

## RESEARCH ARTICLE

# Corrosion Resistance of indigenously Fabricated Dental Magnets for Application in Prosthodontics

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## ABSTRACT

**Aim:** The aim of the study is to evaluate the corrosion resistance of the indigenously fabricated dental magnet.

**Materials and methods:** The Teflon-encased Neodymium-Iron-Boron (Nd-Fe-B) magnet was put to test to comply with the standardized conditions. The corrosion behavior was examined using the statistical immersion analysis according to the International Organization for Standardization (ISO) 10271:2001: "Dental metallic materials corrosion test methods." In this method, the maximum ion release after 7 days was evaluated. The test specimen (magnet) was dipped in corrosive solution for 7 days in polypropylene test tube. Both the control and test magnets were dipped in artificial saliva. The pH of artificial saliva was adjusted to 6.75. After 7 days, the eluate solution was subjected to inductively coupled plasma spectroscopy evaluation to trace the amount of metal ions leached out from the magnets.

**Results:** The mean values for Nd, Fe, and B were 329, 532, and 316  $\mu\text{g}/\text{cm}^2$  respectively. According to the ISO standards, the tested product values of ions leached out should be within the value of 200  $\mu\text{g}/\text{cm}^2$ . The release of corrosion products stayed significantly under the limit as specified by the ISO standard 22674:2006 for all the specimens in the test groups.

**Conclusion:** Within the limitations of the study, the indigenously fabricated dental magnet had negligible corrosion in comparison with the control group.

**Clinical significance:** Magnetic attachments have most commonly been used for the retention of mandibular overdentures. Patients with magnet-retained overdentures have reported a high degree of satisfaction with their dentures. Due to the lack of indigenous fabrication and high costs of imported magnet has led to restricted use of magnets in developing countries. Indigenously developed dental magnets can reduce the cost and make them affordable to our native population. The abutment-friendly benefits of magnetic attachment will help retain the removable prostheses effectively.

**Keywords:** Corrosion, Dental magnet, Neodymium-Iron-Boron.

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## INTRODUCTION

Rare earth alloy magnets have been used in prosthetic dentistry for many years.<sup>1</sup> The two main areas of their use are orthodontics<sup>2,3</sup> and removable prosthodontics.<sup>4</sup> Intraoral magnets are small but offer satisfactory retentive forces to be used in various prosthodontic procedures. The force they deliver can be directed, and they can exert their force through mucosa and bone, as well as within the mouth. Despite their many advantages, which include ease of cleaning, ease of placement for both dentist and patient, automatic reseating, and constant retention with number of cycles, magnets have poor corrosion resistance within oral fluids and therefore, require encapsulation within a relatively inert material.

Permanent magnets based on intermetallic compounds are employed in dentistry to fix dental prosthesis. Nd-Fe-B-based magnets were developed in the beginning of the 1980s. They have a maximum energy product between 36 and 50 MGOe, and are progressively replacing Sm-Co magnets (maximum energy product 33 MGOe). Despite their excellent magnetic properties, Nd-Fe-B magnets are unstable at moderate to high temperatures and are highly susceptible to corrosion in environments of high humidity. The literature has associated the low corrosion resistance of these magnets to their complex microstructure.<sup>5-7</sup> The corrosion attack arises from the preferential oxidation of the Nd-rich phase in the grain boundary region.<sup>8</sup> The different electrochemical potentials arising from a multiphase composition leads to galvanic corrosion in the presence of an electrolyte.<sup>9</sup>

Nd-Fe-B magnets are usually produced by powder metallurgy (P/M). The Nd-rich phase is one of the most active phases present in the P/M Nd-Fe-B magnets. Preferential attack of this phase gives rise to intergranular corrosion leading to detachment of  $\phi$  grains, and eventually disintegration of the material.<sup>9</sup> This leads to the deterioration of the magnetic properties and can affect the performance of other components in the neighborhood, due to loose corrosion products on the surface.<sup>10</sup>

Much of the effort to improve the corrosion resistance of Nd-Fe-B magnets has concentrated on the use

of coatings to protect the magnet.<sup>11</sup> Attempts have also been made to increase the corrosion resistance of Nd–Fe–B-based magnets by addition of alloying elements.<sup>6,7</sup> However, alloying often deteriorates the magnetic properties, and despite the improvements made by the addition of alloying elements, protective coatings are still needed for practical applications.

