

A microscopic insight of the morphological changes induced by dental zirconia prosthetic structures

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Abstract

As zirconia is today probably the dental material with the largest increase in the frequency of use in dental prosthetics, the reason for this study was based on a series of clinical observations made following its use in clinical prosthetics. Thus, we were interested in two aspects: the histological evaluation of the response of the oral soft tissues to the presence of the prosthetic structures in zirconia, and the microscopic evaluation of the abrasion lesions that appeared in the hard dental tissues of the zirconia prostheses antagonists. For the first part, samples from three zirconia-based dental prosthetics commercial products were implanted submucosal in the oral cavity of male Wistar rats. After six weeks, the oral soft tissue reaction was clinically and then histologically investigated. For the second part, we made two study groups to investigate the influence of the zirconia-glazed surface vs. polished surface to the wear pattern of the antagonist enamel, using a tribological equipment and a dedicated software. Our study showed a good clinical response of the oral soft tissues surrounding the inserted zirconia samples, with subclinical, only histological revealed, signs of inflammation, of a foreign body reaction, while polished zirconia samples determined abrasion surfaces, with a different pattern and significantly smaller dimensions, compared to zirconia glazed samples, at the level of the hard dental tissues of the antagonist teeth. Despite the generally good response of the biological structures to the presence of zirconia prosthetic structures in the oral environment, more scientifically proved information is needed to obtain the desired biological responses in all clinical situations.

Keywords: zirconia, ceramics, oral soft tissue, enamel wear, implant material.

Introduction

Zirconium dioxide or zirconia (ZrO_2) is one of the most used bio-inert ceramics in medicine [1], its utilization being frequently related today with the hip joint replacement and more and more in dental applications [2]. The good strength of this material, enhanced esthetic and high biocompatibility makes zirconia one of the major today options in several clinical situations [3].

In dentistry, zirconia is used today especially in dental prosthetics to obtain fixed partial prosthesis or implant abutments [4]. The increasing use of zirconia in dental prosthetics is closely linked to the rapid evolution of computer-aided design/computer-aided manufacture (CAD/CAM) technology, the integration of these technological systems requiring suitable advanced materials, such as the zirconia-based ceramics [5]. Even there is already a significant amount of data regarding zirconia restorations obtained through several laboratory tests, technology is running and requires also other studies to be able to

evaluate all the possibilities and the long-term usefulness of this type of material [4].

Zirconia has become a very attractive alternative to the detriment of titanium, even as a dental implant material. The stage reached by the osseointegration process three months after the insertion of the implants, even if it is not fully completed, ensures a good consolidation of the implants that supports the prosthetic structures, which are to be built on them [6], and this data are the basis of doubling the number of zirconia implants from the total dental implant in the US, by 2024 [7].

Zirconia is commonly used as a framework material to be veneered with ceramics, prosthetic solution with generally good mechanical and especially aesthetic properties. However, such zirconia crowns plated with other ceramics may be frequently affected by several clinical failures of the covering material such fissures of the ceramic veneer, porcelain chipping, cracking [8]. Monolithic zirconia restorations proved better mechanical properties, but they offer a limited tooth color reproduction,

while the final surface state and wear behavior still raise some questions [9].

The reason for this study was based on a series of clinical observations made following the use of prosthetic structures in zirconia. Thus, beyond the special aesthetic aspect, the use of prostheses in zirconia allows the observation of a very good gingival clinical response, but the high hardness of this material usually causes the appearance of abrasive surfaces at the level of opposite teeth, despite the fact that the scientific data evidence for the antagonist enamel wear of prosthetic monolithic zirconia restorations are inconstant [10].

Thus, we followed in this study two aspects: on the one hand, the histological evaluation of the response of the oral soft tissues to the presence of the prosthetic structures in zirconia, and on the other, the microscopic evaluation of the abrasion lesions that appeared in the hard dental tissues of the zirconia prostheses antagonists.

