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Evaluation of Tensile Strength of Hand Sewn Anastomoses after Gastric Resections - An Experimental Ex Vivo Study

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Rezumat

Evaluarea rezistenței la tracțiune a anastomozelor manuale după rezecții gastrice - un studiu experimental ex-vivo

Introducere/ scop: Studiul a avut ca scop evaluarea într-un experiment biomecanic *ex-vivo* a rezistenței anastomozelor la tracțiune mecanică, pentru a determina cea mai rezistentă sutură manuală pentru restabilirea continuității tractului digestiv după diferite tipuri de rezecție gastrică pentru cancer.
Material şi Metode: Rezistența la tracțiune a diferitelor tipuri de anastomoză a fost testată comparativ *ex-vivo* folosind esofag, stomac şi intestin subțire de porc. Configurația de testare a inclus un dispozitiv de testare la tracțiune, care a aplicat o forță controlată asupra anastomozelor până la ruperea acestora, care fost înregistrată pentru fiecare tip de anastomoză şi a fost exprimată în N. Prelucrarea datelor şi analiza statistică au fost realizate în programul GraphPad Prism, folosind un test T pereche şi test ANOVA. Am considerat valoarea p<0,05 ca fiind statistic semnificativă.
Rezultate: Anastomoza gastro-jejunală biplan (Roux-en-Y) şi eso-jejunală termino-terminală au prezentat cea mai mare rezistență la tracțiune. Anastomozele biplan au arătat o rezistență la tracțiune semnificativ mai mare comparativ cu cele monoplan. Rezultatele sugerează că tehnica de sutură biplan oferă o stabilitate mecanică mai bună, ceea ce poate reduce riscul complicațiilor postoperatorii.
Concluzii: Anastomozele efectuate biplan după rezecțiile gastrice pot reduce complicațiile postoperatorii şi pot îmbunătăți rezultatele pacienților.

Cuvinte cheie: anastomoză, rezistența la tracțiune, experimental

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Abstract

Introduction: This study aimed to evaluate the resistance of anastomoses to

mechanical traction in an ex vivo biomechanical experiment, to determine the most resistant manual suture for restoring digestive tract continuity after various types of gastric resection for cancer.
Materials and methods: The tensile strength of different types of anastomoses was compared ex vivo using porcine esophagus, stomach, and small intestine. The test setup included a tensile testing device, which applied a controlled force on the anastomoses until they broke, which was recorded for each type of anastomosis and was expressed in N. Data processing and statistical analysis were performed in the GraphPad Prism program, using a paired T-test and ANOVA test. We considered the p-value <0.05 to be statistically significant.
Results: Double-layer gastrojejunal (Roux-en-Y) and end-to-end esophagojejunal anastomosis presented the highest tensile strength. Double-layer anastomoses showed significantly higher tensile strength compared to monoplane ones. The results suggest that the double-layer suture technique offers better mechanical stability, which may reduce the risk of postoperative complications.
Conclusions: Biplane anastomoses after gastric resections may reduce postoperative complications and improve patient outcomes.

Keywords: anastomosis, tensile strength, experimental

Introduction

Gastric cancer is the fifth most common cancer and the third most common type of cancer worldwide in 2022. According to Globocan, there were 970000 new gastric cancer cases reported and about 660000 gastric cancer-related deaths, ranking this pathology as the fourth most common cause of cancer-related deaths globally (1).

Case management implies a multidisciplinary treatment plan, including both surgical and systemic treatment for localized gastric cancer (2). The radical surgical treatment consists of partial or complete removal of the stomach, depending on the tumor location, along with D2 lymphadenectomy, followed by anastomosis to restore the continuity of the digestive tract (2).

Although surgical techniques have advanced, and there is a large variety of manual and mechanical sutures, anastomotic leak remains a significant complication, leading to increased morbidity and mortality, prolonged hospitalization, and increased hospital costs (3). The incidence of anastomotic leaks varies in the literature but typically ranges from 2% to 10%. These leaks often become clinically evident within the first postoperative week, although delayed presentations can occur.