Corrosion is a physiochemical interaction between a metal or an alloy and its environment that results in a partial or total destruction of the material or in a change of its properties. Both samarium cobalt and neodymium iron boron magnets are extremely susceptible to corrosion, especially in chloride-containing environments. Therefore, these magnets are encapsulated with different corrosion-resistant materials. Stainless steel and titanium are mostly used for encapsulation.<sup>12</sup> Apart from these, ceramic, Teflon, and aluminum have also been tried for encapsulation to prevent corrosion of the magnets. Therefore, the aim of this study was to evaluate the *in vitro* corrosion resistance of the indigenously fabricated dental magnet.

## MATERIALS AND METHODS

### Source of Data

#### *Fabrication of Magnet*

A rare earth magnet (Nd–Fe–B) was machine cut to get the desired dimension. The magnet was in a circular shape (Fig. 1). The diameter of the magnet was designed based on the average value of cross-sectional diameter of the mandibular canine and premolar tooth. The diameter of the neodymium iron boron magnet was 3 and 1.5 mm thick in height. The basic design of the magnet was pot-type. Pot-type meaning the magnets were encased in the corrosion-resistant material. Teflon was used to encase the bare magnet to act as corrosion-resistant material. The Teflon encasing was done in a computer numerical

control microlathe. The wall thickness of the Teflon sleeve was 0.7 mm (Fig. 2).

### Corrosion Test

The Teflon encased Nd–Fe–B magnet was put to test to comply with the standardized conditions. The corrosion behavior was examined using the statistical immersion analysis according to ISO 10271:2001: "Dental metallic materials corrosion test methods." In this method, the maximum ion release after 7 days was evaluated.

The test specimen (magnet) was dipped in corrosive solution for 7 days in polypropylene test tube. The preparation of specimen and test solution was carried out in compliance with the corrosion test methods for dental metallic materials. Corrosive solution used was artificial saliva. The pH of the artificial saliva was adjusted to 6.75 with KOH. Since there are often traces of rare earth elements in glass test tubes, polypropylene test tubes (TPP, Trasadingen, Switzerland) were used to avoid contamination by the used test tubes and thus a falsification of the results. Each specimen was put into a single, sterile polypropylene tube. The corrosion solution was freshly prepared for every test interval. The magnet was dipped in 23 mL of artificial saliva. This is to comply with the total surface area of the magnet. The total surface area of magnet is 23 cm<sup>2</sup>. According to ISO standards 10271:2001, the test extract should be in consideration of a surface/volume ratio of 1 cm<sup>2</sup>/mL of the test solution.

After 7 days of dipping the magnet, it was removed and the eluate solution was subjected to inductive-coupled plasma (ICP) spectroscopy test. The ICP traced the different ions released into the corrosive solution in terms of quantity. The ions released into the corrosive media should be within the limit of 200 mg/cm<sup>2</sup> to certify that the given specimen is corrosion-resistant. This is based

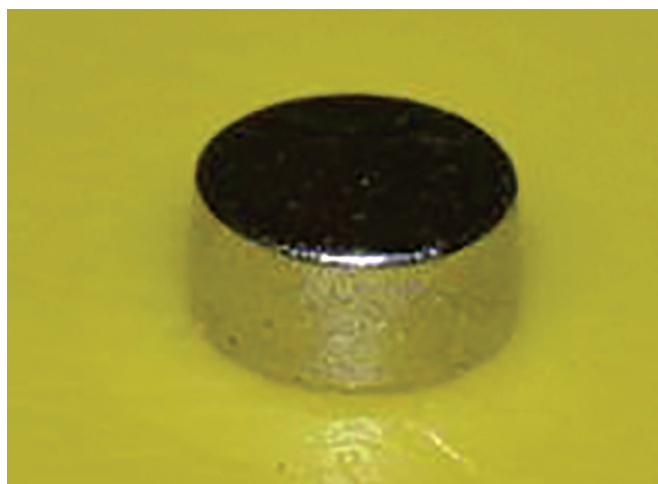


Fig. 1: Bare neodymium iron boron magnet



Fig. 2: Teflon sleeve-encased dental magnet



Fig. 3: Control and test magnets dipped in artificial saliva

on the ISO 10271:2001: “Dental metallic materials corrosion test methods.”

