A New Coating for Non-resorbable Surgical Suture

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Abstract

Suture is a biomaterial used to approximate wound edges to facilitate the healing process. This task could be compromised as a result of wound infection. Zinc is an element that has antibacterial action and can be a member of silicate glasses. The zinc-silicate glasses can be used as a coating for surgical suture to combat wound infection. However, zinc has a negative effect on glass degradation and its antibacterial action is a pH sensitive. In this work, silicate glasses with ZnO at 14 and 17 mole% were used as a coating for non-resorbable Mersilk suture using a slurry-dipping technique. The coating morphology was studied using SEM and its anti-bacterial action was investigated *in vitro* against gram positive and negative bacteria at neutral and acidic conditions. The effect of the coating on tensile strength of the sutures was studied as well. The results revealed that the coating was well-adhered to the suture and had anti-bacterial action at acidic condition. The coating had no effect on the tensile strength of the surgical suture.

Key words: Suture, zinc, silicate glass, coating **.**

الخلاصة

الخيط هو مادة بايوية تستخدم لتقريب حافات الجروح لتسهيل عملية شفاءها. ان هذه المهمة ممكن ان تتعرقل بسبب التهاب الجرح. الزنك هو عنصر ذو خاصية مضادة للبكتريا ويمكن ان يكون احد مكونات السليكا الزجاجية. مادة السليكا– زنك الزجاجية يمكن ان تكون كغطاء للخيط الجراحي لمعالجة التهاب الجروح. مع ذلك ان الزنك له تاثير سلبي على ذوبان السليكا الزجاجية وان الفعل المضاد للبكتريا يكون حساسا لمعامل الحموضة والقاعدية للوسط . في هذا العمل تم تحضير غطاء للخيط الجراحي من مادة السليكا الزجاجية والتي تحتوي على 14 و17 مول من مادة اوكسيد الزنك وذلك باستخدام طريقة التغطيس بالمحلول. تمت دراسة غطاء الخيط بالمجهر الالكتروني وكذلك التاثير المضاد لهذا الغطاء ضد البكتريا السالبة والموجبة في الوسط المتعادل والحامضي. تاثير الغطاء على قوة شد الخيط قد تم دراستها ايضا. النتائج اشارت الى ان الغطاء كان متجانسا وملتصق جيدا للخيط الجراحي. وان الغطاء كان مضادا للبكتريا في الوسط الحامضي. كما ان الغطاء ليس له تاثير على قوة شد الخيط الجراحي.

الكلمات المفتاحية: الخيط , الزنك , السليكا الزجاجي ,الغطاء .

1.Introduction

Sutures are biomaterials used in oral surgery, Periodontology and Implantology. The main task of surgical suture is to approximate the wound edges and promote the healing process (Dennis *et al*., 2016). However, this task could be compromised by bacterial infection, as these microorganisms impede wound healing. In the normal physiological condition where the tissue pH within 7.4 the balance between the host defense and pathogenic bacteria prevents wound infection. However, when the number of bacteria $>10^5$ CFU/ gram of tissue and their virulence potentates, the host defense is overwhelmed and infection occurs (Kirketerp-Moller *et al.*, 2011). The infecting bacteria change the tissue condition to an acidic state. This is by shifting the tissue metabolism to anaerobic phase due to the use of oxygen and nutrients available for tissue cells; consequently, tissue cells will be deprived of oxygen and further production of lactic acid leads to lowering the tissue pH (Shorrock, 2000). In addition to that, during infection the pathogenic bacteria compete with fibroblast cells and prevent wound recovery (Jones *et al.*, 2015).

