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Evaluation of mechanical properties of three commonly used suture materials for clinical oral applications: an *in vitro* study

Procena mehaničkih svojstava tri najčešće korišćena šavna materijala za oralnu primenu u kliničkoj stomatologiji – *in vitro* studija

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Abstract

Background/Aim. Appropriate selection of suture materials is a crucial step in oral, maxillofacial and periodontal surgery for uneventful healing. We have scarcity of comprehensive studies comparing mechanical properties of commonly used suture material in oral surgery. The present *in vitro* study sought to evaluate the effect of saliva on the strength, elongation and stiffness of the commonly used suture material over a period of two weeks. **Methods.** Three suture materials, silk (SL), polyglactin 910 (PG) and polypropylene (PP), were used in 4–0 gauge. A total of 120 suture samples (40 from each material) were used for the investigation. Artificial saliva was mixed with human serum in 1:1 ratio and maintained at pH of 7.4 to 8.1 to simulate oral environment. All samples were tested at pre-immersion (baseline), as well as on the 3rd, 7th and 14th day in the post-immersion period. A universal testing machine was used to test the selected mechanical properties. The collected data were subjected to statistical analysis. **Results.** The distribution of mean baseline strength and percentage elongation was significantly higher in the PP group ($p < 0.001$), whereas stiffness score was the highest in the SL group ($p < 0.001$). Inter-group comparison revealed that the PP group had maximum tensile strength compared to the PG and SL groups at all time points. When percentage elongation was compared, the PP and PG groups showed the highest values on the 7th and 14th day, respectively. The PP group exhibited the highest stiffness values compared to the SL and PG groups on the 7th and 14th day in the post-immersion period ($p < 0.001$). Intra-group comparison showed that all suture materials had significant difference in mechanical properties when pre-immersion values were compared to the 14th day post-immersion values ($p < 0.001$). **Conclusion.** PP sutures are the strongest and have the highest tensile strength and elongation property. PP seems to sustain its tensile strength better than SL and PG at the end of the 14th day. Controlled clinical studies are necessary to verify this finding in an *in vivo* setting.

Key words:
materials testing; polymers; polypropylenes; saliva, artificial; silk; sutures; tensile strength.

Apstrakt

Uvod/Cilj. Izbor odgovarajućeg šavnog materijala je presudan korak za bezbedno zarastanje rane u oralnoj, maksilofacijalnoj i parodontalnoj hirurgiji. Sveobuhvatne studije koje bi upoređivale mehanička svojstva šavnih materijala koji se često koriste u oralnoj hirurgiji su malobrojne. Ova *in vitro* studija imala je za cilj da proceni efekat pljuvačke na čvrstoću, izduženje i krutost šavnog materijala koji se uobičajeno koristi tokom perioda od dve nedelje. **Metode.** Korišćena su tri šavna materijala debljine 4–0: svila (SL), poliglaktin 910 (PG) i polipropilen (PP). Za ispitivanje je korišćeno ukupno 120 uzoraka (po 40 od svakog materijala). Veštačka pljuvačka je bila pomešana sa humanim serumom u odnosu 1: 1 i održavana na pH od 7,4 do 8,1 kako bi se simuliralo okruženje u usnoj duplji. Svi uzorci su bili testirani pre potapanja u pljuvačku (bazalni nivo), kao i 3., 7. i 14. dana nakon potapanja. Za ispitivanje odabranih mehaničkih svojstava korišćena je univerzalna mašina za testiranje. Urađena je statistička analiza prikupljenih podataka. **Rezultati**. Prosečna vrednost čvrstoće pre potapanja u veštačku pljuvačku, kao i procenat izduženja bili su značajno viši kod PP materijala ($p < 0{,}001$), dok je krutost bila najviša kod uzoraka SL ($p < 0{,}001$). Međusobnim poređenjem ispitivanih materijala, ustanovljeno je da je PP u svim vremenskim tačkama imao maksimalnu čvrstoću vlakana u odnosu na PG i SL. Kada se poredilo procentualno izduženje, PP i PG su pokazali najviše vrednosti 7. (PP) i 14. dana (PP). Materijal PP je imao veće vrednosti krutosti u poređenju sa SL i PG 7. i 14. dana nakon potapanja u veštačku pljuvačku ($p < 0{,}001$). Poređenje vrednosti

