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Tribological Characteristics of Dental Crowns

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Abstract

Dental tribology is an emerging field that focuses on improving the design and material choices for artificial dental systems. This paper looks at different dental crown materials, their clinical efficacy and the consequences of tribological wear on teeth due to interfacial movement. Ceramics are commonly utilized in fixed dental restorations because of their superior mechanical and cosmetic qualities, which include exceptional fracture resistance and clinical endurance. Ceramic crowns, often used to restore teeth, are preferred for their excellent mechanical strength, biocompatibility, and aesthetic appeal. Despite several advantages, they remain vulnerable to tribological wear and stress fractures that can affect their long-term performance. CAD/CAM technology advancements have significantly improved the accuracy and fit of these restorations, resulting in better clinical outcomes. However, more study is needed to completely understand the function of fatigue fractures in tribological wear and to assess the long-term durability of ceramic crowns in a variety of oral settings. Improved understanding of friction-wear behaviors and damage mechanisms will aid in the development of crowns that can survive the complex stresses of the oral cavity, resulting in longer-lasting and more effective dental restoration. This ongoing work on tribological damage will be critical to optimizing materials and processes in restorative dentistry, resulting in better patient results.

Keywords: Dental crowns, Ceramic crowns, restoration, restorative dentistry, tribological wear.

INTRODUCTION

Tribo-corrosion is an overlap of the field of tribology and corrosion. It is the wearing of the material due to the corrosion and wear processes that take place during the operation of mechanical and chemical systems. "The progressive loss of substance resulting from mechanical interaction between two contacting surfaces, which are in relative motion" is how the Institution of Mechanical Engineers defines wear [1].

Tribology, or the study of friction, wear and lubrication, is very important in dental crowns because it has a direct impact on the evaluation of performance, durability and patient satisfaction. During chewing, plastic comes into contact with the back teeth and this friction affects digestion. Dental records are available for areas in the mouth where there is a change in pH, temperature and salivary enzymes. This can cause cytotoxicity, allergic reactions or plastic failure. These standards emphasize the importance of tribological considerations in material selection, which improves plastic durability, comfort, aesthetics and cost-effectiveness, ultimately providing better patient outcomes. Figure 1 gives the anatomy of tooth showing how the crown part is in direct contact with the gums and henceforth the nerves and blood vessels. Biocompatibility hence becomes an important feature of the denta restorations.

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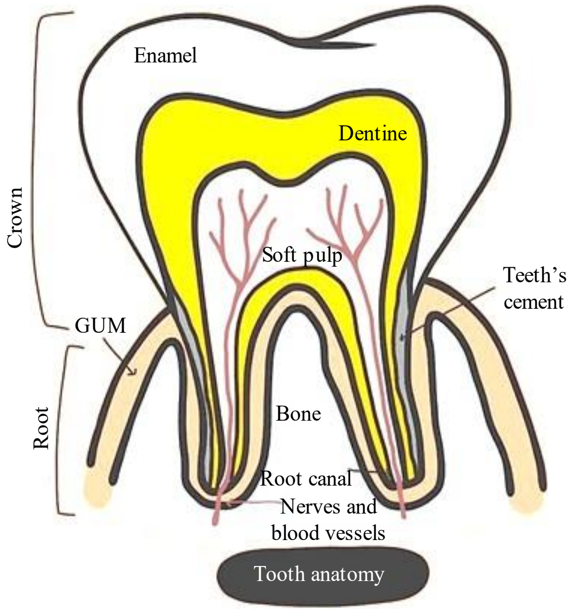

Figure 1. Anatomy of Tooth [24].

In this study, mechanical properties, surface roughness and topography of restoration materials have governed the tribological interactions between enamel and dental restorations. The surface finishing on wear and friction performance of dental crowns can be attributed to the fact that finish alone determines the surface complete finish of these crowns. A review of such findings suggest that enamel and polished restorations result in a lower friction coefficient than the rough restorations. However, the environmental factors can also be taken [2].