Slone and his co-workers stated that most metallic oxides dissolve faster with decreasing pH of the surrounding medium. Furthermore, their study indicated that pH

has an effect on the bioavailability and precipitation of the active metallic ions. Zinc oxide is one of the metallic oxides which exhibited antimicrobial action against gram positive and negative bacteria and fungi (Fiedot *et al.,* 2017). The mechanism by which ZnO have exerted antimicrobial action has been investigated widely in the literature. Studies attributed this action either to cell membrane destructive of Zn ions (Pasquet *et al.,* 2014) or synthesis of intercellular (H_2O_2) or extracellular (OH^- and O_2^{-2}) reactive oxygen species (Li *et al.*, 2012). Zinc oxide is not only has antimicrobial effect, it is found that micro and even a nanoparticles form of zinc oxide are compatible with mammalian cells (Huh and kwon, 2011). Hence, it is logical to develop a coating containing zinc for surgical sutures that has antimicrobial activity and capable of releasing zinc only when required, i.e. during infection and inflammation.

The zinc coating carrier should have specific properties such as excellent chemical durability and controllable degradation to release the active ions in the surrounding environment (Lee *et al,* 2016). Zinc containing glasses are the best choice, since zinc can be a member of glass network and can be released into the surrounding media by the active degradation process of the amorphous nature of the glassy matrix (Esteban-Tegeda et al, 2014). Though, zinc oxide might have a negative impact on the glass network and consequently on glass dissolution especially when used in higher concentration (El-Kady and Ali, 2012).

The antimicrobial activity of glass containing zinc with different composition has been discussed in the literature. Esteban-Tejeda and his coworkers found that zinc containing glasses in the powder form exhibited antimicrobial activity against *E. coli*, *S. aureus* and yeast. Another study demonstrated that these glasses have anti-bacterial effect against *P. aeruginosa* (Baghbani *et al.,* 2013). However, most studies did not take in their consideration the effect of zinc on glass network connectivity and degradation of glasses at different pH conditions. In addition, they investigated the biocide activity of zinc glasses at neutral pH and according to the author's knowledge there was no research explored this action at acidic condition.

In this study, silicate glasses with 14 and 17 mole% zinc oxide was fabricated as a coating for non-resorbable surgical suture. Coating morphology and its antimicrobial activity against gram positive and negative bacteria at neutral and acidic conditions was investigated. The effect of this coating on tensile strength of the surgical suture was studied as well.

2. Materials and methods

2.1 Glass Synthesis:

Zinc-silicate glasses were prepared by melt-quenched technique. The glass ingredients (SiO_2-$CaCO_3$-Na_2CO_3-K_2CO_3-MgO-ZnO) were mixed in a platinum crucible and melted at 1450^o C using an electrical furnace (UK) for one and half hour. The molten mixture was quenched in deionized water and the glass fragment left to dry overnight. Then, the glass fragment was ground using Gyro mill and sieved to obtain particle size less than 45 micron. The same technique was used for synthesis of zinc free glass. The composition of zinc silicate glasses with different zinc concentration and zinc free glass is shown in table 1.

Table 1 Glass composition (mole%)

Glass	SiO_2	CaO	Na_2O	K_2O	MgO	ZnO
Zn14	46.00	14.00	19.00	5.00	2.00	14.00
Zn17	52.00	10.00	18.00	1.00	2.00	17.00
Zn0	52.00	22.00	19.00	5.00	2.00	0.00

2.2 Coating surgical suture

Commercially available non-resorbable Mersilk suture size 3/0 was coated with zinc silicate glass using a slurry dipping technique. The slurry was produced by mixing 1 g of glass powder and 2 ml distilled water and stirred with magnetic stirrer for 15 minutes. The glass slurry was autoclaved at 121^{o} C for 15 minutes. Then , the glass slurry left to settle and a sterilized 1-2 cm Mersilk suture was dipped in the solution for 15 minutes inside the fume hood. The coated sutures were kept in a sterilized Petri dish and left to dry at room temperature. The coated surgical suture was characterized by scanning electron microscopy (SEM).

