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ORIGINAL RESEARCH

Comparison of Galvanic Corrosion Potential of Metal Injection Molded Brackets to that of Conventional Metal Brackets with Nickel-Titanium and Copper Nickel-Titanium Archwire Combinations

D Praveen Kumar Varma, S Chidambaram, K Baburam Reddy, M Vijay, D Ravindranath, M Rajendra Prasad

ABSTRACT

Aim: The aim of the study is to investigate the galvanic corrosion potential of metal injection molding (MIM) brackets to that of conventional brackets under similar *in vitro* conditions with nickel-titanium and copper nickel-titanium archwires.

Materials and methods: Twenty-five maxillary premolar MIM stainless steel brackets and 25 conventional stainless steel brackets and archwires, 0.16 inch, each 10 mm length, 25 nickel-titanium wires, 25 copper nickel-titanium wires were used. They were divided into four groups which had five samples each. Combination of MIM bracket with copper nickel-titanium wire, MIM bracket with nickel-titanium wire and conventional stainless steel brackets with copper nickel-titanium wire and conventional stainless steel brackets with nickel-titanium wires which later were suspended in 350 ml of 1 M lactic acid solution media. Galvanic corrosion potential of four groups were analyzed under similar *in vitro* conditions. Precorrosion and postcorrosion elemental composition of MIM and conventional stainless steel bracket by scanning electron microscope (SEM) with energy dispersive spectroscope (EDS) was done.

Results: MIM bracket showed decreased corrosion susceptibility than conventional bracket with copper nickel-titanium wire. Both MIM and conventional bracket showed similar corrosion resistance potential in association with nickel-titanium archwires. It seems that both brackets are more compatible with copper nickel-titanium archwires regarding the decrease in the consequences of galvanic reaction. The EDS analysis showed that the MIM brackets with copper nickel-titanium wires released less metal ions than conventional bracket with copper nickel-titanium wires.

Conclusion: MIM brackets showed decreased corrosion susceptibility, copper nickel-titanium archwires are compatible with both the brackets than nickel-titanium archwires.

Clinical significance: Clinically MIM and conventional brackets behaved more or less similarly in terms of corrosion resistance. In order to decrease the corrosion potential of MIM brackets, more precise manufacturing technique should be improved to get a more smoother surface finish.

Keywords: Premolar teeth, Brackets, Aligning archwires, Energy dispersive spectroscope.

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INTRODUCTION

Modern orthodontic appliances used intraoral are alloys like stainless steel, cobalt-chromium, beta-titanium and nickel-titanium. These alloys when left for long duration in the oral cavity[2,4] undergo many stresses like masticatory loading and temperature fluctuations which can result in corrosion.[5,8]

Acidic conditions and chloride ions can interfere with passivation process.[9,11] Therefore, a diet rich in sodium chloride and acidic carbonated drinks provides a regular supply of corrosion agents. Oral bacterial fermentation leads to production of fermentable carbohydrates like lactic acid which will change the local pH value to acidic[10] which may dissolve the protective oxide layer on the surface.

Corrosion resistance of the contemporary orthodontic appliances is important for prevention of ion release in to the oral cavity. Some of these ions, such as nickel (Ni),[7] chromium (Cr), iron (Fe) have been associated with allergic, cytotoxic or carcinogenic effects.[6,7,12]

In an effort to prevent galvanic corrosion, metal injection molding (MIM)[3] has been introduced. These are single unit brackets with uniform elemental distribution without any brazing components, thereby eliminating the possibility of galvanic corrosion that occurs within a bracket.

The aim of the study were to investigate the galvanic corrosion potential of MIM brackets to that of conventional brackets under similar *in vitro* conditions with nickel-titanium and copper nickel-titanium archwires.

AIMS AND OBJECTIVES

The aims and objectives of the study were:

1. To compare the galvanic corrosion potential of MIM brackets to that of conventional brackets under similar *in vitro* conditions with commonly used orthodontic aligning archwires–nickel-titanium and copper nickel-titanium archwires.
2. To compare the precorrosion and postcorrosion elemental composition of MIM and conventional stainless steel bracket by scanning electron microscope (SEM) with energy dispersive spectroscope (EDS).
3. To evaluate whether the MIM bracket has improved corrosion resistance potential when compared to that of conventional brackets.

MATERIALS AND METHODS

Electrochemical measurements were made with a Gill AC Potentiostat, ACM Instruments, England. The main focus of the study is to measure the galvanic current and potential difference in relation to time and to check the elemental composition analysis.

Materials

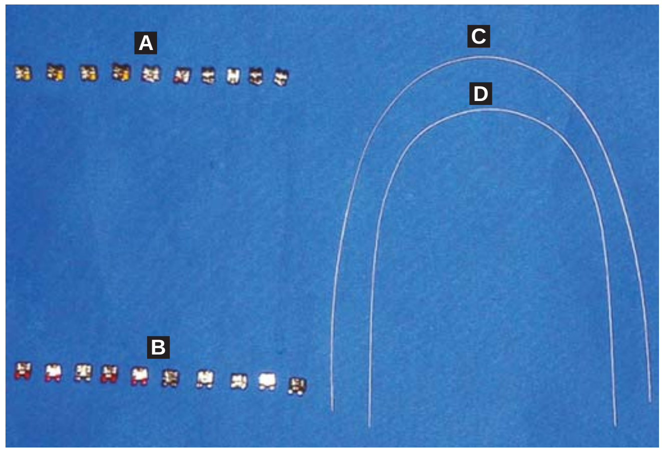
1. Brackets: Maxillary premolar bracket (0.22 Roth series)
   a. Metal injection molded stainless steel bracket (SIA Orthodontics)—25 nos (Fig. 1A)
   b. Conventional stainless steel bracket (American Orthodontics)—25 nos (Fig. 1B)
2. Archwire, 0.16 inch, each 10 mm length
   a. Nickel-titanium wire (G&H)—25 nos (Fig. 1C)
   b. Copper nickel-titanium wire (Ormco)—25 nos (Fig. 1D)
3. Media: 350 ml of 1 M lactic acid solution (pH = 1.3) (Figs 2A to D)
4. Gill AC potentiostat machine (Fig. 3), ACM Instruments, England (Fig. 4)
5. Scanning electron microscope (SEM, JEOL JSM – 5610 LV, Germany) with EDS detector (6587, Oxford Instrument, England) (Fig. 5).