Materials and Methods

Histological evaluation of the oral soft tissues

For the first part of the study, our aim was to evaluate the oral soft tissues response for three commercial dental zirconia products used for dental fixed prosthesis manufacturing. The commercial products used were ZircoStar (Kerox Dental, Hungary), Prettau Zirconia (Zirkonzahn, Italy) Tizian Zirconia (Schütz-Dental, Germany). Therefore, we used 15 laboratory rats divided in three study groups, a study group for each commercial product. The samples were implanted submucosal, in the oral cavity of male Wistar rats (Figure 1A), after a technique that we already used and described [11, 12]. The surgical procedures were performed under general anesthesia within the Laboratory Animal Facility of the University of Medicine and Pharmacy of Craiova, Romania, and the study protocol was approved by the Ethics Committee of our University (No. 141/16.05.2017).

After six weeks, the laboratory rats were euthanized and the oral soft tissue reaction was clinically investigated (Figure 1B), then samples and surrounding soft tissues

were harvested, fixed and passed through all the stages preceding the histological examination to obtain sections of 5 to 7 μm stained with Hematoxylin–Eosin (HE) and Goldner–Szekely (GS) trichrome.

Microscopic evaluation of the abrasion lesions

For the second part of the study, we made two study groups to investigate the influence of the zirconia surface preparation to the wear pattern, especially the wear of the antagonist enamel. The first study group contains zirconia samples whose surface was covered with a glaze, vibrated for a uniform coating, then dried and fired. For the second study group, the surface was hand polished with polishing gums and paste. The samples were prepared with an electric handpiece, at 10 000 rpm, with hand pressure and water-cooling. The preparation was made for one minute, with medium burs and then fine gums. The null hypothesis was there would be no difference in the enamel wear related to the surface preparation of the zirconia samples.

Zirconia samples (Prettau, Zirkonzahn) were embedded in resin using the METAPRESS-A equipment (technical characteristics: 230 V voltage, 50 Hz frequency, 1400 W power, 240°C maximum temperature, 330 bar maximum pressure, working posts: simultaneously two samples and subjected to the tribological tests). The equipment, TRB 01-02541 (Anton Paar, Austria), is accompanied by the InstrumX software, version 2.5A and works by a cyclic repetition of a vertical force from the antagonist on the sample followed by a horizontal slip (Figure 2A). The specific parameters for this test were: 2 N load, 10 Hz frequency, 15 mm sliding distance, 1 mm radius, 1 cm/s linear speed, 33% glycerin lubricant as artificial saliva. For the antagonist enamel cusps, we used extracted teeth that were prepared with diamond burs, in order to create a circular shoulder to maintain the dental structure in the right position, during the wear test (Figure 2B).

The macroscopic aspects of the teeth worn parts were analyzed using the Nikon SMZ-745T stereomicroscope and specific software for data acquisition and measurements (NIS-A AMEAS and NIS-A EDF).