2.3 Antimicrobial test:

The antimicrobial test of zinc silicate glass coating of surgical suture was investigated *in vitro* against *Staphylococcus aureus*, *Streptococcus mutants*, *Lacto bacillus* and *Escherichia coli* using sensitivity test. The studied bacteria were isolated from dental clinic. The inoculum was prepared by inoculating bacterial colonies to 5 ml brain heart broth and incubated at 37 ^{o} C for 24 hours. Then after, inoculated broth was centrifuged at 2000 rpm for 10 minutes. The supernatant was removed and normal saline was added until the turbidity reached that of 0.5 McFarland standard tube . The bacterial strains were swabbed in Muller Hinton agar plate and the sterilized coated sutures were placed on the surface of the agar plate and incubated for 24 hours at 37^{o} C. The investigation under acidic condition was carried out by adjusting the pH of Muller Hinton agar to pH 5 using hydrochloric acid (0.1N) during media preparation and sterilized at 121 ^{o} C for 15 minutes. After that, the inhibitory zone was measured in millimeter(mm) using a transparent ruler and compared with that of zinc free glass coating which was used as a control. The investigation was carried out three times for each bacterium (CLSI, 2012).

2.4 Tensile strength of the coated sutures:

Tensile strength of the treated sutures with zinc silicate glass was measured using a universal testing machine (China) and compared with non-coated suture. Coated suture of 15 cm in length was fixed between two arms of the machine at a distance of 8 cm and pulled at a speed rate of 1 mm/s till the suture cut off. The test was carried out three times for each sample.

Statistical analysis

One way analysis of variance ANOVA test was used to compare the zone of inhibition (ZOI) of glass coating containing zinc oxide at 14 and 17 mole% and to compare the tensile strength of the coated and non-coated surgical sutures. P value < 0.05 was considered significant statistically.

3. Results and Discussion

3.1 Morphology of the coating

The morphology and characterization of the coated suture were investigated using SEM. Figure 1 shows that zinc-silicate glass coating was homogenous and well-adhered to the surgical suture. Coating thickness appeared to be uniform and there was no discontinuity of the coating can be detected at higher magnification. This is probably because the coating material filled the inter-filaments spaces and not just covered the suture surface.

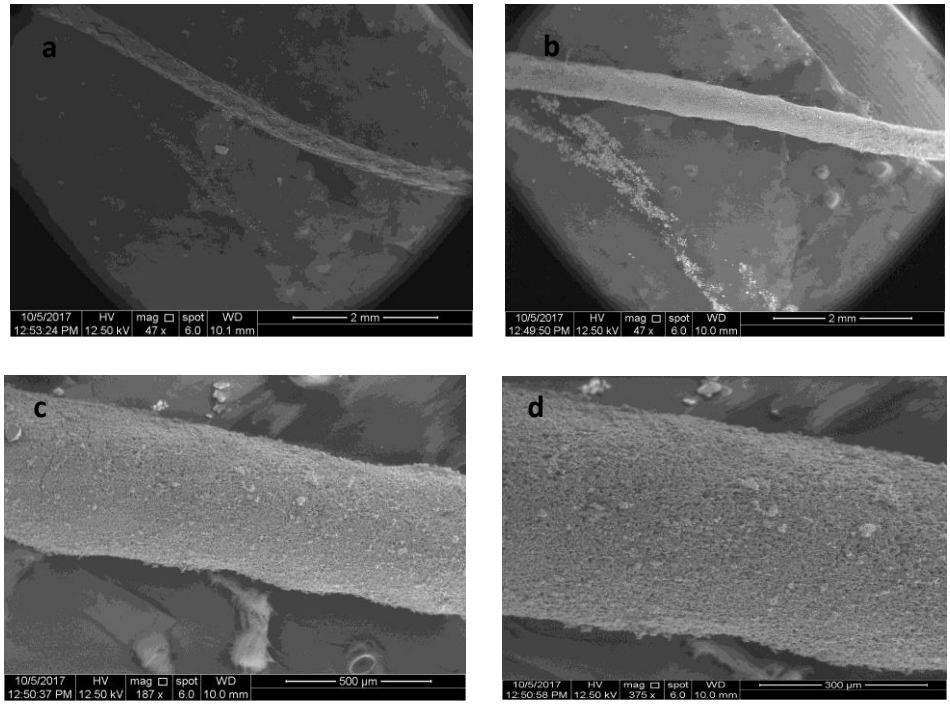

Figure 1 SEM of (a) uncoated suture (b) coated suture and (c&d) coated suture at higher magnification.

