ORIGINAL ARTICLE

In vitro evaluation of a passive radio frequency identification microchip implanted in human molars subjected to compression forces, for forensic purposes of human identification

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Abstract

Objective: To evaluate the *in vitro* behavior of a passive Radio Frequency Identification (RFID) microchip implanted in human molars subjected to compression forces to determine its technical and clinical viability. **Materials and Methods:** *In vitro* experimental study to evaluate the physical behavior of a passive RFID microchip (VeriChip™) implanted in human molars through resin restoration (Filtek P90™ Silorane 3M-ESPE®) to determine the clinical and technical possibilities of the implant and the viability to withstand compression forces exerted by the stomatognathic system during mastication. **Results:** Through the ANOVA test, it was found that the teeth on which a microchip was implanted show great resistance to compressive forces. It was also evident that teeth with microchips implanted in Class V cavities are more resistant than those implanted in Class I cavities. **Conclusions:** Although microchip dimensions are big, requiring a sufficiently large cavity, from the biomechanical point of view it is plausible to implant a microchip in a Class V cavity employing restoration material based on resin for forensic purposes of human identification.

Key words: Compression tests, dental biomaterials, dental identification, forensic dentistry, forensic sciences, passive radio frequency identification microchip

Introduction

In Colombia, there are more and more deaths whose identification process is hindered because of the state of the corpse or of the human remains (advanced state of decomposition, skeletonization, burns, carbonization, incineration, mutilation, among others), where there is alteration of soft tissue, the elimination of fingerprints, bad quality of tandem repeated deoxyribonucleic acid (DNA) sequences susceptible to being interpreted and analyzed, or the lack of other elements that lead to the positive or reliable identification of an individual. For this reason, institutions in charge of said identification process should have more effective methods that permit rapid recognition of an individual, to comply, not merely with the social work with respect to the surviving family members, but also with streamlining of the case from the judicial point of view.

Currently, the use of passive Radio Frequency Identification (RFID) microchips implanted in humans is becoming popular with different medical and economic objectives,

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whose main function is identifying and providing some information about an individual. Said implant is sub-dermal (generally in the back of the hand and on the forearm) and has been approved by the Department of Health and Human Services of the United States Food and Drug Administration, and regulated by ISO norms.

Use of dental devices for dental identification

In specialized literature, we found different reports of mechanisms to mark different oral rehabilitation devices for identification purposes like those by Harvey,[1] Turner *et al.*,[2] Ryan *et al.*,[3] Berry *et al.*,[4] Cross and Wolfaard,[5] Ling,[6] Reeson,[7] and Moya *et al.*,[8] Likewise, the American Dental Association (ADA) developed a 3 to 4-mm diameter acrylic micro-disc (blue for men and pink for women), which would be cemented on the vestibular surface of the first upper right molar. This device would have a unique alphanumeric code engraved to identify each individual.[9,10]

Rajan and Julian[11] indicated the use of microchips for these purposes, for which Millet and Jaeannin[12] conducted a study where they incorporate a microchip onto total acrylic prosthesis through the passive RIFD scanning or readout system. Currently, Dentalax® commercializes a microchip and reader to label partial and total removable prosthetic devices that contain acrylic.[13]

Regarding the implant of microchips within teeth, Theviessen *et al.*,[14,15] conducted a study *in Vitro* in which they implanted several veterinary-use passive RFID microchips (EasyTrac-ID®) in human molars, concluding that these types of systems are of good utility for the identification of an individual within a forensic context. Nevertheless, little has been researched on the implanting of these microchips in the teeth, which would afford greater protection to the mechanism by virtue of the great resistance offered by the teeth against high temperatures, acid attacks, and humid and saline environments; similarly, this would be of great use in the case of inhumation of several cadavers from the same grave, or the dismemberment of several individuals; such methods are employed by perpetrators to hinder the identification process. Microchips implanted in the teeth would remain in place after latent cadaveric phenomena and would reduce the possibility for confusion among several microchips and their loss on the field. For this purpose, this research evaluated the physical behavior *in Vitro* of a passive RFID microchip (VeriChip™) implanted in human molars.