Several patient - and procedure-related factors contribute to anastomotic leaks. Poor nutritional status, as evidenced by hypoalbuminemia and low preoperative body mass index, is a significant risk factor for anastomotic leaks (6). Comorbidities such as diabetes, hypertension, and chronic obstructive pulmonary disease increase the risk of anastomotic leak development. Still, the patient's advanced age is associated with impaired tissue healing, increasing the likelihood of anastomotic leaks (7).

Some surgical factors have also been identified. Choosing between hand-sewn and stapled anastomosis remains a subject of debate, with varying outcomes reported regarding anastomotic leaks (8, 9). It remains a personal preference of the surgeon, depending on local anatomy, available equipment, and personal preferences.

Rapid diagnosis and correct management are crucial for treating anastomotic leaks. The diagnosis is based on local and general clinical signs of peritonitis and should be confirmed by imaging investigations, preferably contrast-enhanced (10).

Management strategies include conservative treatment with antibiotics, nutritional support, and percutaneous drainage for minor leaks. Major anastomotic leaks may require surgical intervention, including resection, diversion procedures, and revision of the anastomosis.

Preventive measures to reduce the risk of anastomotic leaks include optimizing patient nutrition, meticulous surgical technique, careful patient selection, and appropriate postoperative care. Minimally invasive surgery, when feasible, may also reduce the risk (10).

Creating an anastomosis during gastric cancer surgery can be hand-sewn or using stapling devices. Mechanical anastomoses are undoubtedly superior in terms of time for execution, so in many cases, they become the preferred approach, but there are no defined indications for either. A recent large population-based study demonstrated that handsewn and stapled anastomoses are useful and can be applied as anastomotic techniques per surgeon preference (8).

The manual restoration of the digestive tract after gastric resections can be performed in single-layer or double-layer sutures. Studies have reported variable anastomotic leak rates depending on the suture technique, although no significant difference in safety has been observed (11).

The study aimed to evaluate in an ex vivo bio-mechanical experiment the resistance of the anastomoses to mechanical traction, to determine the most resistant manual suture for restoring the continuity of the digestive tract after different types of gastric resection for cancer.

We mention that all other patient-related risk factors for anastomotic leakage (comprehensively studied in the literature) were ignored, such as the blood supply of the stumps, proteinemia, and comorbidities, so the study exclusively focuses on the suturing techniques.

Material and Methods

This experimental study was carried out in collaboration with Sapientia University, the faculty of Technical Sciences and Humanities, Târgu Mureş.

Experiment Protocol

Porcine stomach, esophagus, and small intestine tissues were used to assess the mechanical strength of anastomoses. All tissues were harvested from freshly slaughtered pigs and transported to the laboratory in isotonic saline solution to maintain tissue integrity. The tissues were kept hydrated throughout the procedure by immersing them in saline solution to prevent desiccation. After sectioning it to equal 20 cm segments, a single surgeon performed all anastomoses listed in *Table 1*, using standardized suturing techniques, ensuring uniform suture spacing of approximately 3 mm and consistent tension across all samples. 5 breaking strength tests were performed for each type of anastomosis, using the universal manual tensile strength measuring device. Measurement values were expressed in Newton (N). We tested the types of anastomoses most often used in gastric cancer surgery, for which we used the suture materials presented in *Table 2*. This protocol aimed to ensure reproducibility and physiological relevance in the evaluation of anastomotic strength.

The Suturing Technique

For single-layer anastomosis, 3/0 non-absorbable polypropylene suture material was used; while for double-layer anastomosis, 4/0 absorbable polyglycolic acid running stitches, covered by the sero-serosus layer sutured with 4/0 non-resorbable polyamide stitches (*Tables 1, 2*).

