The Biomechanical Properties of Suture Materials and Their Relationship to Bacterial Adherence

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Sutures are classified into non-absorbable and absorbable, and mechanical properties of these materials vary by the composition. In this study we analyze four different types of sutures used commonly in surgery: silk, nylon, polyglycolic acid (PGA) and polytetrafluoroethylene (PTFE). The materials were chosen to represent a wide range of suture material categories: absorbable and nonresorbable, monofilament and multifilament, natural and synthetic in order to assess their mechanical properties but also the bacterial adherence to each type. The objective of this study was to measure the total bacterial adherence by using real time PCR at 7 days postop and to analyze the antibacterial and mechanical properties comparatively depending on the type and composition of sutures. Tensile properties such as maximum tensile load, elongation rate, stiffness and energy absorbed before breakage were taken into consideration. Experimental determination pointed out that the average total bacterial load was lowest for PTFE and highest for silk. The results of the study are useful in choosing an appropriate suture wire according to the mechanical properties taking into account the bacterial load of the surgical site in order to aid in tissue repair.

Keywords: sutures, silk, nylon, polyglycolic acid, polytetrafluoroethylene, mechanical properties, bacterial adherence

Even though sutures are not always the principal feature of surgical procedures, they have an important role in assisting a patient's successful recovery. An optimal suture should produce minimal tissue injury, have a resistance to bacteria contamination, and foremost, facilitate suitable tissue support [1]. Choosing the suitable suture by taking into account the particular biological structure, function, and potential healing outline of the tissue favors the surgeon to approach a multitude of the potential risk factors associated linked to wound closure [2]. Wound dehiscence, oroantral communications and surgical site infections are complications that can compromise the surgical result and add to morbidity and mortality [1, 3]. As the needle and suture material passes through tissue it creates a favorable environment for bacteria to invade in the deeper layers from the patient's own skin or mucosa [4]. In addition, the surgical incision creates a breach in the epidermis that can become contaminated from a failed wound closure or other complications. Antibacterial-coated material was created as a means to address this issue, however significant clinical benefits have yet to be highlighted [5].

In general, for infection to arise bacteria is required to be present in significant numbers [4, 6]. In an ordinary subject, the infective dose is more than 100,000 microorganisms per gram of tissue, albeit this number is dependent on the types of species and if the patient has a weakened immune system caused by certain medication or disease [4]. Sutures can negatively impact the infective threshold and studies have reported that they can decrease necessary number of bacteria to cause an infection to just 100 staphylococci per gram of tissue [4].

When placed in the oral cavity, the inert area of a foreign structure is covered in proteins such as fibrinogen, fibronectin, collagen, and other substrates, almost instantly which act as adhesives for microbes [5]. Biofilm is created by several types of bacteria and this encourages multiplication but also acts as a shield from the hosts defenses and antibiotic therapy [7, 8].

The aim of this study was to measure the total bacterial adherence on four types of suture materials: silk, nylon, polyglycolic acid (PGA) and polytetrafluoroethylene (PTFE) 7 days after intraoral surgery and to analyze the antibacterial and mechanical properties comparatively depending on the type and composition of sutures.

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Experimental part

Material and methods

Study design

This was a prospective, controlled, comparative, single-center study conducted on 28 patients (age 23–71 years old) undergoing various surgical intraoral procedures (third molar extractions, closure of oroantral communications). The subjects were sutured with four types of wire materials in the same surgical site.

Written informed consent was obtained from all patients prior to enrollment in the study. The ethical norms settled by the Helsinki Declaration have been respected in the conduct of this research.

Exclusion criteria were: contaminated wound sites, evidence of malnutrition or debilitation, coexisting conditions that may impair wound healing, including acquired immunodeficiency syndrome (AIDS), diabetes mellitus, chronic infectious diseases, incision sites prone to expand, stretch, distend, or require support, antibiotic therapy in the last six months or an allergy to any of the suturing materials.

Subjects underwent a rigorous clinical examination, accompanied by radiological exploration and hence the formulation of a complete dental diagnosis was established.

All procedures were performed by the same experienced surgeon in order to limit interoperatory variations.

Patients were instructed not to use mouth rinses or to brush their teeth in the surgical area for the duration of the study.

Seven days after the surgery the sutures were removed in accordance with standard procedures under sterile conditions with sterile scissors and tweezers. The suture materials were immediately transferred into sterile tubes containing reduced transport fluid medium.

When the sutures were removed there were no signs of local infection.