Radio frequency identification microchip

Passive microchips, electronic labels, RFID tags or transponders for electronic identification consist of an electric resonance artifact made up of a capacitor circuit, a reception and transmission antenna, and an electronic microchip, which, upon coming into contact through the antenna at an approximate 10-cm distance with a low power and modulated amplitude (MA) specific electromagnetic field generated by the scanner, is powered by the voltage induced in the resonance (from a frequency ranging from 125 kHz to the Industrial Scientific and Medical (ISM) band at 2.4 gHz, and greater) so that it can transmit the unique identification code to the scanner. Once there, the code is amplified and converted to digital format; thus, it is deciphered and the unique identification number is shown on the scanner's liquid crystal display (LCD) screen. The *tag* consists of the microchip, which stores a 16-digit identification code, laser engraved on the surface unalterably prior to its assembly; the antenna is a copper wire coil around a ferrite core, which receives and transmits the different signals to and from the reader; and the capacitor receives the necessary voltage from the scanner to allow the microchip to activate and transmit the identification code [Table 1, Figures 1 and 2].

Materials and Methods

An experimental *in Vitro* study was conducted to evaluate the physical behavior of 10 passive RFID microchips (VeriChip™) implanted in 10 human molars for the purpose of determining the technical and clinical possibilities of the implanting and guiding its protocol, with respect to the diagnosis of the host tooth, the size and depth of the cavity, the selection of the dental restoration material and the viability of these to withstand the compression forces exerted by the stomatognathic system during mastication. Currently, these devices are for sub-dermal implantation, for this reason this study evaluated the possibility of dental implantation [Figure 3].

Sample collection

Upon obtaining endorsement from the Human Ethics Committee of the Health Faculty at Universidad del Valle, according to Resolution 8430[16] and to the Helsinki Declaration,[17] and verifying the minimum risk entailed in this study, we proceeded to collect a simple of 20 teeth, obtained from the patients who attended the Oral Surgery Clinic of the Dental School at Universidad del Valle and who required extraction of molars because of periodontal or

Table 1: Technical specifications of the radio frequency identification device

VeriChip™ RFID	
Memory	EEPROM
Frequency	125 KHz a 134.2 kHz
Size	12 mm×2 mm
Capacity	128 bits (16 digits)
Cover	Glass
Anti-migration	Polymer of polypropylene
Durability	To 99 years
VeriChip Pocket Reader™	
Material	Plastic
Frequency	125 KHz/134.2 KHz
Size	285 mm×80 mm×32 mm

RFID: Radio frequency identification

orthodontic reasons and who signed an informed consent.

Handling and preservation of the sample

Once the teeth were extracted, we proceeded to wash them profusely with tap water to eliminate traces of blood and tissue, and they were thereafter placed in a dark tightly sealed container with the Chloramine T fixative solution at 5%. The teeth remained in Chloramine T for a week and were then placed in saline solution at room temperature according to that stipulated in ISO/DIS 11405:2003 Norm.[18]

Sample distribution

Four groups were formed. Two control groups and two intervention groups receiving the microchip implants [Table 2].

Preparation of the passive radio frequency identification microchips to be implanted in the sample

Given the size of the microchip (VeriChip™) used in this study, it was necessary to reduce its dimensions to set up a dental cavity that would have sufficient resistant dental material; to keep the microchip from coming into contact with the cavity walls (dental tissue) so that the restoration material could cover the entire microchip and fulfill its

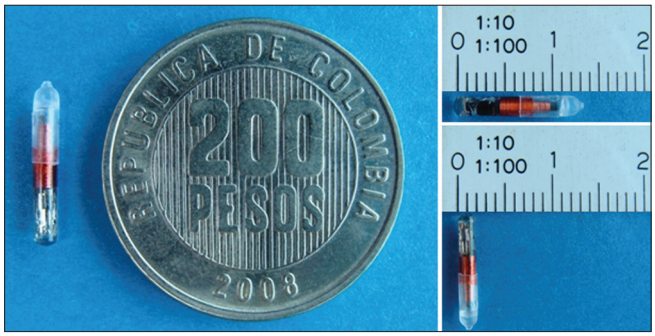

Figure 1: Passive radio frequency identification microchip VeriChip™

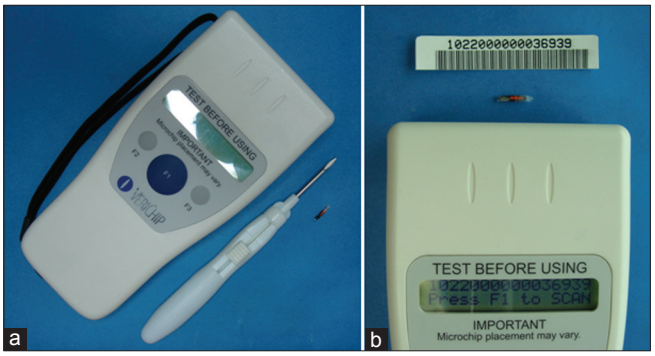

Figure 2: VeriChip Pocket Reader™. (a) Pocket reader, hypodermic application system (12 gauge needle with plastic ejector rod) and passive radio frequency identification microchip VeriChip™. (b) Pocket reader and passive radio frequency identification microchip reading and functioning