The results of the measurements were gathered in a Microsoft Excel table, and the data processing and statistical analysis were performed in the GraphPad Prism program, using a paired T-test and a one-way ANOVA test with post-hoc correction. The Q values in the table are the results of the post hoc multiple comparisons test, reflecting the magnitude of differences between group means adjusted for multiple testing. The associated p-values indicate the probability that these observed differences occurred by chance. Significant differences are indicated by p values below the threshold of 0.05

Results

For each type of anastomosis there were performed 5 resistance measurements were performed. From the gastro-jejunal anastomoses, the highest mean resistance was obtained in the end-to-side Roux-en-Y double-layered suture (22.5 N), while across the eso-jejunal anastomoses, the highest mean resistance was measured in the end-to-side double-layer suture (22.4 N).

Table 3 summarizes the results of the resistance measurements and shows the descriptive statistical elements.

Table 1. Types of anastomoses tested (GEA: gastro-entero-anastomosis, EJA: eso-jejunal-anastomosis), each with different suture types.

GEA	EJA
Omega- continuous, single layer	End to end -continuous, single layer
Omega- double layer	End to end -double layer
Roux en Y - continuous, single layer	End to side- continuous single layer
Roux en Y- double layer	End to side – double layer

Table 2. Suture materials used for the experiment and their characteristics

Suture materials used	Thickness	Absorbability
Dacryl - polyglycolic acid	4/0	Absorbable
Biopro - polypropylene	3/0	Non-resorbable
Bionyl - polyamide	4/0	Non-resorbable

Table 3. Descriptive statistical elements and individual resistance measurements in tested anastomoses

	GEA Omega SL	GEA Roux en Y DL	GEA Roux en Y SL	GEA Omega DL	EJA E-E DL	EJA E-E SL	EJA E-S SL	EJA E-S DL
1	25.6	25.7	16.2	19	13.5	20.6	10.2	24
2	26	24	18.1	17.2	12.7	7.9	9.6	22
3	22.7	25.1	18.1	14	11.4	24	11.9	23.1
4	14.2	21.5	10	18.4	12.1	14.4	9.9	19
5	21.5	16.2	6.6	20	13.2	11.2	13.4	24.2
mean	22	22.5	13.8	17.72	12.58	15.62	11	22.46
median	22.7	24	16.2	18.4	12.7	14.4	10.2	23.1
STD	4.75	3.87	5.22	2.31	0.84	6.62	1.61	2.12
min	14.2	16.2	6.6	14	11.4	11.2	9.6	19
max	25.7	26	18.1	20	13.5	24	13.4	24.2

GEA- gastro-entero anastomosis; SL- single layer; DL- double layer; EJA- eso-jejunoanastomosis; E-E-end to end; E-S- end to side

We compared the tensile strength of various types of gastrojejunal anastomoses using a one-way ANOVA test. The results showed and statistically significant difference in tensile strength in favor of Roux-en-Y loop in the double layer. The results of the pairwise comparison of the tensile strength are shown in *Table 4.*

The graphical representation of the tensile strength values of different gastro-entero anastomoses is shown in *Fig. 1.*

We compared the tensile strength of various types of eso-jejunal anastomoses using a one-way ANOVA test. The results showed a statistically significant difference in tensile strength in favor of end-to-side double-layer anastomosis. The pairwise comparison of the tensile strength of these anastomoses is shown in *Table 5.*

Fig. 2 represents the comparison of tensile strength values of different eso-jejunal anastomoses.

In our experimental study, the results of quantitative measurements showed that the most resistant anastomosis to traction forces is the double-layered gastro-jejunal anastomosis with

Table 4. Pairwise comparison of the tensile strength values of the different gastro-enteroanastomoses.