Sutures

Suture surgical threads can be classified in: natural and synthetics (origin), absorbable and nonresorbable (biological behavior) and finally, monofilament, multifilament and pseudo-monofilament (structure). The sutures selected for study were chosen to represent several common categories of suture material and basic construction properties. Silk (D-tek SK®, multifilament, natural, nonresorbable), polyglycolic acid – PGA (RESORBA, PA11418®, synthetic, absorbable, multifilament), nylon - polyamide (Prima®, synthetic, monofilament, nonresorbable), polytetrafluoroethylene - PTFE (Medipac Profimed® PTFE – synthetic, monofilament, nonresorbable).

All sutures were size 4-0 and were purchased from commercially available, unexpired, sterilized packets. All sutures were taken directly from the package into the surgical site without additional machinations. Interventions, such as knot tying, abrasion with forceps or needle driver were kept to a minimum as all these procedures could alter the bacterial adherence to the sutures in an effort to maintain the ideal performance characteristics and mechanical properties of each suture material.

Mechanical properties of sutures

Mechanical properties of sutures encompass: knotted and unknotted tensile strength, modulus of elasticity, elongation at break, and toughness.

Tensile strength is most comonly reported and studied mechanical characteristic of suture materials. Due to the fact that it is conveyed as the cross sectional area of a material, it can be normalised according to the size of the material and thus it can be compared to wires which have diverse chemical structures. Tensile breaking force on the other hand does not take into account the size of the suture.

Viscoelasticity is the ability of a suture to hold a wound and a thread will eventually become “relaxed” as a consequence of the contraction of wound edema, thus leading to a knot loop becoming to unhinged and it may hinder the healing process.

Bending stiffness is in close relation to knot security and the handling ease of the material. As a result braided sutures have greater flexibility when compared to monofilament types regardless of their chemical components.

Suture compliance is in relation to the elongation capacity when a tensile force is applied and this property should be taken into account when considering the compliance and polymorphic structure of tissues at the surgical site.

Capillarity depicts the competency of a material to transit liquid along the strand and is an inherent physical property of multifilament sutures due to the available interstitial space. Due to this fact it is an important property when considering wound healing at an infected site because of the ability to transport or disseminate microorganisms.

Fluid absorption is related to capillarity and may also account for the spreading of bacterial organisms through tissues. Fluid absorption is determined by the chemical structure foremost but also secondarily by the physical structure.

Packaging memory is the capacity to maintain the kink form after unpacking. This ability makes it harder for surgeons to tie a knot during surgical procedures especially for materials like nylon which have a high memory and have a tendency of untying as they try to return to their packing form.

Biological characteristics

Reabsorption ability is the capacity of a thread to degrade in the tissue in polymers of the synthetic type thisoccurs with hydrolysis.

Sterility is accomplished by various techniques that provide the use of the ethylene oxide or cobalt 60, gamma rays.

Tolerability is the capacity of a suture wire to determine a minimum amount of tissue inflammatory reaction. Regrettably no material is biologically inert, howbeit it behaves like a foreign body and generates an inflammatory process more or less substantial.

Wire sampling

The portion of the wire from which the surgical knot was made was harvested and placed in a sterile 1.5 mL Eppendorf tube and transported to the laboratory. In order to obtain comparable results between samples, only a 4 mm portion of each sample was used for DNA extraction.

DNA extraction

DNA extraction was performed with a Wizard® Genomic Purification Kit commercial extraction kit (Promega, USA) following the manufacturer's instructions. Simultaneously with the execution of the extraction protocol, the control of contamination between samples was carried out by processing a sample of water with a degree of purity for molecular biology.

The quantification and purity of the isolated DNA were determined by spectrophotometry. NanoPhotometer® (Implen Gmbh, Germany) was used. The quantification was determined at the optical density (OD) at 260 nm and the OD 260 nm/OD 280 nm ratio indicates the purity of the DNA. Generally values of the OD 260 nm/OD 280 nm ratio of 1.7-2.0 mean pure DNA.

Determination of bacterial load

The determination of total bacterial load, quantification of streptococci, lactobacilli and enterococci was performed according to Burgeois et al. [9]. The primers target highly conserved regions of the waaA (kdtA) and waaG (2) genes.

Both genes are in the genome of the species listed above in a single copy, which simplifies the actual quantification of bacteria. The qPCR result represents the number of amplicons and in the present case, because the amplicon represents a fragment of a single copy gene, it translates directly into the number of copies of the genome, equivalent number of bacteria.

For the construction of the standard curve and as a positive control, respectively, a recombinant plasmid was used in which the DNA sequence of interest flanked by complementary sequences to the primers is incorporated to allow their attachment. This synthetic plasmid was purchased from Primer Design, UK. Decimal dilutions of positive control 10-10^7 copies / reaction were performed. As a negative control, biopure water was used to replace the DNA isolated from the sample to be analyzed. The amplification was performed according to the following thermal program: initial distortion at 95 ° C for 10 minutes and 40 cycles of 95 ° C-30s, 60 ° C-1 minutes.