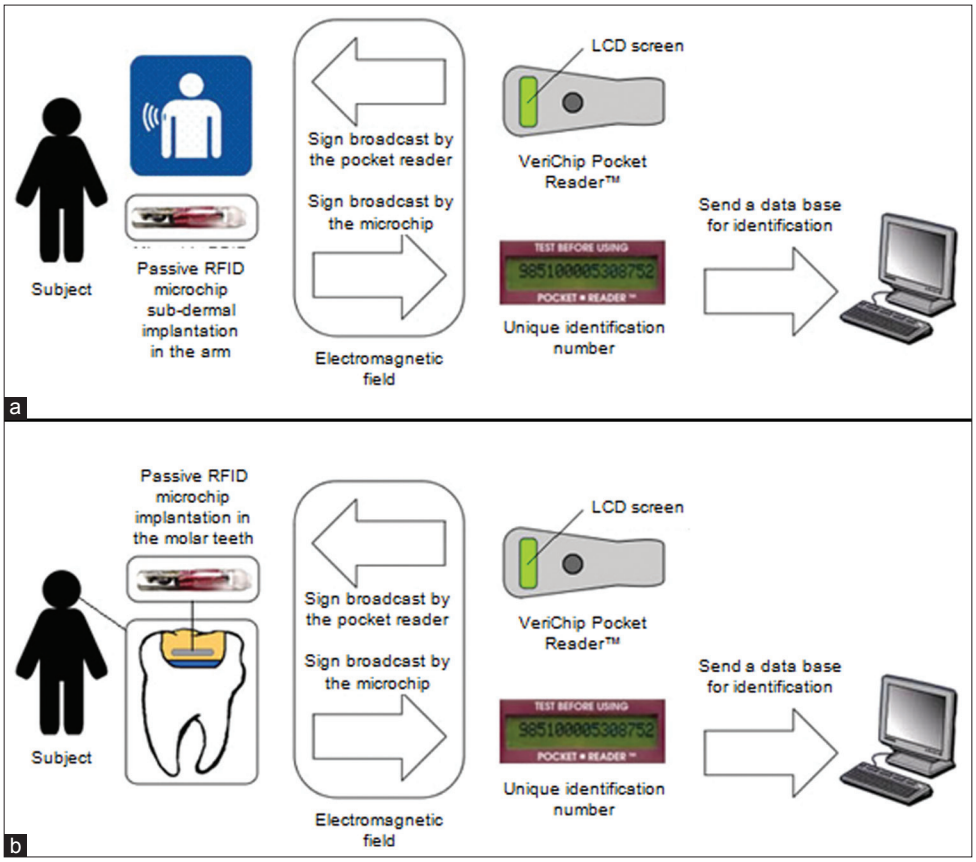

Figure 3: (a) Conventional model of sub-dermal implantation in the arm. (b) Model proposed in this study of implantation in molar teeth

physical, biological, and aesthetic functions. To accomplish this, and according to indications by Thevissen *et al.*,[14,15] the polypropilene porous polymer coating the end of the microchip was removed with a No. 15 scalpel and with diamond burs the scanned-glass capsule (VeriChip Pocket Reader™) was eliminated, constantly scanning the microchip to monitor its operation. These procedures diminished the microchip dimensions from 13 to 9 mm length and from 2.5 to 1.5 mm diameter [Figure 4].

Preparation of the dental cavities

A Class I cavity was made in the teeth from group 2, those in group 3 had a Class I cavity, and those in group 4 had a Class V cavity done with a high-speed, high torque dental hand-piece with four water outlets (Kavo 7000c®) with constant refrigeration and medium grain diamond cylindrical burs for operatory (Intensive Swiss®). The cavities were carried out from the occlusal and buccal midline, respectively, controlled through silicon caps placed on the bur and corroborated with an electronic guage [Figure 4].