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posmatranih mehaničkih svojstava unutar pojedinih vrsta šavnog materijala pokazalo je da je kod svih materijala postojala značajna razlika u tim parametrima 14. dana nakon potapanja u veštačku pljuvačku u odnosu na bazalne vrednosti ($p < 0,001$). **Zaključak**. Šavni materijal PP je najčvršći i ima najveću zateznu čvrstoću i svojstvo izduženja. Čini se da PP zadržava čvrstoću vlakana bolje od SL i PG na kraju 14. dana od potapanja u veštačku pljuvačku. Neophodne su kontrolisane kliničke studije da bi se ovaj nalaz potvrdio u uslovima *in vivo.*

Ključne reči:
materijali, testiranje; polimeri; polipropileni; pljuvačka, veštačka; svila; šavovi; čvrstoća, zatezna.

Introduction

Important concerns of periodontal, oral and maxillofacial surgeons refer to the selection of proper suture material. The suture material should be biocompatible and easy to use. Also, it should form a proper knot, have the property of elongation, be biodegradable in some circumstances and resist breakage during its use [1]. The mechanical properties of the suture materials play an important role in regulating their behavior.

Placing sutures in the oral cavity is challenging due to varied functions of mastication, speech, swallowing and high tissue vascularization along with continuous pooling of saliva [2]. Suitable sutures must possess specific physical and mechanical properties, amongst which the tensile strength is one of the most important properties. The function of the suture while in use is controlled by its elasticity, stiffness and tensile strength [3].

The flap edges should remain in close approximation after suturing of the surgical site to assist primary healing, failure of which can have a negative effect on the desired results of the surgery. Tensile strength is an important feature that is required to be maintained because the suture material tends to lose between 70% and 80% of its original strength. Therefore, the required original tensile strength must always be maintained to avoid breakage of the suture material [4, 5]. Moreover, a compromise with the strength of the suture material can result in incomplete coaptation of the flap and consequent healing by secondary intention [6]. Most of the published studies related to mechanical properties discussed mainly a breaking force. There are very few reports that actually compare other useful aspects, like failure elongation, failure stress/strain and stiffness across suture materials. However, exhaustive studies that are cited on suture materials are comparatively less pertinent to materials used for oral and periodontal surgical procedures [7, 8].

A distinct suture material shows discrete behavior in the oral cavity [9]. Various experimental researches indicated that the suture tensile strength could be affected by saliva, various solutions or consumed fluids. It has been found that there is a reduction in the strength of Vicryl® after it is immersed in saliva, bovine milk, and soy milk for 35 days [10]. Another study described remarkable reduction in the strength of two different suture types (Vicryl® and Monocryl®) after they were submerged in artificial saliva, chlorhexidine and essential oil mouth rinse [11].

Of the various commercially available suture materials, silk (SL) and polyglactin (PG) are most often used in oral and periodontal surgery. Silk is the most frequently used natural suture material, due to its better handling properties [12].

Consequently, the aim of this study is to assess and compare the tensile strength, percentage elongation and stiffness of SL, polyglactin 910 (PG) and polypropylene (PP) suture material in an environment simulating the oral cavity (immersed in artificial saliva) and a pre-immersion dry condition for an interval of fourteen days. The results mentioned in the present study are meant to provide a baseline data for oral surgeons and periodontist by assembling the mechanical and physical properties of these sutures under controlled conditions. So, this data will help in the selection of suitable suture material depending upon the required area of surgical procedure.

Methods

The present *in vitro* experimental study design was approved by the King Khalid University Ethical Review Committee (ERC), Abha, Saudi Arabia (SRC/ETH/2017-18/090). The study was conducted in the period from November 2018 to February 2019. Three distinct suture materials were involved in the current study and their physical properties were evaluated: SL, which is observed by many surgeons as a benchmark due to it easy handling [12], PG (Vicryl®), which is a multifilament absorbable synthetic suture comprised of a copolymer of glycolide and L-lactide, and PP monofilament, non-absorbable material made of an isotactic crystalline stereoisomer of polypropylene (Table 1). Suture materials were divided into the control (pre-immersed) and the test group (immersed in artificial saliva – Table 2). All the test suture materials were exposed to thermo-cycling (alternate temperature change from 5 °C to 55 °C), so as to simulate the challenges in the oral cavity.

