An In Vitro and In Vivo Evaluation of Tensile Strength and Durability of Seven Suture Materials in Various pH and Different Conditions: An Experimental Study in Rats

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Abstract Development in material engineering provide many kinds of suture materials to medical fields. The choice of utilization depends on the surgeons decision, the durability, absorbtion times, tensile strength of the suture, and operation site in means of organ and tissue. In this study we aimed to investigate 7 different suture materials in vivo and in vitro conditions to evaluate the properties and durability. Basal tensile strength (TS) values of all sutures were measured and 168 Wistar albino rats were utilised in vivo groups. The sutures were placed in the bladder, stomach, intestine and bile duct (after obstructive jaundice). Urine and bile of rat, pH 1 and pH 10 were used as in vitro conditions. Seven different suture materials (Maxon, Vicryl, Plain Catgut, Surgical Silk, Polypropylene, Caprosyn and Biosyn) were investigated in 9 different in vitro and in vivo conditions. All sutures were chosen to be in size 5/0. In the following 5th day the sutures were tested related to durability and stability. Results were compared stastically using the Mann-Whitney U test and $p < 0.05$ was considered as stastically significant. Among all the suture materials only polypropylene proved to preserve its stability in vivo and in vitro surveys. Cat-gut and caprosyn lost its TS in all medias. Silk and biosyn lost its TS in all conditions except the stomach and intestines. Maxon also lost its TS in all condition except urine. Utilisation of caprosyn and biosyn

in urinary procedures reduces stone formation and infections. The suture of choice in biliary tract should be vicryl, maxon or biosyn since polypropylene preserves its stability that could result in stone formation. In intestinal operations polypropylene, vicryl, and silk could be preferred.

Keywords Suture materials · In vitro · In vivo conditions

Introduction

For years, surgeons have sought the perfect suture material. Ideally, this material should be easy to handle, maintain good knot security, have low tissue drag, and have lasting tensile strength [1]. The employment and choice of different surgical suture materials are dependent on a multitude of factors. Decision making is based on the one hand on objective criteria, such as physical and biochemical material properties of given suture and on the other hand very much on subjective criteria, such as handling characteristic and personal preferences [2]. However, all of the objective criteria could not be made during the decision making because, having experimental in vitro testing is all hospitals is not feasible. Since the function of a suture is to hold several tissues in opposition until the healing process has resulted in the wound with sufficient strength to withstand stress, it is important to know how the different chemical components of the body fluid, particularly the pH level, can affect the retention of strength of suture materials. It is known that the pH of gastric juice in the stomach can go as low as 0.0 to 1.5, while pancreatic juice in the duodenum ranges from 7.5 to 8.2. Urinary pH often ranges from 4.5 to 8 [3]. This study aimed to investigate the effects of pH and in vivo and in vitro

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effects of different intraabdominal organs and fluids on the retention of tensile strength (TS) of seven different suture materials. Because of the unavailability of suture testing means in each hospital, we believe that this study could serve as a guide to surgeons in deciding the suture materials to be used in certain organ systems.

Materials and Methods

This study was performed in 9 *in vitro* and *in vivo* conditions regarding TS values and durability. The protocol was approved by the committee for the ethical care and use of laboratory animals of the Gazi University. A total of 168 rats were used in all groups. For each condition and suture material 6 Wistar-albino rats were used with a body weight range of 220–280 gr. Animals were fed laboratory chow and tap water *ad libitum* during the experiment and were kept under artificial lighting 12 h daily, at 20–22 °C. The rats were anesthetized with ketamine (40 mg/kg intramuscular injection) and were maintained under anesthesia during the procedures. Laparotomy sites were prepared by povidone iodine solution. At first a midline abdominal incision was performed using sterile techniques followed by different procedures in each study group. After that, the laparotomy incisions were closed in two layers with 4/0 silk sutures. No analgesic agent was used until the second operations because no painful procedure was implemented.

TS was measured on a tensile meter in unit of Newton (N). TS is the force applied per unit original cross-sectional area, to a test specimen at any given time (Fig. 1).

Seven commonly used suture materials of size 5-0 were tested in various chemical conditions and intra-abdominal organs. The chosen suture materials were Maxon (co-polymerization of polyglycolic acid), Vicryl (polyglycolic acid), Plain Catgut, Surgical Silk, Polypro-

pylene, Caprosyn (monofilament polyglytone) and Biosyn (monofilament glycomer).

Baseline Six independent TS measurements were obtained for each of the suture materials.

Intragastric Through a 3-mm. gastrotomy incision on the anterior surface of the stomach, 15-cm long suture material to be studied was placed and tacked at one end inside the stomach. Gastrotomy incision was closed by 6-0 prolene, inverting, interrupted, single-layer sutures.