Obturation of cavities

Prophylaxis procedure was done with a prophylaxis brush and a solution of sodium bicarbonate; the surface was dried with absorbent paper and a P90® 3M-ESPE® adhesive system was applied (the first was applied for 15 seconds, it was aerated and photo-cured for 15 seconds; then the adhesive was applied for 10 seconds, the resin was aerated and photo-cured for 10 seconds). Thereafter, we placed a first layer of resin (Filtek P90™ Silorane 3M-ESPE®) at the bottom of the Class I and Class V cavities; the microchip was set in place and it was photo-cured for 20 seconds. Finally, obturation of the cavity was completed through two increments – each photo-cured for 20 seconds; the restoration was polished and shined with disks (Soflex® 3M-ESPE®) and a sealing agent (Concise White Sealant 3M-ESPE®) was applied to the restorations of the Class I cavities to seal the cusp union [Figure 5]. For the restoration process, we followed the manufacturer's indications[19] and the microchip was constantly scanned (VeriChip Pocket Reader™) to test its proper operation. The teeth were preserved in saline solution and labeled with the microchip serial until the application of the compression tests.

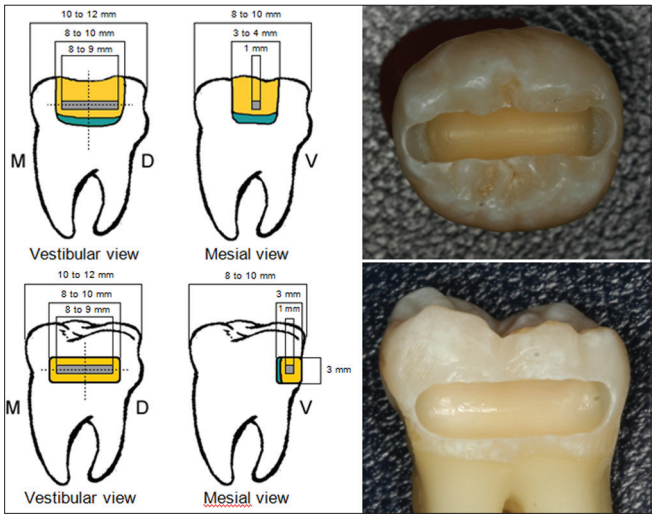

Figure 4: Dimensions of Class I and Class V cavities

Application of physical compression tests

A self-polymerization (New Stetic®) acrylic resin base was made for each sample from the four groups, these were mounted on a universal testing machine (Tinius Olsen® H50KS) at the Physical and Mechanical Test Laboratory in the School of Materials Engineering at Universidad del Valle with a 50 Kilo-Newton capacity and vertical constant compressive force was applied at a crosshead speed of 1 mm per minute through a rounded tempered steel tip 3 mm in diameter localized on the center of the occlusal surface until the software in the machine (Tinius Olsen Horizon®) registered a fracture [Figure 6]. After the compressive tests were done, a scan (VeriChip Pocket Reader™) of the microchips was conducted to check for proper operation.

Statistical analysis

The values corresponding to the compression tests were processed with the SPSS® ver. 17 Software. A Kolmogorov-Smirnov test was performed to check for the normality of the data distribution and then the ANOVA test was applied to assess if there were differences in resistance to compression among the 4 groups studied ($P < 0.05$). Finally, the Turkey test was applied to identify the differences among the groups ($P < 0.05$).

Results

Upon applying constant compressive force, we obtained the maximum-load values (Newton) of the 18 specimens (2 specimens were lost during compression tests) [Table 3]. The rounded tip in contact with the occlusal surface of the tooth initiated the compression from a starting extension of 0 mm at a rate of 1 mm per minute until the machine

Table 2: Distribution of the sample

Control groups		Intervention groups	
Group 1	**Group 2**	**Group 3**	**Group 4**
5 teeth with no preparation	5 teeth with a class I cavity and filled with Filtek P90™ Silorane 3M-ESPE® Low Shrink Posterior Restorative	5 teeth with a class I cavity, with VeriChip™ microchip implanted and filled with Filtek P90™ Silorane 3M-ESPE® Low Shrink Posterior Restorative	5 teeth with a class V cavity, with VeriChip™ microchip implanted and filled with Filtek P90™ Silorane 3M-ESPE® Low Shrink Posterior Restorative