Wear maps have been studied several times [3], some of which have tried to depict how they can be used as a reference, in order to make forecasts on wear in dental implants. According to Wang in this regard, the natural extension of the same study by et al. is the analysis of the loss of volume conducted in 2018 [4].

On the increase in load, the material loss; increased as the presence of corrosion in a direct relationship with the applied load can be stated as the underlying dependence observed in the target model. This is easily seen by observing the potential profile with reference to the load which is as follows: that the higher the load, the lower the potential, and the higher the corrosive wear. The static condition is characterized by a higher static friction coefficient and, consequently, the greater the static time, the greater the corrosive wear.

MATERIAL BIO-COMPATIBILITY

Criteria for Selecting Crown Materials for the Study

A dental crown is a metallic or polymeric cap used to cover or restore broken or damaged teeth, as depicted in Figure 2. Selection of crown material is one of the crucial decisions for patients as well as the dentist. Therefore, they detail material property, performance and this shows that there is a need to prepare a requirement chart. The relationship between the dentists or the clinical person and the patient must be simple for real, efficient, and sustainable lasting dental restoration. In dental crown components, the mechanical, thermal and biocompatibility characteristics of several material combinations are compiled in Table 1.

Clinical needs assessment: Determine which clinical issues or gaps—such as greater biocompatibility, improved aestheticsor enhanced wear resistance—the new material is intended to fill in the present dental materials.

Figure 2. Dental Crown [25].

Material Properties: Outline the new material's intended mechanical, physical, and chemical characteristics. Hardness, flexural strength, fracture toughness, wear resistance, and aesthetic attributes.

Formulation: Create the material composition considering the basic material (coal, metal alloys, polymers, etc.) and any fillers or additions that improve performance (coal, glass fibres for strength, pigments for colour, etc.).

Prototype Development: Prepare tiny amounts of the novel substance for preliminary examination. Depending on the kind of material, this stage may entail a variety of chemical processes including sintering or polymerization.

Table 1. Material Properties and Biocompatibility for Dental Crown Components [6-9].

Material Combination	Component	Tensile/Flexural Strength (MPa)	Fracture Toughness (MPa·m^0.5)	Young's Modulus (GPa)	Thermal Conductivity (W/m·K)	Biocompatibility
1. Titanium/ Zirconia/ Poly-urethane	Inner Core (Titanium)	900	10	110	-	Excellent
	Outer Layer (Zirconia)	900	10	110	2.5	High
	Adhesive Layer (Poly-urethane)	20	-	1.5	-	Moderate
2. Cobalt-Chromium Alloy/ Alumina/ Epoxy	Inner Core (Cobalt Chromium Alloy)	600	4.5	210	-	Good
	Outer Layer (Alumina)	300	4.5	25	25	Excellent
	Adhesive Layer (Epoxy)	30	-	3.5	-	Moderate
3. Stainless Steel/Glass Ceramic/ Acrylic	Inner Core (Stainless Steel)	520	1.0	200	-	Good
	Outer Layer (Glass Ceramic)	200	1.0	50	1.5	Excellent
	Adhesive Layer (Acrylic)	20	-	2.5	-	Moderate

Comparative Overview of Ceramics, Metals, and Plastics

Ceramics (Dental Porcelains)

Dental ceramics closely mimic natural teeth, providing excellent clarity and aesthetic appeal. Porcelain and lithium disilicate are examples of such materials. These ceramics offer superior biocompatibility, resistance to staining, and robustness against wear and fracture, respectively. However, porcelain crowns are particularly susceptible to chipping or breaking under extreme pressure. Additionally, ceramic materials can be expensive and require advanced manufacturing techniques, making repairs and adjustments more difficult. (Van Sterkenburg et al., 2019) (Van Lienden et al., 2021) (Shaw et al., 2023) (Egbert et al., 2022) (Van Sterkenburg et al., 2021) (Peguero & Williams, 2011) (Rhodes et al., 2022) (van Sterkenburg, 2011) (Murji & Solomos, 2014) (Kivisto & Croll, 2012). Due to their exceptional aesthetic and structural properties, ceramics are frequently employed in the fabrication of crowns and bridges for both front and back teeth. They are also ideal for creating veneers, inlays, and onlays [7, 8].