A total of 120 suture samples were collected from commercially available unexpired stocks. Forty samples were obtained from each suture material type. All the suture samples were measured at a uniform length of 18 cm. Ten specimens from each group were tested for tensile strength before immersing into artificial saliva and referred

Table 1

Description of the suture material used in the study

Suture material	Brand	Manufacturer	Degradation
Silk (SL)	Mersilk®	Ethicon, Johnson & Johnson Pvt. Ltd. India	non-absorbable
Polyglactin 910 (PG)	Vicryl®	Ethicon, Johnson & Johnson Pvt. Ltd. India	absorbable
Polypropylene (PP)	Prolene®	Ethicon, Johnson & Johnson Pvt. Ltd. India	non-absorbable

Table 2

Chemical composition of artificial saliva

Chemical components	Concentration (g/L)
Sodium chloride (NaCl)	0.125
Potassium chloride (KCl)	0.963
Potassium thiocyanate (KSCN)	0.189
Monopotassium phosphate (KH_2PO_4)	0.654
Urea (CH_4N_2O)	0.200
Sodium sulfate decahydrate (Na_2SO_4 $10H_2O$)	0.763
Ammonium chloride (NH_4Cl)	0.178
Calcium dhloride dihydrate ($CaCl_2$, $2H_2O$)	0.227
Sodium bicarbonate ($NaHCO_3$)	0.630

to as a control group. Remaining suture specimens were kept in artificial saliva until exposed to an experimental procedure (Figure 1). A detailed description of the study protocol has been described in Figure 2.

Artificial saliva was formulated by mixing the compounds shown in Table 2 in one liter of distilled water [13]. To prevent any chemical changes, the prepared mixture was kept secured in an amber color bottle until used for the ex-

Fig. 1 – Different suture specimens immersed in artificial saliva.

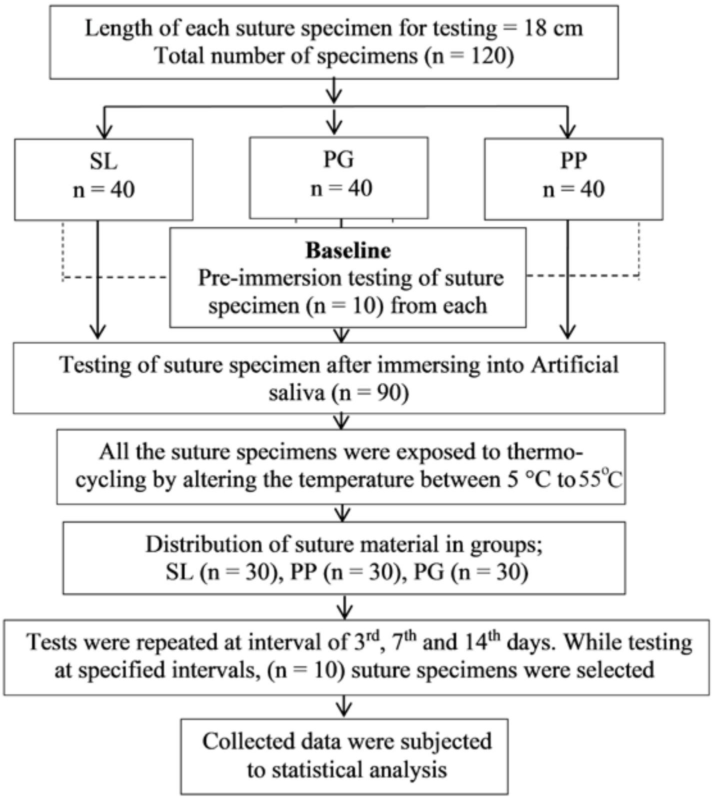

Fig. 2 – Flowchart of the study design.
SL – silk; PG – polyglactin 910; PP – polypropylene.

periment. During the experiment, the prepared artificial saliva was mixed with human serum in 1:1 ratio, to simulate oral environment. This biologic mixture was kept at a pH of 7.4 to 8.1 in an incubator at 37 °C [14].

The setup of the experiment and the testing machine are shown in Figure 3.