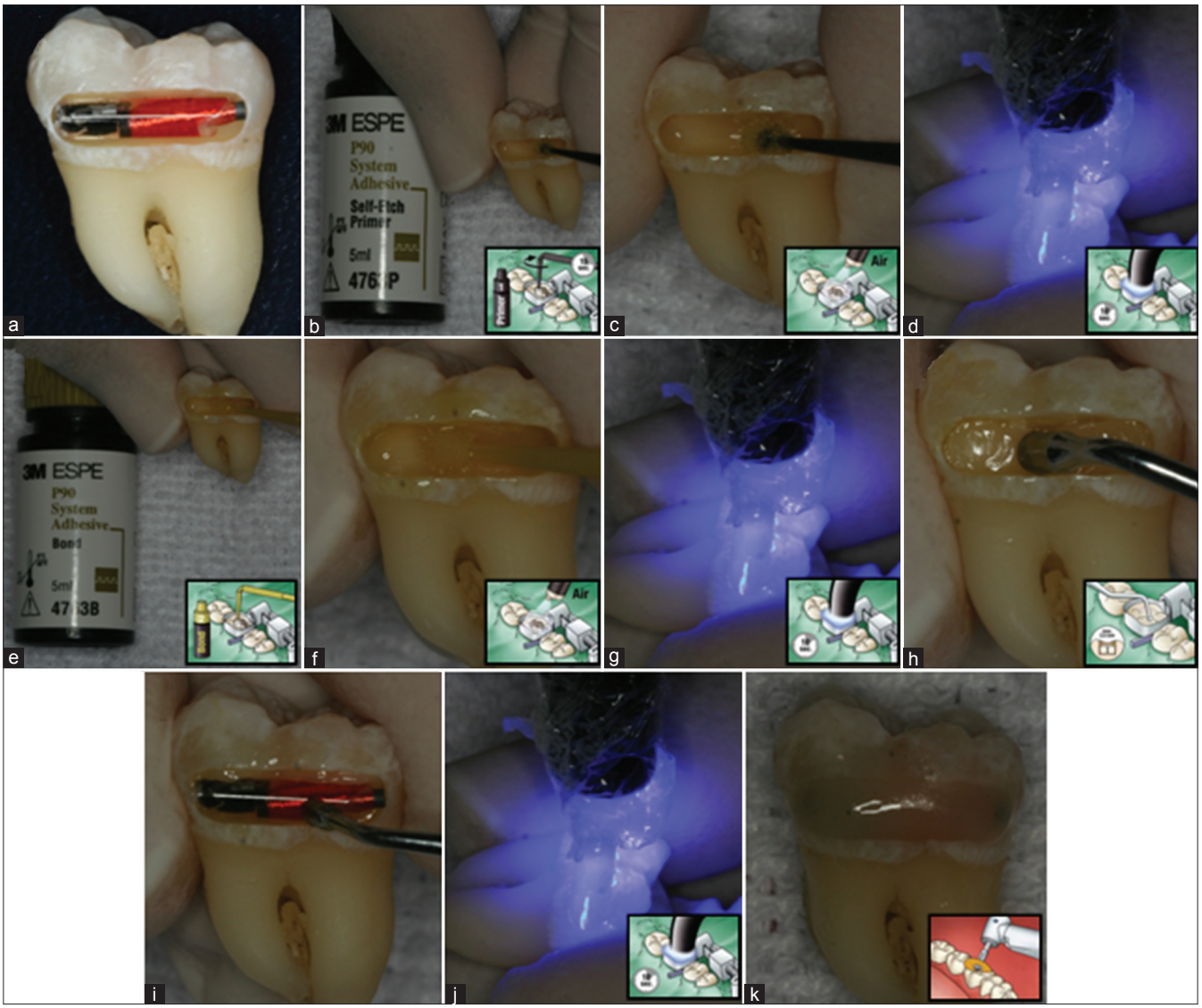

Figure 5: Obturation of cavities and implantation of radio frequency identification microchip. (a) Adaptation of the dimensions of the radio frequency identification microchip at the class V cavity. (b-d) Application of silorane system adhesive self-etch primer. (e-g) Application of silorane system adhesive bond. (h) Application of Filtek Silorane Low Shrink. (i) Placement of radio frequency identification microchip in class V cavity, (j) 20 seconds light curing. (k) Finishing and Polishing

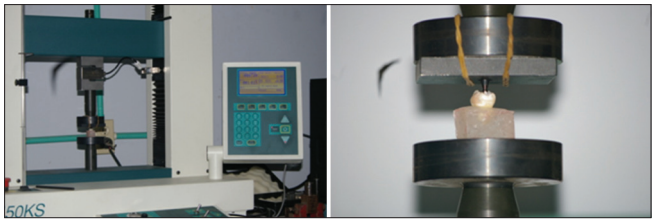

Figure 6: Application of physical compression tests on a universal testing machine (Tinius Olsen® H50KS)

registered a fracture at a force x in a final extension. The load required to reach the fracture is illustrated in the load-extension graphic for each specimen [Figure 7], likewise, the descriptive statistics can be observed in Table 4.