Metals

Since metals are rigid they can withstand chewing pressures. This is due to the features they possess which makes them extremely strong and hard wearing. For example, those made of gold and dental alloys. They are suitable because they are biocompatible and typically have a long lifespan, making them suitable for even long-term spinal implants used for spinal cord restoration. Sections of the mouth prefer metals less as compared to other material categories which are transparent; they are not seen as the same as other types of aesthetic appeal as ceramics. Furthermore, there is a minimal probability of bonafide allergic reactions to some alloys.

Food prices and other essentials such as rubber and precious metals for example gold can be very expensive. In the case of posterior restorations, metalized restorations rated higher than those made of porcelain-fused to metal crown and bridge are usually put to use. It therefore covers products that are more sturdy and less concerning with the appearance.

Plastics

In dental applications, plastic materials like acrylic resins provide a number of benefits. When compared to metals and ceramics, they are more economical because of their cost-effectiveness. Their adaptability makes it simple to shape, change, and repair them, giving dentists freedom in their choice of dental procedures. Furthermore, many patients find acrylic resins to be pleasant and lightweight. Plastics do, however, have certain disadvantages, such as less durability and a propensity to deteriorate or change colour over time. They also need more regular upkeep and are more likely to discolour. Plastics are less suited for high-stress locations because of their low strength. In clinical settings, they are frequently used in dentures, especially for fake teeth and denture bases, as well as in minor applications like dental fillings and temporary restorations like crowns and bridges.

TRIBOLOGICAL FINDINGS

Friction & wear

Researchers investigated the ways that natural tooth enamel and dental ceramics interacted with one another and with abrasion patterns. The different types of dental ceramics that were used in the study: glass ceramics, zirconia in all its forms, porcelain, and lithium disilicate. Their uses demonstrated both the present benefits and the obstacles that still need to be addressed. Achieving a balance between superior cosmetic finishing and strong mechanical qualities is still a challenge but is also necessary in order to replicate the optical characteristics of real teeth [22]. Other tribological tests were conducted in environments that replicated artificial saliva lubrication, found that saliva is one biological component that may have a significant role in wearing of tooth enamel [23]. Human teeth that had recently been unearthed as well as samples with varying surface roughness were used in the experiments [5].

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The wear experiments were conducted in a reciprocating ball-on-plate tribometer at 37°C with artificial saliva to simulate oral circumstances and alumina balls as antagonists. The friction coefficient (COF) and specific wear rate were calculated, and dominant wear processes were identified using SEM/EDS tests. Zirconia had the strongest wear resistance, with an average specific wear rate of 1.63E-07 mm3.

The result of N−1 m−1 differed greatly from other materials. Composite materials demonstrated the lowest wear resistance (k = 1.24E-05 mm3 N−1 m−1). The study found that ceramics' wear behavior is influenced by their optical qualities, which may be linked to changes in their crystal structure.

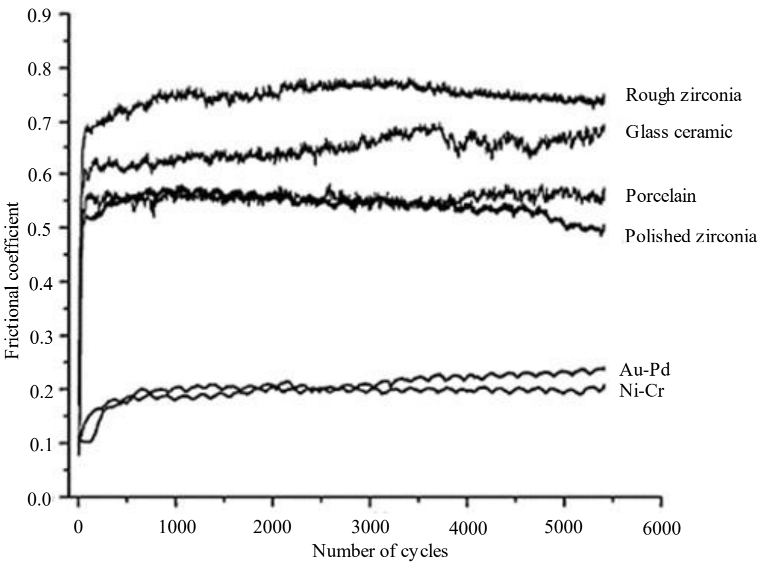

Figure 3. Different materials with their frictional coefficient vs number of cycles [28].