Pairwise comparation	Difference of means	Result
Omega SL- Omega DL	4.78	Q = 2.55 (p = 0.30747)
Omega SL- Roux SL	8.70	Q = 4.64 (p = 0.02186)
Omega SL- Roux DL	0.50	Q = 0.27 (p = 0.99752)
Omega DL- Roux SL	3.92	Q = 2.09 (p = 0.47189)
Omega DL- Roux DL	4.28	Q = 2.28 (p = 0.39836)
Roux SL- Roux DL	8.20	Q = 4.38 (p = 0.03178)

SL- single layer; DL- double layer, using a one-way ANOVA test.

Table 5. Pairwise comparison of the averages regarding the tensile strength values of the different eso-jejunoanastomosis using the ANOVA test. (SL- single layer; DL- double layer)

Pairwise comparation	Difference of means	Result
End to end SL: End to end DL	3.04	Q = 1.89 (p = 0.55426)
End to end SL: End to side SL	4.62	Q = 2.87 (p = 0.21779)
End to end SL: End to side DL	6.84	Q = 4.25 (p = 0.03766)
End to end DL: End to side SL	1.58	Q = 0.98 (p = 0.89760)
End to end DL: End to side DL	9.88	Q = 6.14 (p = 0.00254)
End to side SL: End to side DL	11.46	Q = 7.13 (p = 0.00063)

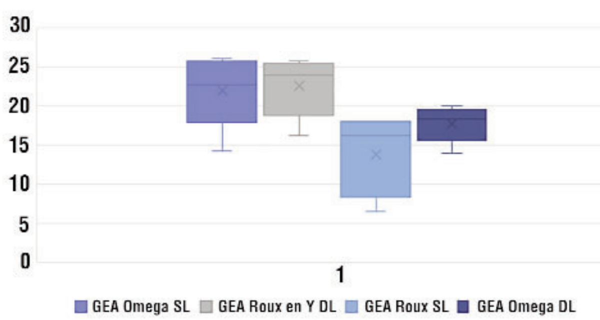

Figure 1. Tensile strength of gastro-entero anastomoses
(GEA- gastro-entero anastomosis; SL- single layer; DL- double layer)

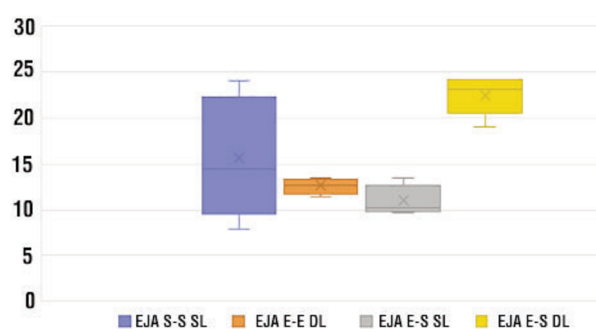

Figure 2. Tensile strength of eso-jejuno anastomosis
(EJA- eso-jejunal anastomosis; E-E- end-to-end; E-S – end-to-side; SL-single layer; DL- double layer)

Roux-en-Y compared to other anastomoses used after partial gastrectomy (p=0.02), and the double-layered end-to-side eso-jejunal anastomosis compared to other techniques used after total gastrectomy (p=0.03)

Discussions

In this ex vivo biomechanical experimental study, we measured the mechanical breaking strength of different types of anastomoses used in day-to-day surgical practice after gastric resections for cancer.

Taking into consideration that the anastomotic fistula is the most severe local complication after gastrointestinal resections, we aimed to find the most resistant type of anastomosis from a mechanical point of view, to reduce postoperative complications and improve the patient's outcome.

A clinical study published in The American Journal of Surgery, which analyzed the outcome of 682 patients with gastrointestinal anastomoses, found that anastomotic tension is an independent prognostic factor for anastomotic leaks (12).

As the patient-related prognostic factors for anastomotic leakage (hypoproteinemia, vascular supply, comorbidities) are widely researched, our purpose was to focus exclusively on the technical issues leading to anastomotic leaks.

The present study compares the breaking strength of single and double-layered gastro-jejunal and eso-jejunal anastomoses positioned end-to-end and end-to-side to determine the safest anastomosis to use after resections in gastric cancer surgery.