After applying the Kolmogorov-Smirnov test to check for data distribution normality, the ANOVA test showed that there are differences in compression resistance among the 4 groups studied (P = 0.028). Through the Tukey test it was noted that the groups whose teeth were implanted with microchips (groups 3 and 4) presented statistically significant difference (P = 0.032). This difference can be evidenced in the box-and-whisker plot [Figure 8], which shows that group 3 behaves different from the other three groups, in such a manner that the specimens from this group withstood a lower compressive load.

Discussion

During the masticatory function in the stomatognathic system, the maximum loads produced are around 500 N for premolars and 1032 N for molars.[20] Thereafter, after using a gnathodynamometer, it was concluded that the

Table 3: Physical compression tests results

Sample		Cavity type	Serial microchip	Peak load (*N*)	Maximum extension (mm)	RFID microchip function
Group	Teeth					
1	3	-	-	2326	1,04	☑
	5	-	-	1992	0,98	☑
	11	-	-	2167	0,83	☑
	17	-	-	2205	0,97	☑
	19	-	-	2347	1,05	☑
2	12	I	-	2082	0,76	☑
	14	I	-	1998	0,97	☑
	15	I	-	2134	1,02	☑
	16	I	-	2243	0,75	☑
	10	I	-	2187	0,88	☑
3	2	I	1022000000051415	-	-	-
	4	I	1022000000039087	1318	1,08	☒
	8	I	1022000000050566	1584	1,14	☑
	18	I	1022000000041870	1678	0,92	☑
	13	I	1022000000027869	1178	1,11	☑
4	1	V	1022000000037672	3488	1,04	☑
	6	V	1022000000034048	1708	0,80	☑
	7	V	1022000000039850	2193	0,90	☑
	9	V	1022000000039518	1904	1,08	☒
	20	V	1022000000050788	-	-	-

Table 4: Descriptive statistics analysis

Group	Samples	Mean	Standard deviation	Confidence interval for te mean at 95%	Minimum value	Maximum value
1	5	2207,40	142,8	2030,06-2384,73	1992	2347
2	5	2128,80	94,5	2011,40-2246,19	1998	2243
3	4	1439,50	231,5	1070,98-1808,01	1178	1678
4	4	2323,25	801,64	1047,65-3598,84	1708	3488
Total	18	2040,67	494,02	1794,99-2286,33	1178	3488

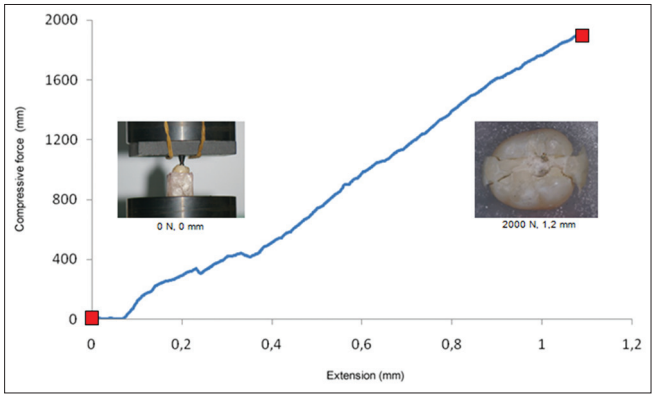

Figure 7: Physical compression tests results. Sample 9 for the group 4

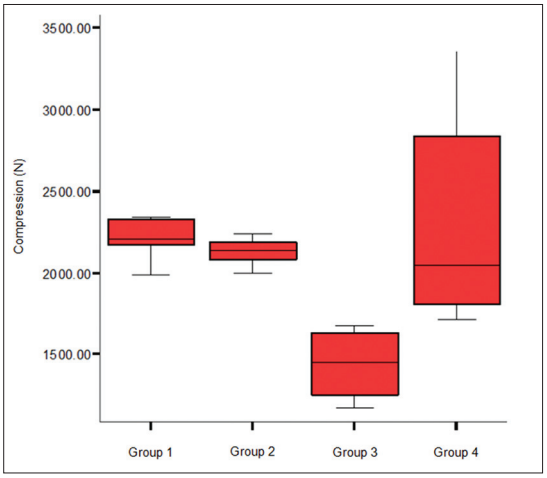

Figure 8: Box-and-whisker plot. The figure shows that group 3 behaves different from the other three groups, in such a manner that the specimens from this group withstood a lower compressive load