3.2 Antimicrobial test:

The antibacterial action of zinc silicate glass coating of surgical suture was investigated against gram positive and negative bacteria *in vitro* at neutral (7.35) and acidic pH 5. This is to test the hypothesis that bioavailability of metal ions increases with decreasing pH level and hence increasing their antimicrobial activity. The pH value at 5 was selected as most bacterial strains can tolerate this acidic level and grow within normal range (Saliani *et.al.*, 2015). The results of this study showed that zinc containing glasses at 14 and 17 mole% were stable and had no effect on studied bacterial strains at neutral pH. At acidic pH, both glass coatings revealed biocide activity against the studied bacteria, as an example shown in figures 2. However, zinc-silicate glass at 17 mole% exhibited higher antibacterial action than that with 14 mole%, as shown in figure 3 . The differences between the action of the former and the later were statistically significant ($p<0.169$).

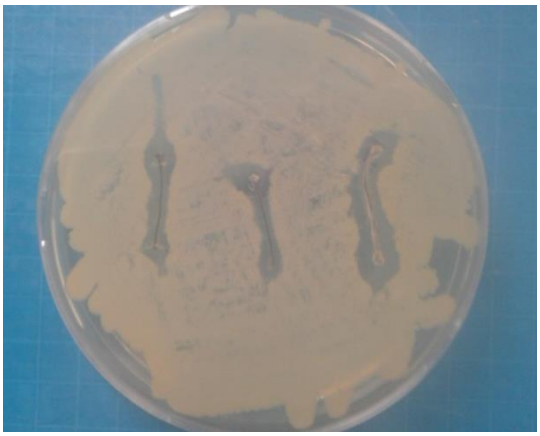

Figure 2 Sensitivity of Staph. aureus to zinc silicate glass coating (14 mole%) at pH=5.