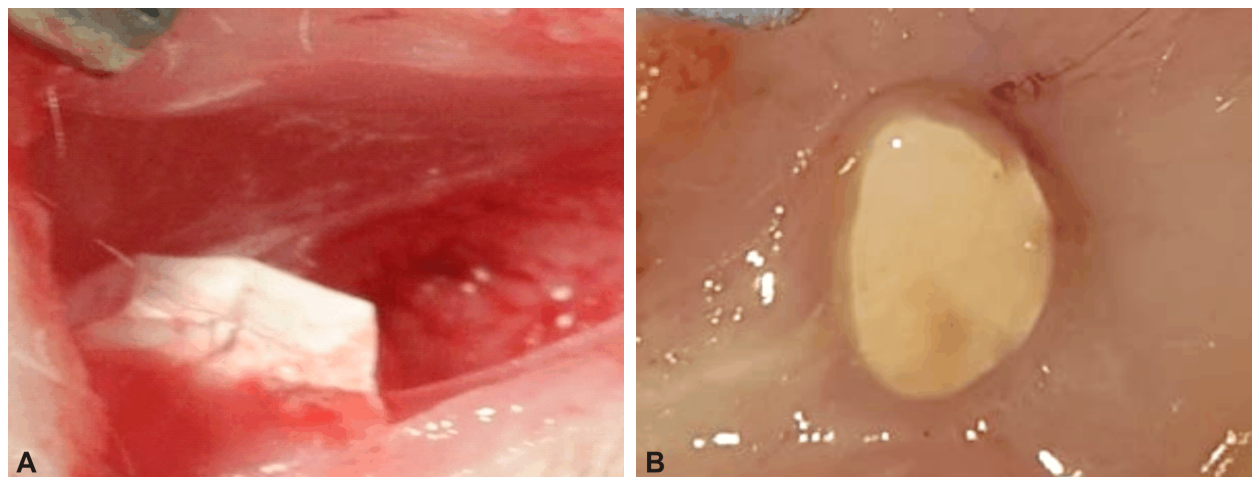


Figure 1 – Aspects of the experimental zirconia sample during the surgical insertion in the oral soft tissue (A) and after six weeks revealing the normal clinical aspect of the surrounding soft tissues (B).

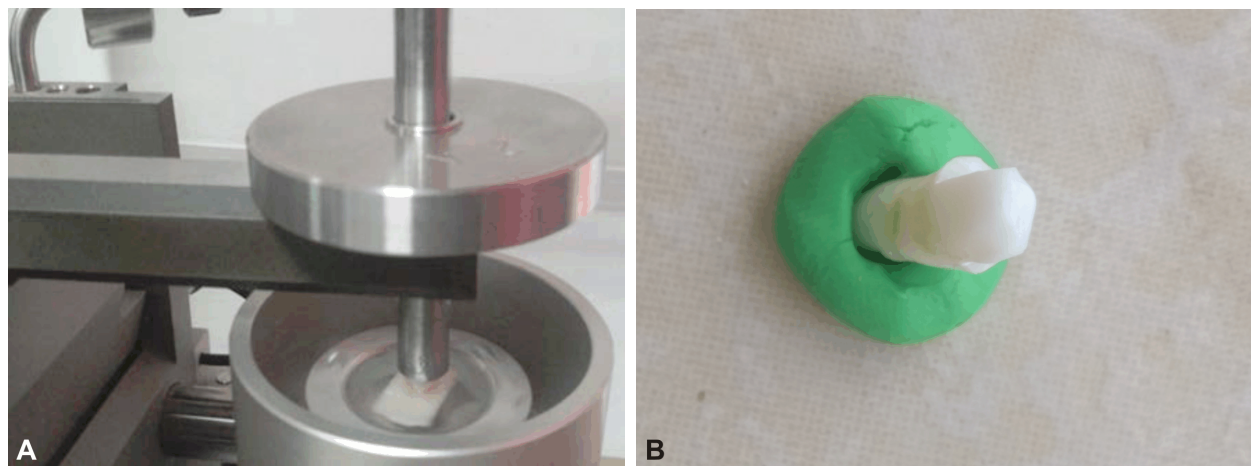


Figure 2 – The tribological equipment used for testing the zirconia wear (A) and the tooth used as an antagonist for the zirconia sample with the prepared circular shoulder (B).

Results

Histological evaluation of the oral soft tissues

The macroscopic evaluation of the oral tissues located around the inserted samples, evaluation performed after the euthanasia of the laboratory animal during the samples harvesting for the histological study, revealed a good biological response with the lack of clinical inflammatory manifestations to the samples collected from all the study groups.

The histological examination showed the presence of minimal signs of inflammation, of a foreign body reaction, in almost all the analyzed samples. The differences highlighted in the amplitude and pattern of the local tissue response were less related to the study group, as to the depth of the sample insertion, the presence of muscle or adipose tissue in the vicinity.

Thus, we frequently encountered signs of local inflammation with varying intensity from minimal to moderate both between samples and within the same sample, with the appearance of neoangiogenesis vessels of different caliber (Figure 3A). Areas of vascular congestion were frequently identified with the presence of numerous cells in the vascular lumen, frequently oriented towards its margin, with areas of minimal to moderate perivascular edema. Extravascular cell infiltrate also varied from minimal to moderate forms until the onset of chronic inflammation with granulation tissue synthesis (Figure 3B).