forces developed by the masticatory system vary from one individual to another, 445 N for women and 534 N for men; although under compatible conditions with the health of the periodontal tissue, the stomatognathic system only uses between 15% and 20% of the maximum bite strength capacity, equivalent to 103.1 N,[21] and depending of the different factors like regulation by the brainstem, its execution through force and muscular dynamics, the transmission of this force through the periodontal proprioceptors, disposition of the masticatory pressure through the occlusal contacts, sensitivity of the mucosa, and food hardness and control in the mouth; in addition

to other factors like age, gender, and psychological, social, environmental, or life-style factors.[22] In the current study, the four groups presented resistance to compression much greater than that exerted by the stomatognathic system.

Naranjo *et al*.,[24] conducted an *in Vitro* study in which compressive forces were applied on extracted human teeth, finding that fracture resistance between restored teeth and intact teeth did not reveal significant differences and ranged between 400 and 1980 N in the intact teeth and between 4215 and 2097 N in teeth restored with Filtek P60™ 3M-ESPE® resin. This study contrasts with the results in our investigation, given that the compressive resistance was much higher, between 1992 N and 2347 N in teeth from group 1 and between 1998 N and 2243 N in teeth from group 2. However, both studies corroborate that shown by De Freitas *et al*., who manifested that the restoration materials should not only replace the lost dental structure, but should also increase the resistance to fracture of the teeth in so as to promote an effective seal.[25]

Theviessen *et al*.,[15] in the only study reported in literature until now dealing with the implantation of microchips in teeth, found that in all the samples tested, the maximum resistance without microchip failure reached 2200 N. In this study, the behavior was different. Theviessen *et al*., only implanted microchips in Class 1 cavities and in their study the specimen revealing the greatest resistance to compression only reached 1678 N. Regarding these two findings, there is indeed significant difference with respect to the specimens in which the microchip was implanted in Class V cavities, which reached a maximum value of 3488 N.

From a quantitative point of view, we noted cohesive failure (dental tissue vs. dental tissue) in the teeth from group 1, while the teeth from groups 2, 3, and 4 presented cohesive failure (dental tissue vs. dental tissue and resin vs. resin) and adhesive failure (dental tissue vs. resin and resin vs. microchip) [Figures 9-11]. However, it is not possible to associate these types of failures (represented by fracture) for a determined group of teeth given individual variations, like manifested by Naranjo *et al*.,[23] in tooth morphology (size, shape, and inclination of the cusps), in the size of the teeth, in the conformation of the cavities and of the point of contact of the rounded tip during the test, which may contribute to the standard deviation in the resistance to compression behavior. This can be seen in Graphic B of Figure 4, where group 4 presents a greater dispersion in the compressive resistance of the specimens, associated to the occlusal table area and to the vestibular-lingual width of the teeth and to the proximity of the cavity to the axis of force, which did not occur in the teeth in groups 2 and 3 in which the load was directly received by the resin.

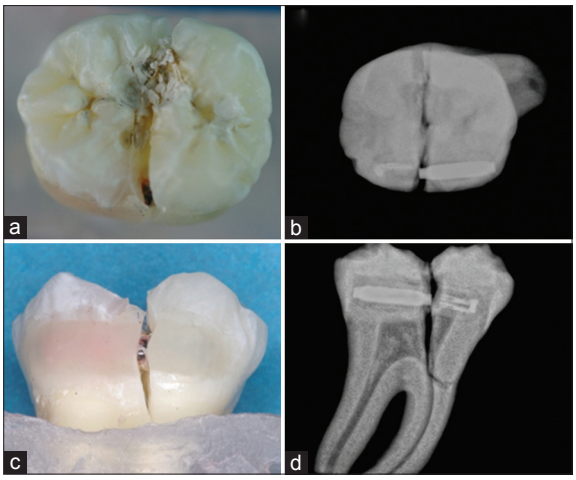

Figure 9: Sample 9 for the group 4. The figures show the cohesive failure (dental tissue vs. dental tissue and resin vs. resin). (a) Oclussal view. (b) Periapical radiography oclussal view. (c) Buccal view. (d) Periapical radiography buccal view

