Reviewing Materials Modification Techniques to Enhance the Durability of Surgical Scissors

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ABSTRACT. Around 22-33% of medical waste is contributed to the disposal of surgical tools. With over 310 million surgeries carried out annually, the burden of surgical tool waste becomes critical in terms of cost and effort in approaching zero net waste. Among the most common surgical waste is surgical scissors, often disposed of due to corroded surface, fracture, or loss of functionality. Since surgical scissors play such a major role in dissecting various organs, the reduced quality results in bleeding, uneven cutting, and contusion and enhances the risk of site infection. One way to reduce the amount of surgical waste is by enhancing durability achieved by applying surface modifications, such as coating. This paper reviews three surface modification approaches for surgical scissors coating, namely (1) anodized coating, (2) thin metallic glasses, and (3) chemical vapor deposition. Some experimental data from the reported studies were summarized to assess the potential methods to enhance surgical scissors' durability and reduce medical waste.

Keywords: surgical scissors; durability; medical waste; CVD, thin metallic glasses. Anodized aluminum.

1. INTRODUCTION

The World Health Organization (WHO) data in 2023 reflected that the number of performed surgical procedures worldwide annually is 310 million [1, 2]. Among the tools to create incisions in surgery are scalpels, scissors, blades, puncture needles, and drill bits [3]. However, the scalpel plays a less significant role and is limitedly intended to create a skin incision [4]. Scissors play a more crucial role in the dissection of superficial or deeper organ tissue [4]. The most common materials used for surgical scissors are anodized medical grade stainless steel SS316L, SS304, martensitic AISI 420, and tungsten carbide.

There are currently over 2000 types of commercial medical scissors, most of which are reusable [4]. Among the surgical scissors are Mayo scissors, which are used to cut sutures, ligaments, and tendons. The more specific scissors are used to cut delicate and fragile tissues, i.e., Periosteum, which is named Metzenbaum scissors. The surgical scissors specifically intended for eyes/ophthalmic use are iris scissors.

The highest standard for surgical scissors used in surgery is with the diamond tip, which costs around 200-600 USD, and Titanium scissors, which cost around 250-1000 USD [5]. The expensive production costs hinder the use of high-quality scissors, especially in third-world countries, which have a much higher annual number of procedures. The expensive scissors are limited in high-precision surgery such as eye and coronary microsurgery [5].

Surgical scissors are designed for different purposes, such as single-use or reusable. After only three procedures and exposure to heat and steam during autoclave sterilization [6], stainless steel or carbon steel scissors tend to be impaired, which often relates to the wear of metallic surfaces [7]. The blunt surgical tools cause the surgeons, especially the less experienced ones, to put more force, which could lead to non-precise cuts [8], biological damage [3], bleeding [6], contusion, and tissue deformation. White et al. stated that there are correlations between the sharpness of surgical cutting tools and post-surgery infections [9]. Mechanically degraded surgical tools might have contributed to the production of contaminants in the surgical sites [9].