In other areas, we could observe the rough organization of the collagen fibers around the samples, with areas of interfibrillar edema, but also areas of collagenous fibrosis (Figure 3, C and D). In the samples inserted near some muscle fibers, we could highlight changes in their structure, with interfascicular edema and reactions of local tissue irritation, offering the picture of an inflammation with a subacute character or of collagenous fibrosis (Figure 3, E and F).

Microscopic evaluation of the abrasion lesions

The observations made in the second part of our study rejected the null hypotheses and showed us differences in the extension and pattern of enamel abrasions of the antagonist teeth between glazed samples and polished ones.

Thus, the natural teeth were subjected to the wear test having contact with the glazed ZrO_2 surface through the incision edge. The microscopic examination of this surface reveals the appearance of a wear surface that starts from mesial continuing the pre-existing physiological abrasion surface and continues to the distal, however becoming much less obvious in the distal half of the tract (Figure 4, A and B). One particular aspect that we observed was the way a pre-existing crack developed at the sample level after testing for wear. The measurements made show an increase in the maximum crack width, at the incisal margin from 93 to 130 μm and the tendency to extend it to the palatal face (Figure 4, C and D).

The polished ZrO_2 surface of samples had also contact with a natural tooth through the incision edge. In this situation, we could get a wear surface with a different pattern, with a pointy appearance. The test produced a loss of limited hard substance, maintaining the point-like aspect of the initial contact, without transforming into a linear surface as in the case of the previous group, with a similar width due to the size of the contact surface (Figure 4, E and F).

Discussions

For the *in vitro* tests, to show the biocompatibility of zirconium-based ceramics, fibroblasts and osteoblast cells were mainly used [3]. Moreover, the biocompatibility of zirconia has also been studied in several *in vivo* studies, leading also to no adverse answer after the insertion of zirconia samples into the bone or muscle [13].

Our histological study showed that despite the good biological response with the lack of clinical inflammatory manifestations of the soft tissues surrounding the inserted samples, we may found signs of inflammation, of a foreign body reaction, in almost all the analyzed samples. Zirconia-based restorations show usually a very good biological response from the periprotetic periodontal tissues. However, a bacterial plaque accumulation appears when a fixed dental prosthesis has not a correct marginal adaptation leading to infiltration of bacteria from the oral environment and periodontal diseases consequently [14]. CAD/CAM technology, used almost any time today when we make a dental zirconia structure, has the big advantage of a precise

estimation of the ceramic shrinkage during sintering, which leads to an important improvement in marginal adaptation of dental zirconia prosthetics [7]. Actually, also other studies showed that the histological aspect of the gum near a dental fixed prosthesis is less related to the material but more with the mechanical irritating spine represented by the prosthesis itself [15].

In our study, the samples inserted into the oral tissue were sintered, without receiving any further mechanical processing. Unfortunately, in current practice, there are frequent situations that require mechanical processing

after sintering either in the dental lab or in the dental office. This mechanical processing leads to an increase of surface roughness and contact angle [16], which may increase the dental plaque accumulation, with a further raised incidence of the periodontal diseases, especially in the presence of a poor local hygiene [17, 18]. Also, even the periodontal response is generally good, the material requires a minimum thickness, which may create insufficient embrasure spaces and a mechanical-induced inflammation of the soft tissues from these spaces leading to bleeding on probing [19].