Results and discussions

Bacterial adherence to four different monofilament sutures used in oral surgery was compared. For the *in vivo* study a collective of 28 patients was examined, in all cases each suture material was investigated in the same patient. Seven days postoperative the sutures were removed and the adherent bacteria were isolated and differentiated. Table 1 shows the mean number of total bacteria for each type of analyzed suture.

A total of 112 suture samples were examined for microbial adherence and a statistically significant difference was found between the average gene copy number of bacteria for all for types of sutures considered (Figs. 1 and 2).

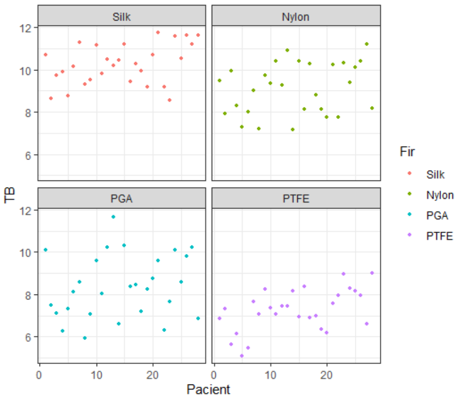

Fig. 1. Individual bacterial load per patient

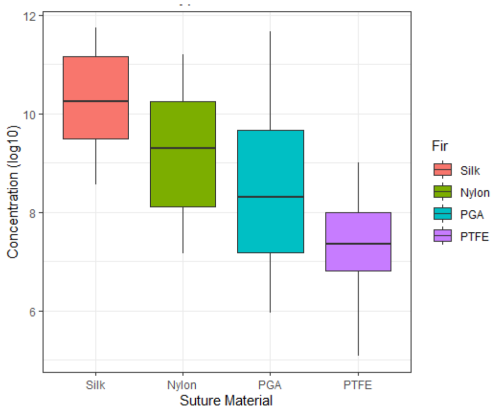

Fig. 2. Bacterial load per suture material

The mean values obtained were as follows: silk - 10.25, nylon – 9.11, PGA – 8.38, PTFE – 7.25 (Table 1). Not only the mean number of total bacteria on silk was higher than on PTFE, but also the average microbial count for the latter was lower than the minimum value for silk.

Removal of all sutures was effortless and without any notable difference between groups.

Table 1
DESCRIPTIVE STATISTICAL INDICATORS

Material	Min	Max	Average	IQR
Silk	8.56	11.73	10.25	1.67
Nylon	7.16	11.19	9.11	2.14
PGA	5.95	11.65	8.38	2.48
PTFE	5.09	9	7.25	1.19

Note: The values are expressed as log10 of total bacterial load.
Min = minimum, Max = maximum, IQR = interquartile range

In the surgical field practitioners use suture materials for a multitude of purposes, among these and the most important is primary closure of tissues, which were divided by surgical procedure or due to a traumatic event, it stimulates the healing process and controls bleeding [10]. The materials utilized for this function include sutures, tissue adhesives and staplers, which are termed as suture materials. Among all of these suture materials, the suture wire is the most frequently used material.

Optimal suture materials should satisfy several technical requirements. A high tensile strength during operation but this should diminish at the same rate as the tissue gains strength, easy to maneuver and tie secure knots. In order to accommodate the inevitable wound edema it ought to be able to stretch and rebound to its initial length as wound contraction starts to develop. As there is not at the moment a single suture wire that possesses all of these properties, it falls on the surgeon to decide as to what material is best suited for a certain procedure, however this task is difficult to assess due to the multitude of factors that intervene in taking this decision [11, 12].

In our study we observed significant differences in the suture materials analyzed regarding total bacterial load at seven days. Silk had the highest bacterial load average with a mean of 10.25, however it is also important to point out that the minimum observed value was 3 units higher than the minimum for PGA and PTFA.

Regarding maximum bacterial load the values obtained were similar and no significant differences were observed except for PTFE which had the lowest maximum bacterial load.

Natural sutures, such as silk, are more likely to cause infection due to their properties. However, it is utilized more by surgeons because of the superior handling and knot characteristics [13]. The main disadvantage is that it has a fairly high possibility in producing an acute inflammatory response, which could hinder the healing process [14].

Polyglycolic acid (PGA) sutures have excellent strength and reduced tissue reactions [15]. Grazivoda et al. stated that in the case of PGA sutures the inflammatory response was diminished when compared to other types of sutures [16]. Polyglycolic acid was the first synthetic absorbable suture that had a higher tensile strength [15]. Silk has unique handling but carries high tissue reactivity [13].