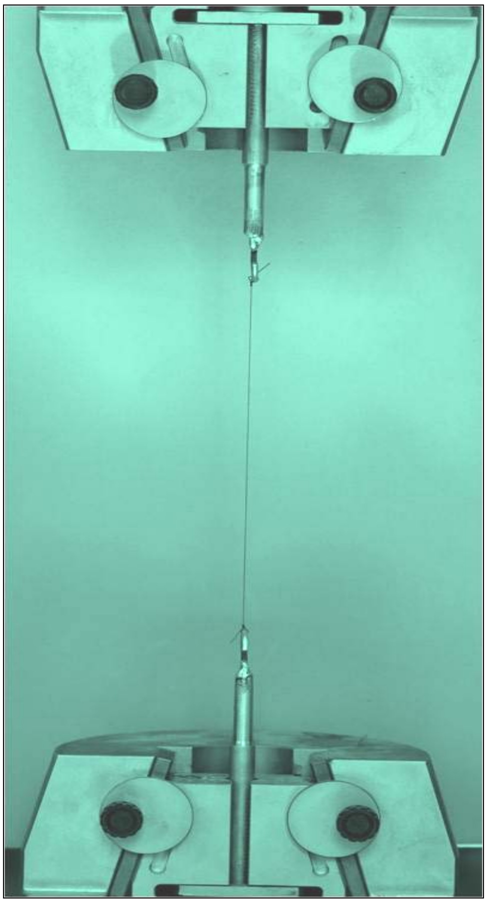

Fig. 3 – Experiment setup showing suture material tied to the hook of the separating arms of a universal testing machine.

Measurements were recorded for tensile strength, percentage elongation and stiffness. Tensile strength was defined as maximum load that can be applied to a suture material before the suture breaks; it was measured in Newtons (N). Elongation was defined as cumulative displacement exhibited by a suture material before it breaks when a gradual load is delivered and it was measured in millimeters (mm). Stiffness was defined as a measurement of the capacity of a suture material to elongate by the application of gradually increasing load before it breaks and it was measured in N per millimeter (N/mm). The stiffer materials would exhibit lesser elongation.

The data on continuous variables is presented as mean and standard deviation (SD) across the study groups. Statistical test analysis of variance (ANOVA) was used for the inter-group and intra-group comparison. In the entire study, the *p*-values less than 0.05 were considered to be statistically significant. All the hypotheses were formulated using two-tailed alternatives against each null hypothesis (hypothesis of no difference). The entire data was statistically analyzed using Statistical Package for Social Sciences (SPSS version 21.0, IBM Corporation, USA) for MS Windows.

Results

Baseline (pre-immersion) comparison of mean tensile strength, percentage elongation and stiffness are presented in Table 3. The distribution of mean baseline strength and percentage elongation was significantly higher in the PP group, followed by the PG group and the least with the SL group (*p*-value < 0.001 for all). However, stiffness score was the highest with the SL group compared to the PP and PG groups, respectively ($p < 0.001$ for all).

Table 4 shows the distribution and comparison of mean tensile strength among three suture groups on the 3rd, 7th and 14th day after the immersion in the saliva. The PP group exhibited the maximum tensile strength when compared to the PG and SL groups at all points in time ($p < 0.001$).

Table 3

Tensile strength, percentage elongation and stiffness of different suture material groups at baseline (pre-immersion)

Suture material	Tensile strength (N)	Elongation (%)	Stiffness (N/mm)
	mean ± SD	mean ± SD	mean ± SD
Silk (SL)	10.60 ± 1.26	4.5 ± 0.54	1.33 ± 0.22
Polyglactin 910 (PG)	14.50 ± 1.27	12.11 ± 1.39	0.67 ± 0.07
Polypropylene (PP)	20.40 ± 1.26	16.78 ± 0.76	0.68 ± 0.06
p-value	0.001***	0.001***	0.001***

SD – standard deviation.
********p*-value – highly significant.**

Table 4

Inter-group comparison of tensile strength (in N) pre- and post-immersion in saliva

Time of immersion	Silk (SL)	Polyglactin 910 (PG)	Polypropylene (PP)	*p*-value (Inter-group)		
	mean ± SD	mean ± SD	mean ± SD	SL vs. PG	SL vs. PP	PG vs. PP
Pre-immersion	10.60 ± 1.26	14.50 ± 1.27	20.40 ± 1.26	0.001***	0.001***	0.001***
Post-immersion in saliva						
3rd day	9.75 ± 1.21	12.80 ± 1.64	19.40 ± 1.39	0.05**	0.001***	0.001***
7th day	8.80 ± 0.83	11.80 ± 1.10	18.15 ± 1.59	0.05**	0.001***	0.001***
14th day	8.25 ± 1.07	10.80 ± 1.76	15.40 ± 1.27	0.05**	0.001***	0.001***

SD – standard deviation.
*******p*-value – significant; ****p*-value – highly significant.**

Table 5 shows the distribution and comparison of mean percentage elongation among three suture groups on the 3rd, 7th and 14th day after the immersion in the saliva. The PP group exhibited the maximum percentage elongation when compared to the PG and SL groups at baseline and on the 7th day after the immersion ($p < 0.05$ and $p < 0.001$), whereas the PG group exhibited the highest percentage elongation compared to the SL and PP groups on the 3rd and 14th day after the immersion ($p < 0.05$ and $p < 0.001$).