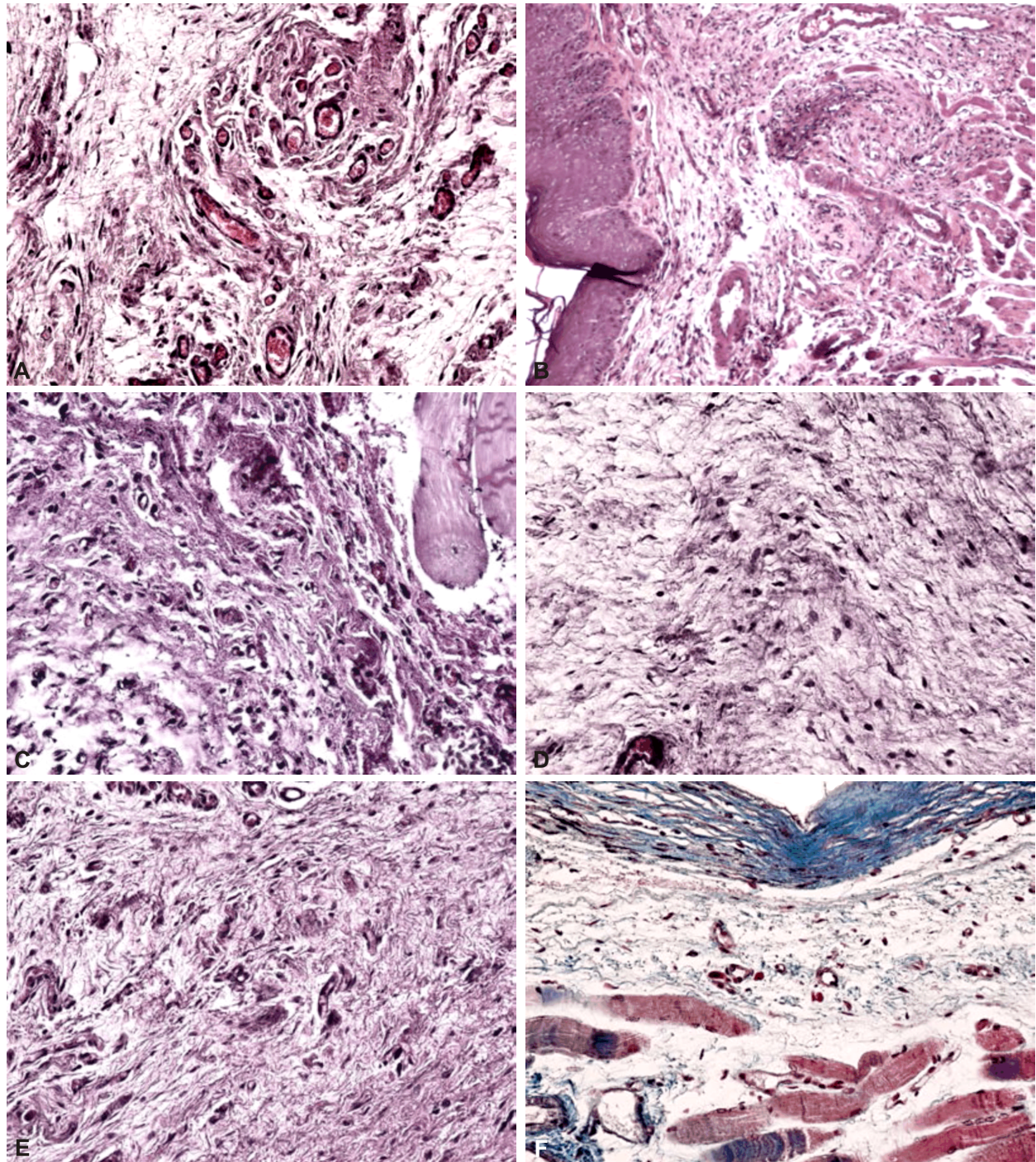


Figure 3 – Histological aspects of the soft tissue surrounding the zirconia samples six weeks after their insertion in the oral mucosa: vascular congestion and moderate angiogenesis (A) and minimal inflammatory reaction (B) in Prettau Zirconia samples; with the increase in the amount of fibrillar collagen (C) and the number of fibroblasts (D) in ZircoStar samples; moderate edema in the connective tissue (E and F) in Tizian Zirconia samples. HE staining: (A and B) $\times 100$; (C–E) $\times 200$; GS trichrome staining: (F) $\times 200$. HE: Hematoxylin–Eosin; GS: Goldner–Szekely.