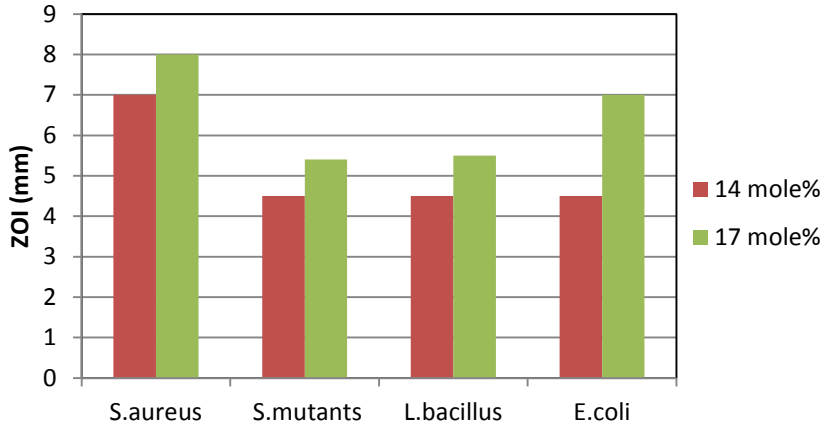

Figure 3 Sensitivity test of gram positive and negative bacteria at pH 5

The inability of these glasses to exert antimicrobial activity at neutral pH could be attributed to the zinc content in the glass composition. It has been stated that zinc increases chemical durability of silicate glasses at higher concentration (>10 mole %), as this ion acts as an intermediate oxide (enter the glass network) and forms Si-O-Zn bond that stabilizes the glass network and decrease glass dissolution (El-Kady and Ali, 2012). Hence, the concentration of the released zinc in the culture media might be insufficient to exert biocide activity at neutral pH. On the other hand, these glasses dissolved in the acidic media as acidity is capable to hydrolyze the Si-O-Zn bonds (Chen et al, 2010) and more zinc ions released in the culture media resulting in higher antimicrobial action. These findings agreed with the ionic dissolution study of zinc-silicate glasses by (Chen *et.al.*, 2010) where only 10 % of zinc ions released in neutral pH compared to 90% of these ions dissolved in acidic pH. Similar finding was observed by the study of Slone et al on silver alginate dressing where the antimicrobial effect of silver ions increased with decreasing pH value to (5.5). The higher antibacterial action of the Zn17 glass coating is assigned to the more concentration of zinc oxide in the glass composition compared to that of Zn14 glass coating. Sutures coated with zinc free glass did not show zone of clearance and this indicated that silicate glass behaved as a carrier and zinc was the active agent, as an example shown in figure 4.

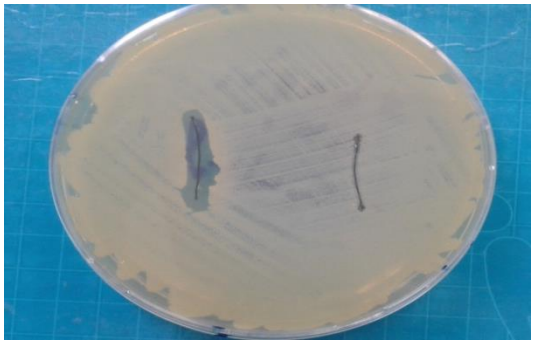

Figure 4 Sensitivity of Staph. aureus to zinc silicate glass coating (17 mole%) and control.

3.3 Tensile strength of the coated sutures

Tensile strength of the surgical suture is very important, as it represents the ability of the suture to withstand the force during performing suture knot. In addition, it is essential to keep the wound edges approximated during the healing process. The results of measuring the tensile strength revealed that the tensile strength of the coated sutures with (Zn14 and Zn17) glasses were slightly lower than that of the non-treated suture (30.7 and 32.7±1.15MPa vs. 34±0.5MPa). These differences could be ascribed to the coating procedure, as the coated sutures were immersed in a slurry for 15 minutes and became wet and then dried at ambient temperature. Therefore, the suture loss part of its tensile strength during this procedure. However, the differences were statistically insignificant ($p< 0.02$) and it seemed that zinc silicate glass coating at both zinc concentrations had no effect on the tensile strength of the original Mersilk surgical suture.

4. Conclusion

Zinc containing glass coating for non-resorbable Mersilk surgical suture appeared to be homogenous and uniform and well-adhered to the surgical suture. The glass coating with ZnO at 14 and 17 mole % exhibited antimicrobial action against gram positive and negative bacteria at acidic condition and had no effect on neutral pH. Tensile strength of the coated sutures was not affected by the glass coating and the difference between the tensile strength of the coated and non-coated sutures was insignificant.

Hence, sutures coated with zinc-silicate glasses can be used in acidic condition as in case of infection and inflammation. These glass coatings reduce the need for using antimicrobial agent for long time and prevent the development of bacterial resistance.

References

Baghbani F., Rzadeh F., Hajibak L. and Mozafari M. , 2013 . Synthesis, characterization and evaluation of bioactivity and antibacterial activity of quaternary glass system (SiO2–CaO–P2O5–MgO–ZnO): In vitro study. Bull. Mater. Sci., 36 (7), Dec.1339–1346.

Chen X., Brauer D., Karpukhina N., Waite R. *et al.*, 2014 . Smart acid degradable zinc releasing silicate glasses. Materials letters, 278-280.

CLSI, 2012 . Performance Standards for Antimicrobial Disk Susceptibility Tests, Approved Standard, 7th ed., CLSI document M02-A11. Clinical and Laboratory Standards Institute, 950 West Valley Road, Suite 2500, Wayne, Pennsylvania 19087, USA .