Table 6 shows the distribution and comparison of mean stiffness among three suture groups on the 3rd, 7th and 14th day after the immersion in the saliva. The highest stiffness was recorded by the SL group, followed by the PP and PG groups at baseline and on the 3rd day after the immersion ($p < 0.001$), whereas the PP group exhibited higher stiffness compared to the SL and PG groups on the 7th and 14th day after the immersion ($p < 0.001$).

Table 7 presents intra-group comparison of different suture material with respect to different variables (strength, percentage of elongation and stiffness) from pre-immersion to the 14th day after the immersion. All three suture material showed a significant difference in strength, percentage of elongation and stiffness when mean values from baseline (pre-immersion) were compared to the 14th day after the immersion.

Discussion

The key step of surgery is a meticulous wound closure. The main purpose of a wound closure is eradication of dead space, apposition of wound margins to generate a closed secure environment and preservation of tensile strength at the wound margins till the tissue tensile strength becomes satisfactory to bear external load [15]. Previously, materials like animal hair, natural fibers, silk, nylon and gut mucosa were used to seal the surgical sites [16]. A surgeon always desires for better handling characteristics and tensile strength of a suture while choosing appropriate suture material. The tensile strength of a suture material is an essential property that helps suture material to bear the tissue traction at the flap margin [17]. Suture materials manifesting low tensile strength are more liable to break during the healing phase because of pull created by edema and tissue tension.

Suture materials are mainly categorized as absorbable and nonabsorbable, natural and synthetic, braided polyfilament and monofilament fibers [18]. Distinct suture materials bearing the same diameter size may differ significantly in their tensile strength. Most of the reported studies on mechanical properties of sutures are done on skin and subcutaneous tissues [18–20]. In these exploratory studies, sutures were

Table 5

Inter-group comparison of percentage elongation pre- and post-immersion in saliva

Time of immersion	Silk (SL)	Polyglactin 910 (PG)	Polypropylene (PP)	*p*-value (Inter-group)		
	mean ± SD	mean ± SD	mean ± SD	SL vs. PG	SL vs. PP	PG vs. PP
Pre-immersion	4.5 ± 0.54	12.11 ± 1.39	16.78 ± 0.76	0.001***	0.001***	0.001***
Post-immersion in saliva						
3rd day	8.67±0.78	20.78 ± 6.33	17.89 ± 0.82	0.001***	0.001***	0.05**
7th day	13.67 ± 1.87	16.44 ± 2.31	19.22 ± 1.78	0.05**	0.001***	0.05**
14th day	15.95 ± 2.12	18.22 ± 1.44	13.33 ± 1.30	0.05**	0.001***	0.001***

SD – standard deviation.
*******p*-value– significant; ****p*-value – highly significant.**

Table 6

Inter-group comparison of stiffness (in N/mm) pre- and post-immersion in saliva

Time of immersion	Silk (SL)	Polyglactin 910 (PG)	Polypropylene (PP)	*p*-value (Inter-Group)		
	mean ± SD	mean ± SD	mean ± SD	SL vs. PG	SL vs. PP	PG vs. PP
Pre-immersion	1.33 ± 0.22	0.67 ± 0.07	0.68 ± 0.06	0.001***	0.001***	0.657ns
Post-immersion in saliva						
3rd day	0.69 ± 0.07	0.36 ± 0.02	0.63 ± 0.04	0.001***	0.576ns	0.05**
7th day	0.38 ± 0.09	0.42 ± 0.07	0.55 ± 0.05	0.05**	0.001***	0.001***
14th day	0.38 ± 0.12	0.39 ± 0.04	0.68 ± 0.07	0.875ns	0.001***	0.001***

SD – standard deviation.
*******p*-value – significant; ****p*-value – highly significant; ns*p*-value – statistically non-significant.**

Table 7

Intra-group comparisons of tensile strength, percentage of elongation and stiffness of different suture materials from pre-immersion (baseline) to the 14th day

Baseline to the 14th day comparison	Silk (SL)	Polyglactin 910 (PG)	Polypropylene (PP)
Tensile strength	0.001***	0.001***	0.001***
% elongation	0.001***	0.001***	0.001***
Stiffness	0.001***	0.001***	0.001***

***** *p*-value – highly significant.**

exposed to few environmental conditions that can influence physical and mechanical properties of the sutures. Studies associated with oral cavity present a number of difficulties, like the presence of saliva, reflux gastric juice, pressure from the surrounding soft tissues and occlusal forces that can markedly change the properties of suture materials [21, 22].