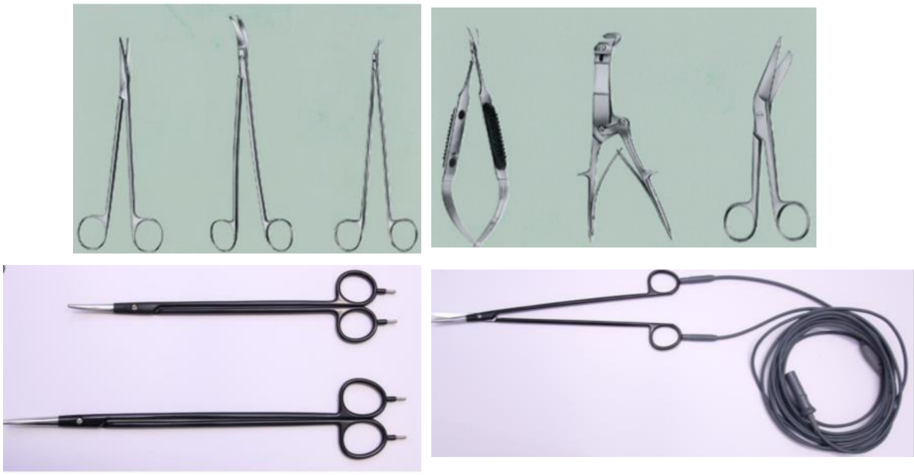


Figure 1 (a.) Metzenbaum scissors are characterized by long shanks and short, curvy blades (b.) Other types of Metzenbaum scissors used in orthopedic and gynecology surgery (c.) Scissor designed to cut blood vessels (d.) The specialized micro-scissors intended for neurosurgery, (e.) the scissors used for ribs, (f.) scissors for cutting bandages, (g.) another variant of Metzenbaum electric scissors, (h.) Metzenbaum electric scissors when connected to cables. The electrical scissors applied a small electrical current to coagulate the dissected tissue and prevent excessive bleeding. Adapted with permission from [4].

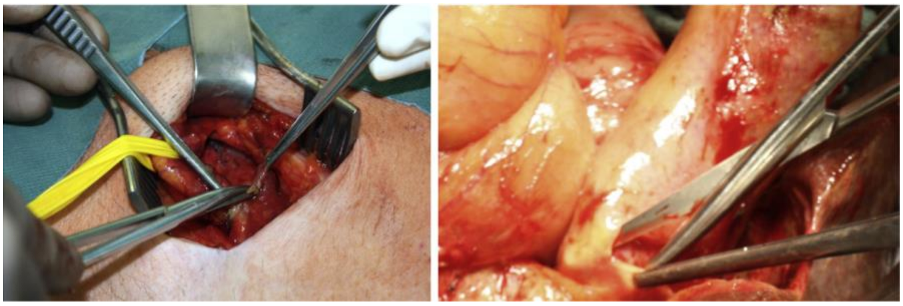


Figure 2. Metzenbaum scissors when used to cut fragile tissues. Adapted with permission from [4].

Figure 3. Stainless steel surgical scissors waste was collected from three hospitals in the Netherlands during five months and reached 1380 Kg. Adapted with permission from [10]

Among the carried-out attempts to maintain the sharpness of scissors are coating the surface with hard films, applying electromagnetic treatment, and designing the alternative geometry of the blade [7]. This paper aims to identify and review various available coating techniques to prolong the life of surgical scissors, ensuring the durability and cost-effectiveness of cutting surgical tools.

Furthermore, data showed that 22-33% of medical waste is generated by surgery, attributed to the single use of medical devices. One study collected stainless steel surgical tools from three hospitals in the Netherlands from September 2018 to 12 February 2019 [10]. The researchers collected 1380 Kg of surgical instrument waste [10]. This is clear evidence of how much waste is produced from surgical tools. Therefore, the second aim of this paper is to reduce the medical waste attributed to single-use scissors to approach the zero net waste targets in hospitals.

2. LITERATURE REVIEW

2.1 The influence of cleaning procedures on mechanical properties

The WHO stated that the remaining protein or blood on the surgical tools will enable microorganisms to access the surgical sites of the new patients [11]. One of the most severe concerns in any surgical instrument is biofilm formation. Biofilm is a thin polysaccharide-based layer secreted by microorganisms and formed when blood or body fluid has dried on the metallic surface [12]. Biofilm is hard to remove later. Hence, scrub personnel must remove it early [12]. Another concern is that the deposition of bodily fluid on the metallic surface will quickly induce pitting corrosion on the stainless-steel surface.