Intraintestinal Through a 3 mm incision at the antimesenteric surface of the ileum, suture materials were fixed inside the ileal segment and open sites were closed by 6-0 polypropylene, inverting, interrupted, single-layer sutures.

Intracholedochal Bile duct was identified and ligated at the distal end by 5-0 silk suture. After 3 days the animal was re-explored under ketamine anesthesia, bile was collected to be used for *in vitro* studies and choledocotomy was done at the enlarged site. After the suture material was fixed and packed inside, the silk suture was removed and choledochal duct was unobliterated. The opened site was closed by 7-0 polypropylene, interrupted, single-layer sutures.

Intravesical The urinary bladders of the rats were opened at the dome, sutures were fixed and the open sites were closed by 7-0 polypropylene, double-layer, single sutures.

These groups were laparotomized again 5 days later under aseptic conditions and ketamine intramuscular anesthesia, sutures that were placed inside the abovementioned organs were removed and TS measurements were performed. At the end of experiments, the animals were killed by intracardiac blood drawing under ketamine anesthesia.

Alkaline Condition Six samples from each of the seven suture materials were placed in different petri boxes filled with NaOH of pH 10 under sterile conditions. The boxes were kept for 5 days in etuves with a temperature of 37°C.

Acid Condition Six samples from each of the seven suture materials were placed in different petri boxes filled with HCl of pH 1 under sterile conditions. The boxes were kept for 5 days in etuves with a temperature of 37°C.

Rat Urine Condition Urine collected from rats which resided in the metabolic cages was placed in sterile petri boxes and 6 samples from each studied suture material were placed in these for 5 days under a temperature of 37°C.

Fig. 1 Tensile strenght machine and measurement technique

Rat Bile Condition Bile collected was put in sterile petri boxes and 6 samples from each studied suture material were placed in these boxes which were kept in etuves for 5 days under a temperature of 37°C.

After 5 days sutures were measured for TS. The results were compared using Mann-Whitney U-test. A value of $p < 0.05$ was considered significant.

Results

Suture materials kept in normal conditions and in gastric juice, intrainestinal, intracholedochal, intravesical, alkaline, acid, rat urine and bile conditions were compared stastically in means of TS and results are shown in Tables 1 and 2.

Except in intravesical condition vicryl lost a stastically significant rate of TS in all other condition. Polypropylene was the only material thar conserved its stability in all in vivo and in vitro conditions ($p > 0.05$). Caprosyn and biosyn were the two material that showed maximal loss in TS in intravesical and urine conditions ($p < 0.05$). Identified stastically significant TS losses are as follows; catgut and in all conditions, silk and biosyn in all except intragastric and intrainestinal conditions, maxon in all except intravesical conditions.

Silk and all absorbable suture materilas dissolved or disintegrated in acid and alkaline. After the procedure the least TS loss was observed in polypropylene, the highest loss in TS was observed in catgut, caprosyn, biosyn, maxon and silk respectively. According to chosen suture material size (5/0) the highest TS was observed with vicryl (5.30 ± 0.45) and the lowest with polypropylene (1.25 ± 0.25).

Discussion

Despite millennia of experience with wound closure biomaterials, no study or surgeon has yet identified the perfect suture for all situations. Tissue characteristics, TS, reactivity, absorption rates, and handling properties should be taken into account when selecting a wound closure suture [4]. The biological characteristics of such materials need to be investigated in order that we can select the most appropriate for each surgical application. The aim of this study was to compare seven different absorbable and nonabsorbable sutures which can be used in the different settings. On the sutures exposed to different in vitro and in vivo conditions, TS studies was done to determine their durability under the chosen conditions.

Gastric juice, bile and pancreatic fluid drain into the stomach and the duodenum. Bile is an alkaline fluid containing water, electrolytes, bile salts, proteins, lipids and bile pigments. Pancreatic fluid contain aproximately 15 enzymes or procursors of enzymes [5]. Degradating kinetics of absorbable sutures are important if the pH level of tissue or body fluids deviates greatly from pH 7.3. As is well known, pH of gastric juice in the stomach ranges from 0.9 to 1.5 and the pH of the pancreatic juice in the duedenum ranges from 4.5 to 8. Urinary pH often ranges from 4.5 to 8.0. In addition, enzymatic transformation of urea to ammonia by Proteus is reported to elevate the urinary pH [6].

Proteolytic enzymes in the body digest catgut suture material. Other synthetic absorbable materials are absorbed via hydrolytic degradation. Non-absorbable sutures can be absorbed over the years [5].

Plain catgut is a natural absorbable suture material obtained from the collagen of submucosal layer of sheep.