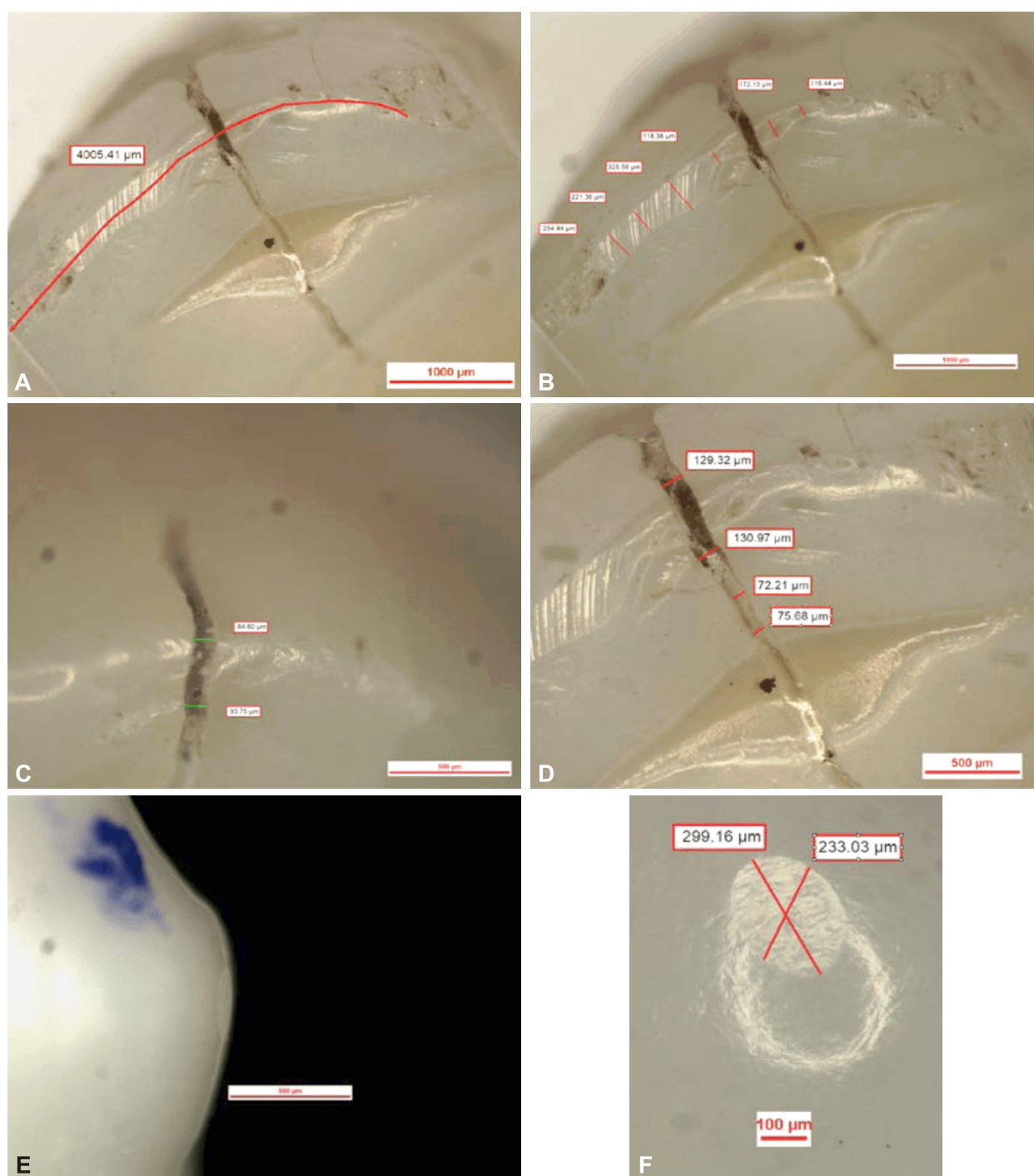


Figure 4 – Microscopic aspects of the abrasion lesions produced by zirconia samples after the tribological test: (A and B) Pattern of a wear surface produced by a zirconia-glazed sample; (C and D) The developing of a pre-existing crack at the sample level after testing for wear; (E and F) Pattern of a wear surface produced by a zirconia-polished sample.