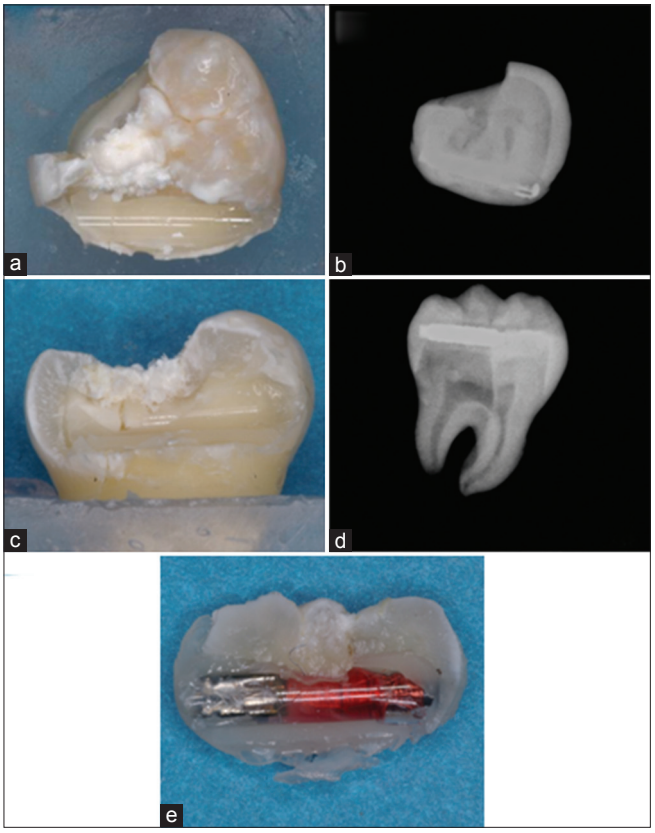

Figure 10: Sample 7 for the group 4. The figures show the adhesive failure (dental tissue vs. resin and resin vs. microchip). (a) Oclussal view. (b) Periapical radiography oclussal view. (c) Buccal view. (d) Periapical radiography buccal view. (e) Fractured fragment with RFID microchip

Conclusions

Given the outstanding resistance to compression, it is viable from the biomechanical point of view to implant microchips in the teeth, making it much more feasible to perform this

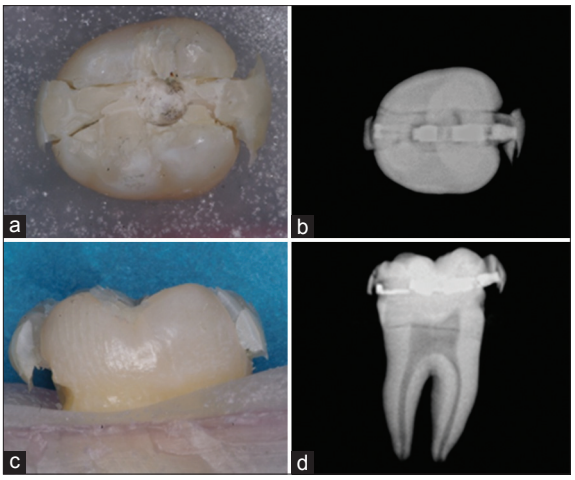

Figure 11: Sample 8 for the group 3. The figures show the adhesive failure (dental tissue vs. resin and resin vs. microchip) and adhesive failure (dental tissue vs. resin and resin vs. microchip) (a) Oclussal view. (b) Periapical radiography oclussal view. (c) Buccal view. (d) Periapical radiography buccal view

implantation in Class V cavities. Nevertheless, from the biological point of view (preservation of the amount and quality of the dental tissue), the dimensions of the microchip should be reduced.

The *Filtek P90™ Silorane 3M-ESPE®* restoration material resulted ideal for microchip implants in teeth, given that the cohesive and adhesive failures when applying the compressive forces are above the forces produced in the stomatognathic system. Only two microchips stopped functioning after the compression tests because of their fracture.

We suggest conducting other *in Vitro* studies, which can permit standardizing cavity size with a smaller microchip, as well as employing other types of materials employing the acid etching protocol.

Acknowledgment

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