Dennis C., Sethu S., Nayak S. *et al.*,2016 . Suture materials-current and emerging trends. J. Biomed. Mater. Res. A 104, 1544–1559.

El-Kady A.M., Ali A.F., 2012 . Fabrication and characterization of ZnO modified bioactive glass nanoparticles, Ceram. Int.38, 1195–1204.

Esteban-Tejeda L., Diaz L. A, Prado C. *et al.*,. (2014). Calcium and zinc containing bactericidal class coatings for biomedical metallic substrates. Int. J. Mol. Sci.15, 13030-13044.

Fiedot M., Maliszewska I., Rac-Rumijowska O. *et al.*, 2017 . The relationship between the mechanism of zinc oxide crystallization and its antimicrobial properties for the surface modification of surgical meshes. Materials, 10(353).

Huh, A.; Kwon, Y. ,2011 . "Nanoantibiotics": A new paradigm for treating infectious diseases using nanomaterials in the antibiotics resistant era. J. Control. Release, 156, 128–145.

Jiang, P.; Zhou, J.J.; Fang, H.F.; Wang, C.Y.; Wang, Z.L.; Xie, S.S. 2007. Hierarchical shelled ZnO structures made of bunched nanowire arrays. Adv. Funct. Mater. 17, 1303–1310.

Jones E., Cochrane C., Percival S., 2015 . The effect of pH on the extracellular matrix and biofilms. Advances in wound care. Jul. 4(7):431-439.

Kirketerp-Moller K., Zulkowski K., James G., 2011 .Chronic wound colonization, infection, and biofilms. In: Høiby N, Jensen PØ, Moser C, Høiby N, editors. Biofilm Infections. New York: Springer; 11–24.

Lee S., Uehara H., Macon L. B *et al.*,2016 . Preparation of antibacterial ZnO-CaO-P2O5-Nb2O5 invert glasses materials transactions, Vol. 57, No. 12 . 2072 – 2076.

Li Y., Zhang,W., Niu, J., Chen, Y.,2012 . Mechanism of photogenerated reactive oxygen species and correlation with the antibacterial properties of engineered metal-oxide nanoparticles. ACS Nano, 6, 5164–5173.

Marzo G., Loffredi R., Marchetti R., Dimartino S. *et.al.*, 2008 . In vitro antibacterial efficacy of vicryl plus suture (coated polyglactin 910 with triclosan) using zone of inhibition assays. Oral Implantology - Anno I - N. 1.

Mingmalairak C., 2011, "Antimicrobial Sutures: New Strategy in Surgical Site Infections," pp. 313–323.

Pasquet J.; Chevalier, Y.; Pelletier, J.; Couval, E.; Bouvier, D.; Bolzinger, M.A, 2014. The contribution of zinc ions to the antimicrobial activity of zinc oxide. Colloids Surf. A Physicochem. Eng. Asp.457, 263–274.

Ricco J.-B. and Assadian O., 2011, "Antimicrobial silver grafts for prevention and treatment of vascular graft infection.," Semin. Vasc. Surg., vol. 24, no. 4, pp. 234–41, Dec.

Salem W., Leitner D R., Zingle F G., *et.al.*,2015 . Antibacterial activity of silver and zinc nanoparticles against Vibrio cholerae and enterotoxic Escherichia coli. Int J Med Microbiol. Jan; 305(1): 85–95.

Saliani M., Jalal R., Goharshadi E., 2015. Effects of pH and Temperature on Antibacterial Activity of Zinc Oxide Nanofluid Against Escherichia coli O157: H7 and Staphylococcus aureus. Jundishapure journal microbiology. Feb, 8(2).

Shorrock S., 2000 . The Exploration of Tissue pH in Wounds and its Relationship to Bacterial Contamination. A master thesis in biomedical engineering. Worcester Polytechnic institute.

Slone W., Linton S., Okel T., *et al.*, 2010. The Effect of pH on the antimicrobial efficiency of silver alginate on chronic wound isolates. Journal of the American College of Certified Wound Specialists. 2, 86–90.