In the present study the suture gauge designation was fixed at 4–0 in order to help in comparisons of a single gauge of suture. For most of the intraoral surgeries the commonly used gauges are in the range of 3–0 to 4–0, with an increasing number of zeros making the diameter smaller and the suture weaker, confirming that as the diameter decreases the suture becomes weaker. For the current study silk, polygalactin 910 and polypropylene suture materials were used because of their demand in various oral surgical procedures [23]. Sutures were immersed in artificial saliva to be used as a control group as previous studies indicated its possible harmful effect on the mechanical properties of suture materials [24, 25]. To the best of authors' knowledge, it is the first original study that assesses the mechanical properties of different suture materials used intraorally by simulating a natural environment.

All the experiments were done by a single investigator to circumvent any inter-examiner error. The time frame and test frequencies of the present study were in accordance with the clinical relevance of the frequent oral and periodontal surgical procedures. Different studies have found a positive correlation between the reduction in tensile strength and resorption rates of distinct suture materials under controlled experimental conditions [10, 26, 27]. A prime element that can influence the resorption rate of suture materials is the variation in pH of the solution. It has been well documented that a decrease in the pH increases the resorption rate of the sutures [24]. The pH of the current study was kept between 7.4 and 8.1 by checking it regularly for stability and changing the solution every 2 days.

The outcome of the current study exhibits that the PP group manifested maximum tensile strength and percentage elongation in contrast to the PG and SL group, whereas the PP group manifested the lowest stiffness. The elongation capacity of the material is inversely proportional to the stiffness, the stiffer sutures exhibit less elongation. Since no comprehensive study had been done *in vitro* to assess the mechanical properties of the PP suture material compared to the PG and SL in the oral environment, we chose this material in our study design. In one study different gauge of sutures were used to evaluate the mechanical properties of strength, elongation and stiffness of the PP suture material [28]. The test values for 4–0 gauge suture were analogous to the values recorded at baseline (pre-immersion) in the present study.

Earlier studies on the PG sutures exhibited good handling properties, high initial tensile strength, and less tissue reactions during healing [29, 30]. A strong correlation between suture degradation and tensile strength has been described in various studies under controlled *in vitro* and *in vivo* settings. PG degradation *in vivo* is mostly due to proteolytic enzymes. The PG sutures preserved more than two-thirds of their initial tensile strength on the 14th day of the post-immersion period [31]. The results of the present study were similar to this result of previous study. Some studies state that, when PG is immersed in saliva, it shows a fast tensile strength loss, especially after 7 days [10]. This is in contradiction to the findings of the present experimental study.

SL is the most frequently used suture material in the surgical procedures even though it exhibits inferior mechanical properties. Even though SL is said to be a non-resorbable suture but acknowledged to be subject to proteolytic degradation over a longer period [32]. Studies indicate that SL is one of the most vulnerable sutures to the differences in pH conditions [24]. In the present study, it was found that mechanical properties of the SL sutures diminished on the 14th day after the immersion. These outcomes are in accordance with the respites presented by Banche et al. [12] where tensile strength of SL declined upon exposure to saliva.

As the present study design is *in vitro,* it has certain constraints as mentioned below. The outcome of the current experiment may not be completely similar to the oral clinical situations. There are various possible confounding factors, such as diet, habits, occlusal forces and medications in the oral cavity that may affect the oral environment and cause variation in the mechanical properties of sutures. More information can be collected by performing molecular interpretation of the selected suture materials upon their reaction with saliva. However, this was beyond the scope of the current experimental study.

Conclusion

The present study affirms that the suture materials tend to lose a significant amount of tensile strength when exposed to oral environment. The PP sutures showed highest mechanical properties when compared to the PG, and SL suture. Under the limitation of the present study, the authors conclude that PP is the best suture material for wound closure after oral and periodontal surgeries, followed by PG and SL, respectively.

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