Two groups were made: (1) Control – noncased bare magnet and (2) Test – magnet encased with Teflon sleeve. Both the magnets were dipped in separate tubes containing artificial saliva (Fig. 3).

**Preparation of Artificial Saliva**

The artificial saliva used in the study was prepared according to Macknight-Hane and Whitford formula. The composition is as follows:

- Methyl-p-hydroxybenzoate: 2 gm/L
- KCL: 0.625 gm/L
- Magnesium chloride: 0.059 gm/L
- Calcium chloride: 0.166 gm/L
- K<sub>2</sub>HPO<sub>4</sub>: 0.804 gm/L
- KH<sub>2</sub>PO<sub>4</sub>: 0.326 gm/L

**Steps in Preparation**

- 2 gm of hydroxyl-p-benzoate was dissolved in 800 mL of distilled water; 20 mL of the solution was stored for other chemical agent solvent. The remaining solution was stored in refrigerator.
- 10 gm of sodium carboxy methyl cellulose was sparkled in the 200 mL boiling water and stirred until total of it was dissolved.
- Cold methyl-p-hydroxybenzoate solution was poured into the sodium carboxy methyl cellulose.
- 0.625 gm of KCl was dissolved in methyl-p-hydroxybenzoate solution and then poured the solution into the item 3 and mixed them together.
- 0.059 gm of MgCl<sub>2</sub> was dissolved in methyl-p-hydroxybenzoate solution from item 1, then poured the solution into the solution of item 4 and mixed them together.
- 0.166 gm of CaCl<sub>2</sub> was dissolved in methyl-p-hydroxybenzoate solution from item 1, then poured

the solution into the solution of item 5 and mixed them together.

- 0.804 gm of K<sub>2</sub>HPO<sub>4</sub> was dissolved in methyl-p-hydroxybenzoate solution from item 1 and then poured the solution into the solution of item 6 and then mixed together.
- 0.326 gm of KH<sub>2</sub>PO<sub>4</sub> was dissolved in methyl-p-hydroxybenzoate solution from item 1 and then poured the solution into the solution in item 7 and mixed together.
- Finally, the pH of artificial saliva is adjusted to 6.75 with KOH.

The ICP spectroscopy detects the ions that are leached out into the artificial saliva from the Nd-Fe-B magnet in test specimen (encased in Teflon sleeve) and also the control specimen (bare magnet). The magnets were removed from the corrosive media after 7 days, and the dipped corrosive solution was subjected to ICP test. The ICP machine will be fed with standard solutions of Nd, Fe, and B in three concentrations. Three different concentrations of the standards were prepared for all the three elements. The lower limit of determination for the found ions amounted to 0.05 µg/mL. If no less than 200 mg/cm<sup>2</sup> (ISO standards) ions are found in the corrosive media, then the test specimen is said to be corrosion-resistant. The control specimen (bare magnet) is expected to have maximum corrosion.

**RESULTS**

The results showed that all the values of the control group are more than the value recommended by the ISO standard 22674:2006. The mean and standard deviation has been presented in Table 1. The mean values for Nd, Fe, and B were 329, 532, and 316 µg/cm<sup>2</sup> respectively. According to the ISO standards, the tested product values of ions leached out should be within the value

**Table 1:** Mean and standard deviation values for the ions leached out from the magnet for the control group (µg/cm<sup>2</sup>)