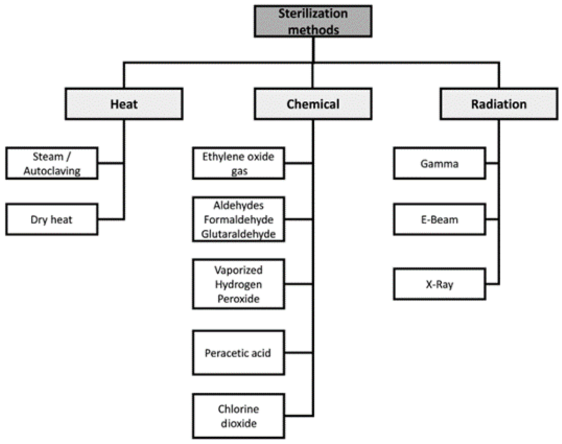
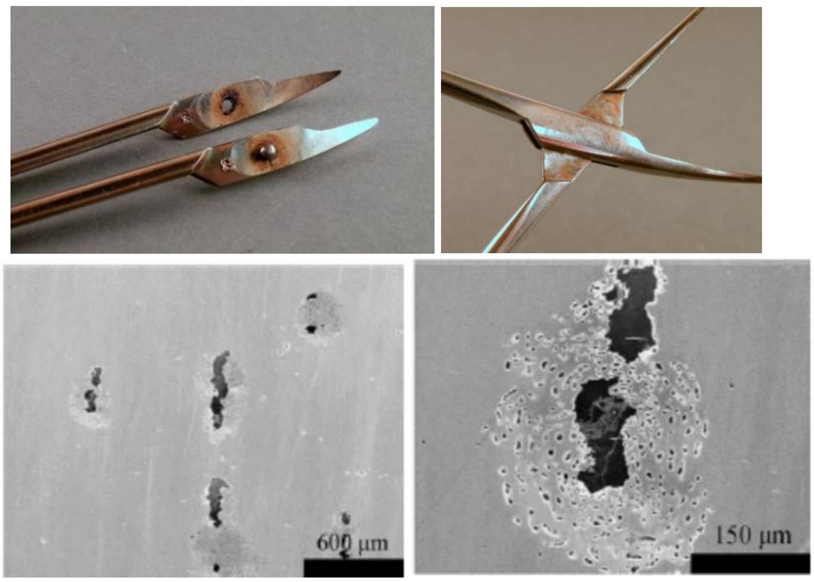


Figure 4. Various sterilization procedures of medical devices. Adapted with permission from [13]

The sterilization procedures for medical devices can be classified into (1) heat, (2) chemical, and (3) radiation cleaning, as visualized in Figure 3 [13]. Heat sterilization utilizes high-temperature and pressure steam sterilizers called autoclaves. The applied temperature for the autoclave is 121℃ -134℃, carried out from 10 to 60 minutes [13]. Moist heat can instantly kill microorganisms by denaturation of its protein structure [13]. Nevertheless, some studies indicate biofilm can



Figures 5 (a.) Various corrosion on the surgical scissors' hinges and pivot joints attributed to crevice corrosion due to entrapped electrolytes in small gaps, pitting corrosion due to the presence of chloride (Cl-) ions in bodily fluid or cleaning solution, and fretting corrosion due to constant friction in a wet environment. Adapted from the collection of Suntorp innovation. (b) Scanning electron microscope (SEM) images of nitinol (NiTi) surgical instruments after autoclave processing. Moisture and temperature in autoclaves are two aggravating factors to corrosion. Adapted with permission from [17].

survive repeated autoclave procedures [14]. In terms of its effect on the quality of surgical tools, previous studies demonstrated that autoclave causes temper shifts, corrosion, changes in hardness, and cutting functionality loss [15]. Corrosion can be prevented using corrosion inhibitors such as 2% sodium nitrite [15]. However, in many cases, corrosion, and the loss of cutting functionality are somewhat unavoidable. The stainless-steel instruments lost their cutting ability only after the fifth cycle of autoclave cleaning [15]. Furthermore, chemical cleaning enhances risks of deposited residual on the joint surface, making the joint surfaces susceptible to crevice corrosion. Based on the considerations, there are three different corrosion mechanisms on the surgical scissors' joints. (1) Crevice corrosion due to entrapped electrolytes in small gaps. (2) Pitting corrosion occurs due to the presence of chloride ions in bodily fluid or cleaning solution. (3) Fretting corrosion due to constant friction in a wet environment.

2.2 Materials modifications to ensure more extended durability of surgical scissors.

The approaches to prolong the functional use of surgical scissors can be made through surface modifications during manufacturing. The most common procedure is anodized aluminum. Among the reported new potential approaches for metallic glass thin coating is using zirconium (Zr) and iron (Fe)-metallic glass [18]. Other methods used are atomic layer deposition (ALD) [21]. The details of each approach will be summarized in the following subsections.