Table 1 First tensile strength (TS) (mean $\pm$ SD) level and % TS levels lost in in vivo conditions of suture materials

Sutures	Baseline	Stomach	Intestine	Bile duct	Vesica
Vicryl	5.30 $\pm$ 0.45	4.62 $\pm$ 0.21 %13	4.15 $\pm$ 0.64 %22	4.10 $\pm$ 0.82 %23	4.8 $\pm$ 0.68* %10
Catgut	2.55 $\pm$ 0.58	lost %100	0.40 $\pm$ 0.07 threadbare %85	0.25 $\pm$ 0.06 threadbare %91	0.18 $\pm$ 0.06 %93
Silk	2.37 $\pm$ 0.33	2.31 $\pm$ 0.64* %3	2.5 $\pm$ 0.28* %0	1.00 $\pm$ 0.07 %58	1.82 $\pm$ 0.30 %24
Maxon	2.54 $\pm$ 0.38	2.04 $\pm$ 0.27 %20	2.06 $\pm$ 0.18 %19	1.97 $\pm$ 0.10 %23	0.83 $\pm$ 0.26 %68
Caprosyn	2.40 $\pm$ 0.30	1.59 $\pm$ 0.33 %34	1.47 $\pm$ 0.68 %43	1.01 $\pm$ 0.14 %58	0.72 $\pm$ 0.27 %70
Biosyn	3.08 $\pm$ 0.13	3.20 $\pm$ 0.70* %0	2.90 $\pm$ 0.48* %6	2.39 $\pm$ 0.30 %23	0.19 $\pm$ 0.08 %94
Polypropylene	1.25 $\pm$ 0.25	0.98 $\pm$ 0.19* %22	1.12 $\pm$ 0.14* %11	1.13 $\pm$ 0.30* %10	1.15 $\pm$ 0.18* %8

*No statistical difference between baseline and in vivo conditions TS levels ($p > 0.05$)

Table 2 First tensile strength (TS) (mean $\pm$ SD) level and % TS levels lost in in vitro conditions of suture materials

Sutures	Baseline	pH 10	pH 1	Urine	Bile
Vicryl	5.30 $\pm$ 0.45	lost %100	lost %100	4.17 $\pm$ 0.31 %22	2.67 $\pm$ 0.97 %50
Catgut	2.55 $\pm$ 0.58	lost %100	threadbare %100	0.89 $\pm$ 0.34 %66	1.06 $\pm$ 0.26 %59
Silk	2.37 $\pm$ 0.33	lost %100	threadbare %100	1.52 $\pm$ 0.24 %36	1.21 $\pm$ 0.10 %49
Maxon	2.54 $\pm$ 0.38	lost %100	threadbare %100	2.44 $\pm$ 0.34* %4	1.40 $\pm$ 0.38 %45
Caprosyn	2.40 $\pm$ 0.30	lost %100	threadbare %100	lost %100	1.08 $\pm$ 0.48 %55
Biosyn	3.08 $\pm$ 0.13	lost %100	threadbare %100	lost %100	1.55 $\pm$ 0.23 %50
Polypropylene	1.25 $\pm$ 0.25	1.25 $\pm$ 0.25* %0	1.35 $\pm$ 0.13* %0	1.32 $\pm$ 0.11* %0	1.22 $\pm$ 0.14* %2

*No statistical difference between baseline and in vitro conditions TS levels ($p>0.05$)

Because of the high protein content of catgut, it is sensitive to proteolytic digestion. In this study, catgut displayed a TS loss of 59%–100% in acid and alkaline conditions and this result was in accordance with previously performed studies. Mizuma et al. demonstrated slower and more consistent loss of TS with polyglactin and vicryl compared with catgut sutures [7]. Müftüoğlu et al. showed that catgut disintegrated in pancreatic juice, bile and mixture within 24 hours. In an in vitro study held by Chu et al. it was demonstrated that plain catgut preserved its TS in a rate of 37% at the end of the 7th day at pH 3 and 0% at the end of the 28th day. At pH 10 these values were observed to be 20% and 0% [3]. In an investigation by Vasanthan et al. the catgut sutures maintained most of their original TS over the 2-week study period -under a biologic simulation that was created in vitro by mixing 9 ml of sterile human saliva and human serum in a 1:1 ratio in a petri dish maintained at a pH of 7.4 to 8.1 at 37°C, which contradicts other reports [8].

Synthetic absorbable sutures degrade more slowly and produce less inflammatory reactions. These sutures are reabsorbed by hydrolysis. Vicryl and polyglactic acid are completely reabsorbed within 60 to 90 days. They retain 70% of initial strength at 10 days and 30% at 20 days. Polydioxanone is a monofilament synthetic absorbable suture the absorption of which is completed within 180 days. It loses 50% of initial strength after 35 days. Chu et al. in their in vitro study showed dextron to preserve its TS at a rate of 96%–0% at pH 3, at pH 10 this rate changed to be 20%–0% at the end of the 28th day. When vicryl is taken into account these rates have been shown to be as follows; 93%–0% to 40%–0% [3]. Of the three suture materials used in Vasanthan's study, the vicryl sutures had the highest tensile strength at baseline, but it decreased rapidly over time [8]. This contradicts the finding that

vicryl sutures have excellent knot-holding capacity and TS [9].