SEM was employed in investigating surfaces of damaged tooth enamel and topography of antagonists. By comparison, between nickel-chromium or gold palladium combinations, enamel has practically the least frictional coefficient. CoF of the enamel on the zirconia/porcelain was found between the CoF of metal & the glass-ceramics. After the surface cleaning the values of coefficient of friction between zirconia and enamel significantly reduced. Figure 3 gives the wear rates of 0.08 to 0.14 micrometers per year; furrows and granular debris were noted as the enamel surfaces of the antagonist teeth wore against the rough GC or zirconia substrate. This kind of fatigue wear was suggested by peeling and fracturing on the enamel surface while sliding against polished zirconia or nickel-chromium alloy, as well as by the existence of flake and pit-like structure.

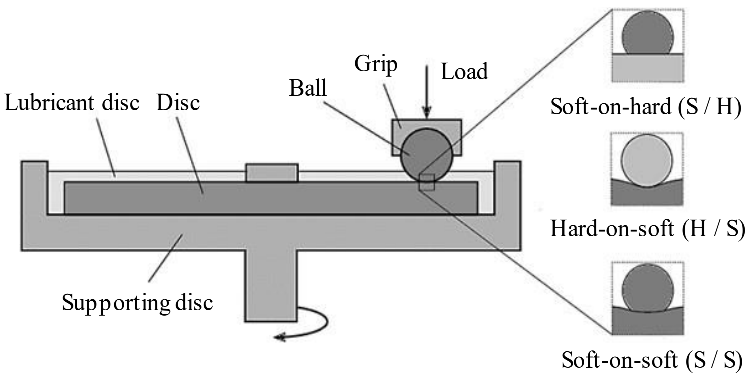

Figure 4. Four-ball tribological test setup [26].

From the results of wear and friction, it can be inferred that by appropriate surface polish on zirconia may significantly enhance its wear and friction characteristics. This finding reflects the reality that in practical practice, appropriate considerations should be paid for the construction of designs for ideal occlusal surfaces and the choices of dental materials [5].

Nowadays, the most used wear model for figuring out sliding wear is Archard's wear model. For a given sliding distance on the disc (S), the volume removed (V) is found to be inversely proportional to the hardness (H) of the softer material and to the normal load imposed on top of the pin during the experiment (F).

$k * \frac{K}{H} = \frac{V}{S}$, where V is the pasteurization rate, S stands for microorganism survival rate, k is Temperature of pasteurization, F= Temperature of food, H = Time.

The spinning ball-on-three-flat tribometer configuration in tetrahedral geometry was applied to the tribological surface contacts of test specimens consisting of a single substance, as shown in Figure 4. When looking at wear rates determined for a number of ceramic-based dental materials with a hard, smooth antagonist, zirconias prove to be the least abrasive, and lithium disilicate as the most abrasive by force.

i. The volume of wear is directly related to the sliding distance in the steady state region in compliance with Archard's model.
ii. Detachment debris of material at specific wear tracks: At low magnification, it is least visible in the zirconia but becomes more evident in the LDIS;
iii. At high magnification, it is most apparent in LDIS while absent in zirconia. The nature of the debris is defined in the micro structural level of the material that is in the composite [10].

The wear experiments were conducted in a reciprocating ball-on-plate tribometer at 37 °C with artificial saliva to simulate oral circumstances and alumina balls as antagonists. The friction coefficient (COF) and specific wear rate were calculated, and dominant wear processes were identified using SEM/EDS tests. Zirconia had the strongest wear resistance, with an average specific wear rate of $k = 1.63 * 10^{-7}\ mm^3N^{-1}m^{-1}$.