Metabolisation of the PGA suture material within the tissue occurs by the uptake of water, thus reversing the synthesis. The monomeric glycolic acid is split enzymatically into CO2 and H2O by the normal metabolism [17]. Suture material containing 10% lactide as copolymerisate differs only slightly in its physical and physiological properties from pure PGA sutures. The fine, precision-braided filaments guarantee a very high tensile strength as well as great suppleness. The special resolactone coating thinly covers the fiber bundles for specific reduction of surface friction [18].

Nylon (polyamide suture), a synthetic non absorbable suture has two forms of presentation: monofilament and braided. Monofilament nylon has high tensile strength and minimal tissue reactivity [19]. When analyzing the microbial affinity of the two types of nylon threads, researchers found that braided has five to eight times higher affinity when compared to monofilament, this being attributed to the capillary nature of braided materials [20, 21].

Poliglecaprone suture (Monocryl - Ethicon, Inc, Somerville, New Jersey), which is a copolymer of glycolide and epsilon-caprolactone, is a synthetic absorbable monofilament suture. It has been found to be nonantigenic and nonpyogenic, and it elicits slight tissue reaction during absorption. Polypropylene suture (Prolene - Ethicon, Inc) is a synthetic nonabsorbable monofilament, it has a high tensile strength and has been found to have minimal tissue reactivity [22]. Silk suture (Ethicon, Inc) is a nonabsorbable suture composed of an organic protein called fibroin derived from the domesticated species Bombyx mori. The silk for the suture material is processed to remove the natural waxes and gums. Polyglycolic acid suture (Vicryl - Ethicon, Inc) is a synthetic absorbable braided suture composed of a copolymer made of 90% glycolide and 10% l-lactide. This family of sutures has been found to elicit only a slight tissue reaction during absorption [23].

The antimicrobial polyglycolic acid suture (VicrylPlus - Ethicon, Inc) has a triclosan antimicrobial coating to limit bacterial growth [24]. PGA is indicated for use in general soft tissue approximation and/or ligation, including use in ophthalmic surgery, but not in cardiovascular surgery or neural tissue. Absorbable suture materials approximate the tissue during the healing phase and progressively lose its tensile strength and breaking load. The precision-braided filaments of polyglycolic acid that make up PGA *RESORBA*® ensure standardised and moderately rapid absorption in tissue [23]. About 21 days after implantation, but depending on the suture thickness, PGA still has at least 50% of its original breaking load (= half-life) [25].

Size refers to the diameter of the suture and in order to describe it two standards are currently used: United States Pharmacopeia (USP) and European Pharmacopeia (EP). The most used is the USP standard in which the size is numbered like 3-0, 4-0. The tensile strength is defined as the ability of the material to resist deformation and breakage and the tensile strength decreases as size decreases [24].

The main attribute of a suture is to bring the tissue edges in contact in order to aid in an optimal healing anatomy [26]. Another important characteristic is that the suture should be resistant during knot tying in order not to break. Silk loses its tensile strength, even though this does not happen for PGA in the first 2-3 days, however, in contact with saliva it decreases rapidly over time.

Capillarity represents the capacity of a fluid to pass through the suture thread [24]. Monofilament sutures have smooth surface and therefore little capillarity [27] meanwhile multifilament sutures express a greater rate of infection due to their increased capillarity especially when used in periodontal surgery or oroantral communications [28, 29].

Memory of a suture is defined as the capacity of a material to regain its original form after being deformed. Nylon sutures have a great memory to regain its normal shape, while silk have a minimum capacity of getting its original form [30].

The coefficient of friction and the pliability mainly determines the handling properties of a suture. Pliability represents the capacity of a material to bend and the friction coefficient represents how a suture passes through the tissue. Braided sutures are more flexible than the monofilament structures [31, 32].

Nowadays we know that knot is influenced by suture material, tying technique, surgeons experience and number of throws [31].

Some important biological properties are biodegradability and biocompatibility [33]. In accordance to our own study, other researchers have shown that braided sutures are less effective in managing infection than monofilament sutures. The absence of knots in barbed sutures leads to lower bacterial adherence whereas silk sutures caused an increased infection [12].

If the suture is contaminated by microbial infection then an immune reaction is triggered leading to the accumulation of granulocytes at the surgical site and thus the development of a local inflammatory reaction [23, 34]. Should this happen, supplementary therapies (antibiotics, anti-inflammatory drugs, adjunctive therapies such as laser or biomodulation) are necessary thus leading to an added systemic burden, and can even increase the healthcare costs [35, 36].

In this context it is important to take into account the bacterial adherence of suture materials and choose according to the clinical situation.

Conclusions

In conclusion, silk suture material had the highest bacterial adherence followed by nylon, PGA and the lowest adherence was observed with PTFA. These results are in accordance to the mechanical properties of wires and further emphasize the necessity for surgeons to customize their choice of material in accordance to the clinical situation.

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