Silk is a nonabsorbable suture material, but its use has been diminishing during the recent years. Mizuma et al. stated that silk maintained its strength in dog pancreatic juice for 14 days [7]. Müftüoğlu et al. did not confirm their results. They found that silk retained its initial strength at 83% in pancreatic juice and at 89% in bile on day 7 [5].

In their in vitro study Chu et al. found a remaining TS rate of silk suture at pH 10 and pH 3 of 88% and 72% at the end of the 7th day and 73% to 42% at the end of the 28th day [3]. In the present study silk suture showed a higher loss in TS than estimated or preserved almost all or most of its TS, depending on the condition. At the end of the 5th day, loss of TS rates of silk suture with regard to initial values were found to be as follows in these conditions; intragastric 3%, intrainstestinal 0%, bile 58%, intravesical 24%, in vitro studies; acid and alkaline 36%, bile 49%. As could be seen, our results showed some deflection from the ones reported in the related literature. We suggest that one could consider using silk especially in gastric and intestinal surgery literally with all of the wound holding capacity remaining after 5 days.

Polypropylene is a monofilament nonabsorbable suture that maintains its TS for >2 years. Müftüoğlu et al. first demonstrated that prolene lost its initial strength by 4%, 19% and 23% in pancreatic fluid on days 1, 3 and 7 respectively [5]. Chu et al. documented a TS preservation of prolene at pH 3 to be 97% and 103% and at pH 10 to be 102% and 106% at the end of day 7 and 28 [3]. The present study showed that in in vitro conditions at the end of day 5 TS loss was only 2% in bile, and in in vivo conditions the results were as follows; 22% intragastric, 11% intrainstestinal, 10% in bile, and 8% intravesical.

Caprosyn monofilament synthetic absorbable sutures are prepared from polyglytone synthetic polyester which is composed of glycolide, caprolactone, trimethylene carbonate and lactide. Absorption begins as a loss in TS followed by a loss in mass. Subcutaneous tissue implantation studies in rat indicate that caprosyn suture retains a minimum TS of 50%–60% at 5 days and a minimum of 20%–30% at 10 days post implantation. All of the original TS is essentially lost by 21 days post implantation. In this study at the end of the 5th day caprosyn dissolved in in vitro acid and alkaline conditions and preserved its TS in in vitro bile at 45%. In vivo conditions resulted in rates as follows; 66% intragastric, 57% intraintestinal, 42% in bile, and 30% in urine.

Biosyn synthetic absorbable sutures are prepared from a synthetic polyester, glycomer composed of glycolide (60%), diaxanone (14%) and trimethylene carbonate (26%). Absorption of biosyn sutures is essentially complete between 90 and 100 days. Subcutaneous tissue implantation studies in rat indicate TS for biosyn sutures to be approximately 75% at two weeks and approximately 40% at three weeks post implantation. In this study at the end of the 5th day biosyn completely dissolved in acid and alkaline in vitro conditions and in vitro urine. Only in bile it preserved its TS of about 50%. It preserved its TS at about 100% in intragastric, at 94% in intraintestinal, 77% in bile, and 6% in urine (bladder). Similarly silk dissolved in acid and alkaline but preserved its TS at a rate of 97% in intragastric and 100% in intraintestinal conditions. These results indicate that biosyn and silk can be used in stomach and intestinal interventions.

In a study by Greenberg et al., reduction in TS was detected for all materials in all urine specimens over time. Polyglyconate and polydioxanone had superior TS in sterile neutral urine, and polydioxanone retained the greatest TS throughout the study period [10]. In intravesical placement in the present study, the highest rates of TS loss were seen in catgut, biosyn and caprosyn. Biosyn and caprosyn dissolved in urine completely in this study. In the light of this information, the utilization of these sutures in urological procedures could decrease stone formation and infections.

Chemical and histological testing for suture materials were not considered when this study was planned. However, this study may be some guide for further studies

because most of the suture materials were dissolved and some remained. Thus, the chemical and physical properties that lead to dissolution and those that result in durability could be investigated as a more advanced study.

In conclusion, prolene suture preserves its stability in all conditions and pH values. Caprosyn and biosyn should be preferred in urological interventions. In biliary surgery the material of highest durability is polypropylene and this is followed by vicryl, maxon or biosyn. Because polypropylene is non-absorbable and could lead to stone formation in the biliary tract over time, we suggest that vicryl, maxon or biosyn be used in biliary surgery.

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