	Nd	Fe	B
Mean	329.1923	532.5077	316.657
Standard error	15.40516	20.22088	23.06388
Median	337.06	509	301
Mode	356	546	332
Standard deviation	84.37753	110.7543	126.3261
Sample variance	7119.567	12266.52	15958.28
Kurtosis	-0.86452	1.883991	16.39391
Skewness	0.048562	1.173364	3.555502
Range	312.11	508	694
Minimum	178	368	208
Maximum	490.11	876	902
Sum	9875.77	15975.23	9499.71
Count	30	30	30

**Table 2:** Mean and standard deviation values for the ions leached out from the magnet for the test group ( $\mu\text{g}/\text{cm}^2$ )

	Nd	Fe	B
Mean	0.672414	2.475333	0.512
Standard error	0.081452	0.16806	0.053138
Median	0.68	2.68	0.48
Mode	0.22	2.68	0.48
Standard deviation	0.438631	0.920505	0.265691
Sample variance	0.192398	0.847329	0.070592
Kurtosis	-0.05248	-0.2271	-0.18853
Skewness	0.709901	-0.2929	0.251948
Range	1.68	3.78	1.03
Minimum	0.12	0.48	0.03
Maximum	1.8	4.26	1.06
Sum	19.5	74.26	12.8
Count	29	30	25

of  $200 \mu\text{g}/\text{cm}^2$ . The release of corrosion products stayed significantly under the limit as specified by the ISO standard 22674:2006 for all the specimens in the test groups (magnet encased in Teflon sleeve) and are displayed in Table 2. The nonencased magnets exceeded the limit. The indigenous dental magnets with Teflon sleeve were corrosion-resistant. In both the groups the patterns of ions leaching out seems to be the same. Iron is the one, which is more readily corroded.

## DISCUSSION

The oral environment and dental structures present complex conditions that can promote corrosion and discoloration. The variables of diet, bacterial activity, drugs, smoking, oral hygiene methods, and saliva unquestionably account for a great difference in corrosion. Corrosion is the actual deterioration of a metal by reaction with its environment. The disintegration of the metal may occur through the action of moisture, atmosphere, acid or alkaline solutions, and certain chemicals. Corrosion may cause the magnet to lose its efficiency by losing its structure. The magnetic flux density reduces, thereby reducing the power of the magnet.

In the previous studies, metallic corrosion was tested in different ways. For example, corrosion was analyzed visually by examining the surface of the specimen, by determining the surface roughness and the loss of weight, or by indirect, electrochemical measurement of the electron flow and the release of elements.<sup>13,14</sup> Other authors used changes in the magnetic flux density or in the retention force for determining the amount of corrosion.<sup>15,16</sup> Added option is the direct, quantitative measurement and identification of released elements with the help of different analytical methods. In these experiments, different solutions were used as the corrosive medium.

The first trials to protect the magnetic alloy against corrosion were carried out with a Proplast coating, which is a mixture of polytetrafluorethylene (PTFE) and graphite. Other tests were made by using epoxide resins,<sup>17</sup> stainless steel,<sup>18</sup> and parylene,<sup>19</sup> a corrosion-protective polymeric coating material applied in vacuum by condensation from gas phase as a nonporous and transparent polymer film on the magnet.<sup>15</sup>

In the present study, Teflon (PTFE) sleeve was made and the magnet was embedded in the sleeve. The sleeve thickness was 0.5 mm. The magnet with Teflon sleeve was immersed in artificial saliva with a pH of 6.2 for 7 days, the magnet was corrosion-resistant, and the ions leached out in the corrosive media were within the limit of  $200 \mu\text{g}/\text{cm}^2$ . This limit is set according to the ISO standard 22674:2006. Ahmad et al<sup>15</sup> conducted a study and showed better corrosion resistance with PTFE-coated neodymium iron boron magnets. Similar results were displayed in the present study. However, the long-term usage of these magnets embedded in Teflon sleeve needs to be investigated in the clinical study.

## CONCLUSION

In the present study, a rare earth magnet, neodymium iron boron magnet, was used. It was encased in the Teflon sleeve. Teflon is known to be biocompatible and corrosion-resistant material. The magnet was encased in a custom-made Teflon sleeve. This was subjected to corrosion-resistance test. From the results of the study we conclude that the indigenously fabricated dental magnet found to be corrosion-resistant.

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