Table 2. Tribological and mechanical properties of dental restorative materials [29].

Material	**Specific Wear Rate (k) (mm³/N·m)**	**Hardness (GPa)**
Zirconia	$3 * 10^{-6}$	17.8 ± 4.06
Feldspathic Porcelain T	$5.5 * 10^{-5}$	6.33 ± 0.73
Feldspathic Porcelain O	$5.5 - 10^{-5}$	6.15 ± 0.46
Polymer	$10^{-8}\ to\ 10^{-6}$	0.26 ± 0.01
Composite	$1 * 10^{-4} to\ 2 * 10^{-4}$	0.96 ± 0.04

The result of N−1 m−1 differed greatly from other materials. Composite materials demonstrated the lowest wear resistance ($k = 1.24 * 10^{-5}\ mm^3N^{-1}m^{-1}$). The study found that ceramics' wear behavior is influenced by their optical qualities, which may be linked to changes in their crystal structure. The conclusions drawn regarding the wearing characteristics of different dental restorative materials from the studies so far are represented in Table 2.

Corrosion

Corrosion is the deterioration of the metal that occurs through an electrochemical reaction in which the metal is attacked by the fluids in its micro-environment and subsequently releases ions into that environment [11].

A layer of dioxide; TiO_2 or ZrO^2 covers the surface of titanium and zirconium implants. This layer reduces activity of the biological media and to some extent hinders corrosion by offering a shield in between the implant and biological medium. It is also charged with biocompatibility.

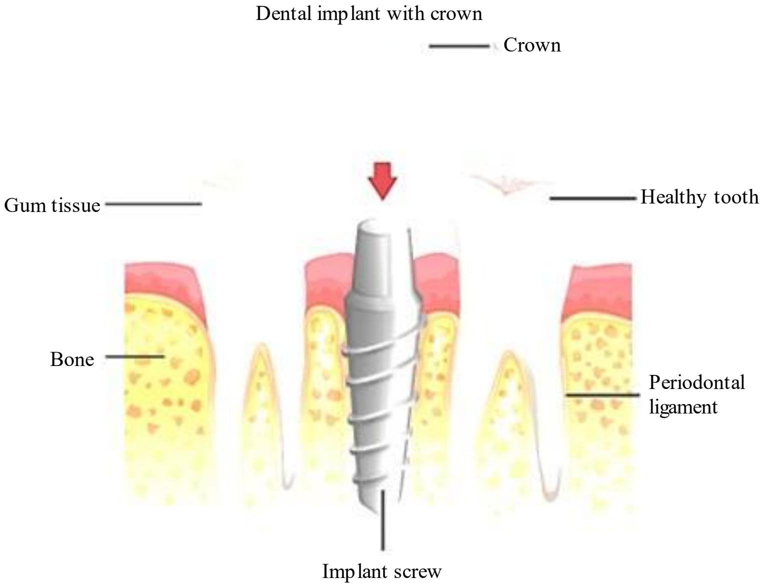

Figure 5. Tooth Implant [27].

Patients who use prosthesis (dental implants, plates and screws for fractures, metal plates for large-scale restoration) may have metal structure corrosion if their cells and/or plasma include titanium or zirconium. Figure 5 shows how crown is fixed over the metallic implant screw. It is already known that the presence of metal traces can cause tissue damage if antioxidant species levels are not raised concurrently, hence increasing a physiological generation of ROS [12–14]. Experimental data indicates that lung phagocytes carrying zirconium and titanium particles are recognised as CD68 macrophages by immunohistochemistry [15]. There is an increase in ROS generation, according to findings from measurements of the oxidative metabolism of lung macrophages exposed to such oxides. Nevertheless, ROS levels were significantly lower in animals treated with ZrO_2 as compared to animals treated with TiO_2. The studies showed that zirconium as stated in the literature is more biocompatible as compared to titanium [16–17].