2.2.1 Anodized coating

Anodized aluminum is the most widely accepted coating method for various medical devices. It is carried out by growing an anodic layer using an electrochemistry approach. The focus of anodized aluminum is not on enhancing hardness and sharpness. Instead, the layer protects against moisture and corrosion [22]. Anodized aluminum has some advantages, such as being lightweight and drying quickly after cleaning. However, it has been reported that the anodized coating layer can be delaminated easily in the presence of more harsh detergent and repeated cleaning cycles [22]. There have been attempts to produce better-anodized coating for medical devices, but this has not resulted in a better standardized anodized coating. Therefore, studies have been shifted to identify more suitable coating methods, as explained in the subsequent sections.

2.2.2 Thin film metallic glass

Chu et al. [18] introduced radio frequency (RF) sputtering (234-255 nm)- of Zr and Fe named thin film metallic glass (TFMG) on dermatome blades. The reported atomic composition was $Zr_{53}Cu_{33}Al_{9}Ta_{5}$ denoted as Zr-TFMG, and $Fe_{65}Ti_{13}Co_{8}Ni_{7}B_{6}Nb_{1}$ denoted as Fe-TFMG [18]. There were reports [23, 24] that Zr blade coating could enhance sharpness and ensure smooth cuts for coated surgical blades. Moreover, TFMG enhances surface hardness and bacterial resistance

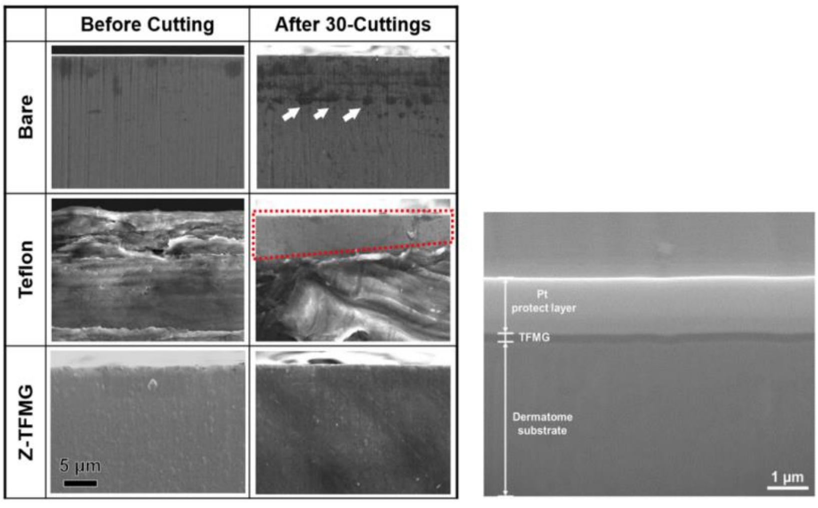
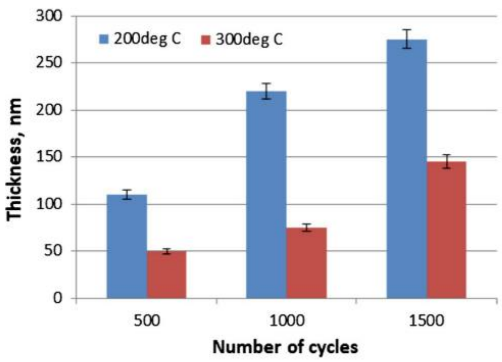


Figure 6. The damaged surface of the bare dermatome blade compared to the surface with deposited Teflon and thin film metallic glass (Z-TFMG). The Z-TFMG shows no damage after 30 cuttings. Adapted with permission from [18]



Surface modification		Wetting angle $\theta°$	STD
Temp, °C	Cycles		
Initial state		81	±2.5
200	500	112	±3.4
	1000	107	±0.6
	1500	104	±2.3
300	500	109	±2.2
	1000	106	±0.9
	1500	109	±1.8

Figure 7 indicates (a.) the thickness of ZnO deposition during three types of cycles, 500, 1000, and 1500, and two temperatures, 200℃ and 300 ℃. The higher temperature and the highest number of cycles produced the thickest coating. (b.) The wetting angle indicates the hydrophobicity of the coating. Similarly, the higher temperature and the highest number of cycles resulted in the most hydrophobic surface, shown by the highest contact angle. Adapted with permission from [28]