Teeth wear is manifested by the loss of hard dental substance due to a series of noncarious processes that can act singly or simultaneously. Today, the wear produced by interaction between teeth and other materials is considered the tooth abrasion. There are lot of scientific works and debates today in order to improve the diagnosis of tooth wear, the detection and monitoring of these kind of dental hard tissues lesions and to understand its various manifestations [20, 21], as occlusal trauma may be leading to several biological effects on the oral environment structures. Thus, several studies found or suggest clinical and morphological changes in the dental pulp and the

periodontal tissues of the tooth affected by the occlusal trauma, but also on the masticatory muscles, the temporomandibular joint and even on the central nervous system [22]. However, there are several disagreements between studies. Thus, a Romanian scientific team found that with the exception of the elements of the dental pulp peripheral zone, most of the correlations between the morphological changes on this level and the occlusal trauma topography may be only suggested and not statistically validated [23]. However, on the different structures of the surrounding periodontium of these teeth, the lesions and their topography can and are influencing locally the morphological aspects [24].

Teeth wear may appear on the occlusal surfaces of the antagonists monolithic zirconia crowns. Glazing is an important stage in the manufacturing process of zirconia restorations leading to a decrease of the surface roughness, regardless of the commercial producer [25], but the clinical need for mechanical readjustment of the zirconia sintered prosthetic pieces results in rougher zirconia surfaces. However, the use of a zirconia polishing kit proved to be a reasonable and timesaving alternative method to re-glazing, from the point of view of the abrasion of the antagonistic hard dental structures [26].

Our results sustain these literature data showing that polished zirconia give less wear on the antagonists enamel glazed zirconia giving more support to the idea that polished zirconia should be preferred in occlusal areas [27, 28]. Moreover, even in the clinical cases where glazing is required for esthetic reasons it is still advisable to polish the surface before glazing [29]. However, not all the clinical literature data converge to the same idea. Thus, a 2015 clinical study found also important wear of the antagonists enamel for the ceramic prosthetic restorations, but comparing to the metal ceramic crowns the wear was even lower in case of the zirconia crowns in the premolar and molar regions after one year [30], while a 2018 study found comparable results between metallo-ceramic and monolithic zirconia groups, but also even with a natural tooth control group [31]. This is why a 2019 review on this subject concluded that, when we place a zirconia restorations, we have to consider the enamel wear of occlusal surfaces of the antagonist teeth even a meta-analysis of the literature data is not yet possible due to the heterogeneity of the used methods and parameters [10].

Even if our data and the literature converge towards the idea of a good response of the biological structures to the presence of zirconium, it remains to investigate the risk that in this biological environment the zirconium structures will undergo phase changes with the implicit change of their properties. There are several reports in literature of adverse changes in zirconia ceramics degradation in the oral environment [32]. Also, in one of our group previous study, we saw that after the same period as the current study in the same oral samples placement, zirconia structures suffer changes in their surface and sub-surface due to the organic compounds presence. Also, we should take into account that co-doping zirconia with other elements may make it susceptible against low-temperature degradation [12].

✉ Conclusions

Zirconia is probably the modern dental material with the largest increase in the frequency of use in current dental prosthetics. The results of our study showed a good clinical response of the oral soft tissues surrounding the inserted zirconia samples, with subclinical, only histological revealed, signs of inflammation, of a foreign body reaction. Polished zirconia samples determined abrasion surfaces with a different pattern and significantly smaller dimensions compared to zirconia-glazed samples, at the level of the hard dental tissues of the antagonist teeth. Even if our data and the literature converge towards the idea of a good response of the biological structures to the presence of zirconia prosthetic structures in the oral

environment, more scientifically proved information are needed to adapt the manufacturing technology of these prosthetic structures and obtain the desired biological responses in all clinical situations.

Conflict of interests

The authors declare that they have no conflict of interests.

Acknowledgments

The histological study took place in the University of Medicine and Pharmacy of Craiova. The interventions on the laboratory animals were made within the laboratory animal facility and the histological study was made within the Research Centre for Microscopic Morphology and Immunology. The evaluation of the abrasion lesions took place in COMING Research Centre of the Faculty of Mechanics, University of Craiova.

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