In the present work the focus is on titanium implants and the examined type of corrosion is Galvanic corrosion, which is the commonest type of corrosion that takes place in dental implantation. An analysis of the material has been made and titanium has been established to be most suitable for end-osseous implantation. Titanium is biocompatible and does not corrode when employed in the live tissue: nevertheless, corrosion may develop through galvanic interaction of titanium with the other metallic restorative materials. Consequently, the type of material that shall form the superstructures covering the implant is a cause of concern. Gold alloys generally used in this situation are selected as a superstructure since it has sound mechanical properties, is corrosion resistant and biocompatible. As the prices of the metallic materials used in dentistry have gone high, the creation of cheap metallic materials is a solution. [18]. Even though these new, diverse kinds of alloys as for instance Ag-Pd, Co-Cr, and even Ti alloys possess excellent mechanical characteristics and they are relatively cheaper, there are negative aspects regarding their corrosion resistance and biocompatibility. In the mouth cavity or in the tissues there could be the close contact of manufactured metals that in their turn can correlate to the galvanic corrosion. Since the galvanic coupling and pitting corrosion are associated with each other, this proves the complexity of the electrochemical process that occurs at the implant-superstructure interface [18]. Conducive to this, ASTM defines galvanic corrosion as a process by which a metal's corrosive environment-induced corrosion rate is increased due to connection to a more noble or non-metallic contact.

The dissimilarity of the corrosion levels of two or more dental prosthetic devices causes a flow when they encounter oral fluids. The formation of an in vivo galvanic cell accelerates the less noble metal's corrosion due to the galvanic current. Pain is caused by the galvanic current that travels through tissues and metal-metal junctions. Two electrolytes—saliva or other oral liquids and the fluids found in bones and tissues—are subjected to current flow.

DISCUSSION

The research underscores the complexity of human tooth structure and the significance of understanding tribological behaviours in the selection of dental materials. Material factors like hardness and microstructure, as well as surface treatments like polishing or glazing, all have an impact on wear and friction in dental crowns. Other considerations include the counter body material, ambient circumstances (such as artificial saliva), loading pressures, and crown design. These measures provide maximum longevity and decreased wear on opposing teeth.

Given the variety of materials available, each with its strengths and weaknesses, there is no one-size-fits-all solution in clinical dentistry. For example, while ceramics offer excellent aesthetic qualities, they may have limitations in terms of wear resistance when compared to metals or zirconia. Composite resins, while versatile, may be prone to degradation under prolonged mechanical stress, particularly in patients with bruxism. Therefore, a holistic approach is necessary in choosing the right material for each patient, balancing factors such as aesthetics, wear resistance, biocompatibility, and cost. Furthermore, advancements in synthetic materials and testing methodologies are essential for refining these materials' tribological properties to better replicate natural tooth behaviour. Collaborative efforts between dental researchers, material scientists, and engineers will be crucial in pushing the boundaries of dental restoration technology, with the goal of improving long-term patient outcomes. As dental professionals become more aware of the tribological implications of material selection, they will be better equipped to make informed decisions that enhance the functionality and lifespan of dental restorations [19-21].

CONCLUSION

The study of tribological properties in dental applications provides valuable insights into the complex interactions between artificial dental materials and natural teeth. The analysis of various materials—such as zirconia, lithium disilicate, composite resins, ceramics, metals, and plastics—reveals their distinct wear behaviours, frictional properties, and overall mechanical performance when used in dental restorations. Key findings emphasize the importance of materials selection that mimic the tribological characteristics of natural tooth enamel and dentin, as these properties play a critical role in ensuring the longevity and functionality of dental restorations. While materials like zirconia and lithium disilicate offer promising durability and aesthetics, there remains a need for a balanced approach that considers not only mechanical performance but also biocompatibility, cost, and patient-specific needs. The future of dental materials lies in enhancing the tribological properties of synthetic materials to more closely replicate the natural behaviours of teeth, as well as exploring novel materials and advanced testing methods to overcome existing limitations in dental restoration technologies.

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