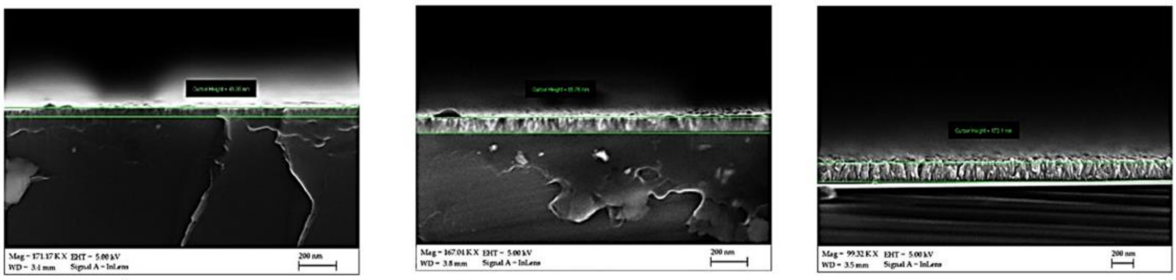


Figure 8. a. The coating of ZnO on metallic substrate deposited after (a.) 500 deposition cycles, (b.) 1000 deposition cycles, and (c.) 1500 deposition cycles. Adapted with permission from [21]

[23, 24]. Another study by Chu et al. highlighted how the TFMG needle reduced the fracture toughness in the pierced rubber and porcine tissues [25]. Furthermore, the TFMG-coated needle measured piercing area was 44% less than the bare needle, demonstrating less damage to both rubber and tissue [25]. In terms of enhanced sharpness, Zr-TFMG showed an increase of up to 27% compared to its bare counterparts [24]. When tested to perform 30 cuttings on porcine skin, Zr-TFMG and Fe-TFMG showed relatively undeformed shapes compared to bare and Teflon-coated dermatome, as shown in Figure 6.

2.2.3 Physical vapor deposition (PVD) and chemical vapor deposition (CVD)

Chemical vapor deposition (CVD) is a vacuum deposition method that deposits hard and thin coating surfaces. These methods have been known for many years to reduce wear and improve the life of medical devices. Among the materials used for CVD coating is diamond-like carbon (DLC) [26]. DLC is the cheaper alternative to diamond scalpel [5]. DLC has been demonstrated to reduce 100% of wear when coated on the metal interface, enhancing durability [27]. Moreover, DLC was proven to have antibacterial properties with less adherence to staphylococci bacteria than uncoated metallic surfaces [27].

Another variation of CVD enabling the deposit of nano-thin metallic oxides and nitride with strong adhesion and temperature up to 500℃ is atomic layer deposition (ALD) [21, 28]. ALD consists of many cycles, with each thin layer deposited in each cycle. Among the first works reporting the coating of ZnO on SS316LVM was by Basiaga et al. [28]. They measured the thickness and hydrophobicity indicated by contact angle measurement in various cycles of depositions at two different temperatures. The results are shown in Figure 7.

Szindler et al. [21] followed the earlier study and investigated ALD using ceramic coating Zinc oxide (ZnO) on 316LVM steel substrate. They examined the influence of applied cycles on the adhesion of the coating, as shown in Figure 8. The SEM and further Raman examinations indicated that the highest number of cycles applied (~1500) showed the best adhesion with uniformly elongated atoms [21]. The study positively stated the influence of ZnO in improving the blades' corrosion resistance, scratch resistance, and surface hardness [21].

3. CONCLUSION

Many surgical tools are discarded after a single or few uses due to corrosion and the loss of functionality. Medical device waste is a huge issue nowadays, with surgical instruments contributing 22%-33% of total waste. With such a huge burden in reprocessing and recycling, the increase in durability is critically beneficial. Sterilization is the standard procedure to ensure safety in reusable surgical instruments, including scissors. However, sterilizations have been proven to alter the mechanical properties, including reduced hardness, wear, corrosion, and loss of sharpness. Among the approaches to increase surgical scissors' durability is surface coating, which can be done through various methods, including thin film metallic glass coating, chemically vapored deposition, and anodized surface. However, the cost and ease of processing must be considered to ensure whether this approach is more cost-effective and environmentally friendly than reprocessing and recycling by melting the metals. To assess and quantify the effectiveness approaches such as Life Cycle Assessment (LCA) and Materials Flow Analysis (MFA) can be considered for future study.

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