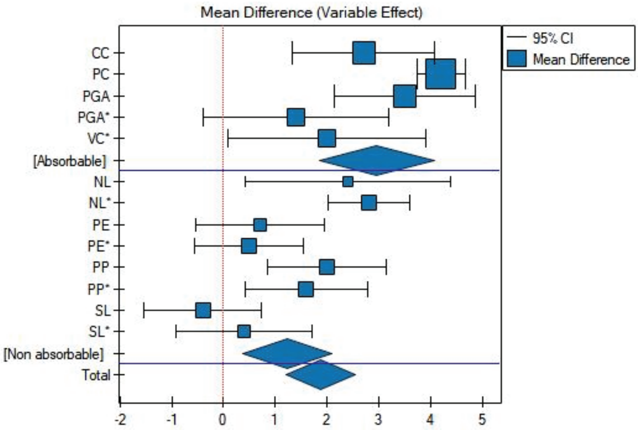

Fig. 4. Distribution of the difference in means between biodegradable and non-biodegradable sutures, with the confidence interval for the literature data – forest diagram

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

Saturate material – codification	No. of sample	Mean	SE	–95%CI	+95%CI	*Z*-test	*P*-value	Part
1	2	3	4	5	6	7	8	9
Group: UPS 3-0								
PDS[4]	7	21.95	0.39	21.19	22.71			12.74%
PDS*	7	19.90	0.57	18.78	21.02			12.58%
PGA*	7	13.80	0.49	12.84	14.76			12.66%
PP[4]	7	18.08	0.48	17.13	19.03			12.66%
PP*	7	17.20	0.53	16.16	18.24			12.62%
SL*	7	19.50	0.76	18.02	20.98			12.36%
VC[4]	7	22.80	0.37	22.07	23.53			12.75%
VC*	7	30.70	1.21	28.33	33.07			11.62%
Total	56	20.39	1.32	17.81	22.98	12.073	0.098	
Group: UPS 4-0								
CC[1]	7	9.70	0.42	8.89	10.51			6.23%
CC[2]	7	8.60	0.32	7.98	9.22			6.38%
NL1	7	11.90	0.60	10.71	13.09			5.87%
NL*	7	11.30	0.79	9.74	12.86			5.44%
PC[1]	7	8.70	0.76	7.22	10.18			5.53%
PE[1]	7	10.10	0.38	9.36	10.84			6.29%
PE*	7	9.80	0.42	8.99	10.61			6.23%
PGA[1]	7	9.20	1.51	6.24	12.16			3.72%

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[2]	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[2]	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								
NL*	7	6.70	0.30	6.11	7.29			11.12%
PC[5]	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[3]	7	9.40	0.23	8.96	9.84			11.16%
SL[5]	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.

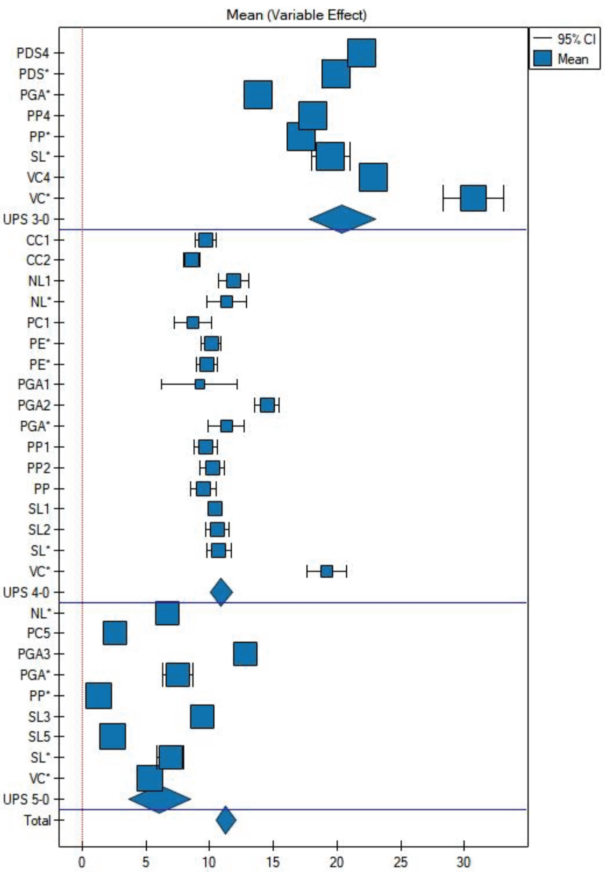

Fig. 5. Means and confidence intervals for the literature data according to suture size – forest diagram

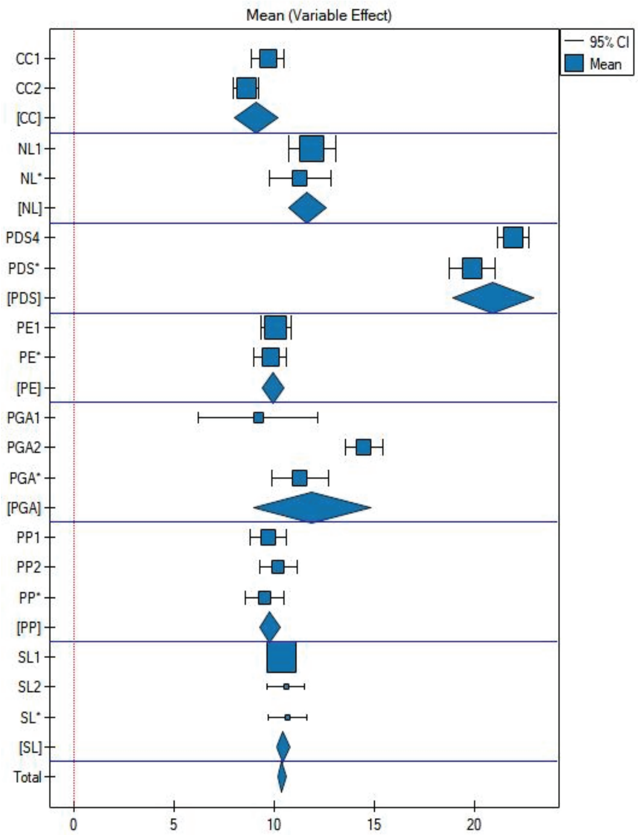

Fig. 6. Means and confidence intervals for the literature data according to type of suture material – forest diagram

Table. 5. Assessment of intragroup data consistency

Saturate material – codification	Q-test	P-value
CC	4.421	0.035
NL	0.362	0.547
PDS	8.859	0.002
PE	0.285	0.593
PGA	21.328	<0.001
PP	1.126	0.569
SL	0.427	0.808

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 needs 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.

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].

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