Our result showed significantly higher breaking strength of the end-to-side double layer in both gastro-jejunal and eso-jejunal anastomoses. (22,5 N and 22.46 N) The value of over 22 N force translates to over 2 kg of traction on the anastomosis, which probably would never happen in a digestive system, caused neither by a food bolus nor adhesions.

Several clinical and experimental studies aimed to find the best suturing technique to decrease the rates of fistulas, but the results are controversial.

A clinical retrospective study conducted in Aachen, Germany, which comparatively analyzed the anastomotic rate after interrupted and continuous sutures, concluded that anastomotic leakage is strongly dependent on the suturing technique. In this study, there were significantly higher fistula rates after interrupted sutures compared to the continuous group (13).

A more recent *in-vivo* experimental study in pigs comparing single and double-layered intestinal anastomoses concluded that there were no statistically significant differences in anastomosis strength between single and double-layered intestinal anastomoses (14).

In contrast with these results, our ex vivo study found statistically significant differences between the strength of single and double-layered anastomoses in both gastro-jejunal and eso-jejunal settings. This difference can be explained by the different anatomical structures of the segments of the digestive system; the tensile strength of the stomach and esophagus is higher than the intestine, which might modify the anastomotic breaking strength as well (15).

An experimental article published in the Annals of Thoracic Surgery studies the biomechanics of esophageal anastomoses. The ex vivo research results showed that handsewn simple continuous anastomoses were found to be the most resistant ones, whereas the other anastomotic techniques tolerated lower traction forces. The single-layer interrupted suture anastomosis was inferior to the continuous suture anastomosis, whereas other techniques did not differ in linear breaking strength. There were never observed ruptures of suturing material (16).

Like these results, in our experimental ex vivo study, the continuous single-layer end-to-side, eso-jejunal anastomoses showed high resistance to traction, but adding a sero-serosus interrupted layer significantly increased the anastomotic breaking strength. Also, we didn't observe either the rupture of the suturing material.

The difference between these results can be attributed to the difference in the design of the study and the suturing material. In von Sochaczewski's study, the tested anastomoses were end-to-end esophageal anastomoses. It is logical to have a slight difference when testing an eso-jejunal anastomosis, in which there is a different structure of the anastomotic partners, including the thickness of the wall.

It is impossible to objectively measure the anastomotic tensile strength in vivo, during surgery. Although there are some practical possibilities to decrease tension in the anastomotic suturing line, like leaving long enough stumps or mobilizing the nearby segments of the digestive tract.

Experimental studies assist in testing various anastomoses, offering valuable insights for daily surgical practice.

The study's limitation is related to the ex vivo porcine model, which does not replicate the full complexity of in vivo environments, such as blood flow, immune responses, and neural regulation, which can influence tissue healing and strength. Vascularization of the anastomotic stumps is very important to prevent leaks, exemplified by the introduction of indocyanine green usage to determine the vascular perfusion of the sutured segments.

However, the cause of the anastomotic leaks is not the increased tension in the suture line nor insufficient blood supply alone; fistulas are likely the appear when multiple patient and disease-related factors occur together, causing insufficient tissue perfusion on an under-tension segment and thereby collusively cause leaks (18).

Conclusions

Our experimental ex vivo study showed that the most resistant anastomosis to traction forces is the double-layered gastro-jejunal anastomosis with Roux-en-Y compared to other anastomoses used after partial gastrectomy, and the double-layered end-to-side eso-jejunal anastomosis compared to other techniques used after total gastrectomy.

We would like to outline that these results are mechanical and are not predictive of clinical anastomotic leak rates. Besides the surgical technique, we consider it equally important to evaluate all the other factors that can contribute to fistula formation to decrease postoperative complications.

Our findings may help guide future clinical research or support surgical technique standardization.

Conflicts of Interests

The authors declared no potential conflicts of interest.

Ethical Approval

Ethical approval was not required, due to the use of non-viable material.

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