Samples

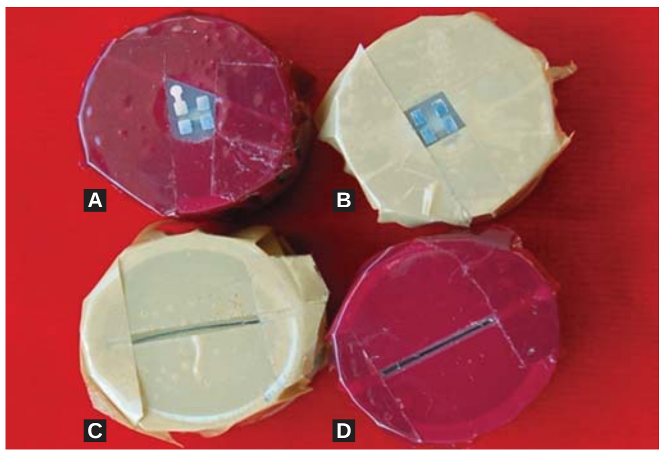
Four groups were taken and each of these groups had five samples in them. Each sample was combined with different groups assigned. The experimental groups comprised of the following four combinations and they are denoted in this table.

Composition of test groups

S.no.	Group code	Specimen
1.	A ↔ C	MIM bracket with nickel-titanium wire
2.	A ↔ D	MIM bracket wire copper nickel-titanium wire
3.	B ↔ C	Conventional bracket with nickel-titanium wire
4.	B ↔ D	Conventional bracket with copper nickel-titanium wire



Figs 1A to D: (A) MIM bracket, (B) conventional bracket, (C) nickel-titanium wire and (D) copper nickel-titanium wire



Figs 2A to D: Mounted samples: (A) MIM bracket, (B) conventional bracket, (C) nickel-titanium wire and (D) copper nickel-titanium wire

Methods

Twenty-five MIM brackets and conventional brackets and 25 nickel-titanium and copper nickel-titanium archwires are placed in 10 cm long polyvinyl chloride pipe embedded in epoxy resin. Five brackets from each case were kept vertically for taking cross-section view to obtain scanning electron image. Twenty bracket MIM and conventional bracket was kept horizontally to expose the bracket wing area to check the corrosion.

All brackets and wire were ground with silicon carbide paper under continuous water cooling until the interface between the tie wings and bracket base was exposed in vertically embedded bracket. Horizontally embedded

ARMAMENTARIUM

Fig. 3: Gill AC potentiostat machine

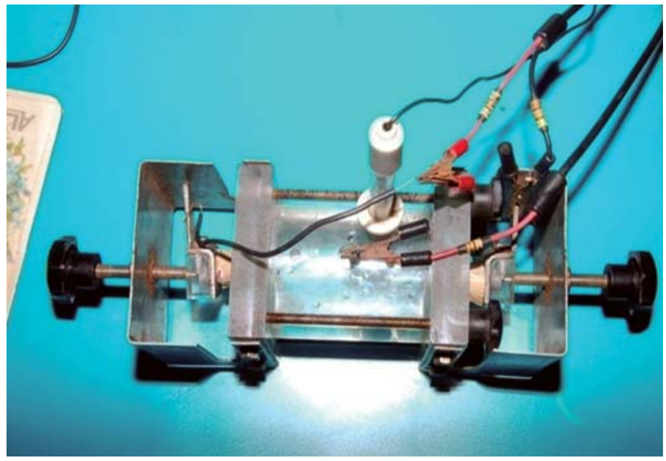


Fig. 4: Sample test in potentiostat machine

Fig. 5: Scanning electron microscope

Fig. 6: Sample for SEM

brackets were grounded until the bracket wing was exposed. All brackets and wings were polished with diamond paste up to 1 mm in a grinding polishing machine.

To analyze the elemental composition of each MIM and conventional bracket (Fig. 6), SEM (JEOL JSM – 5610 LV, Germany) with EDS detector (6587, Oxford Instrument, England) was used, before subjecting them to corrosion testing their composition was recorded.

Electrochemical testing was performed with a potentiostat connected to a desktop computer. The galvanic current and galvanic potential between each possible combination of bracket and wire were tested.

Each testing bracket and archwire was suspended in its own glass container of the potentiostat which contain 350 ml of 1 M lactic acid (pH = 1.3). The bracket cables were connected to anode and the wires cables to the cathode. The reference electrode was platinum and counter electrode was saturated calomel electrode. The galvanic current and potential difference between the anode (brackets) and cathode (archwires) was continuously monitored and recorded for 12 hours. The groups of potential difference and groups of galvanic current flow between the anode and cathode were produced for each of the bracket and wire combinations tested.

After taking reading at the potentiostat for 12 hours SEM-EDS was taken to evaluate the composition and this was compared with postcorrosion records.

There were a total of four different bracket archwire combinations and each was tested five times.

RESULTS

The present study was carried out to study the corrosion potential of MIM bracket to that of conventional bracket and to evaluate whether the MIM bracket has improved corrosion resistance potential when compared to that of conventional bracket. The electrochemical measurement were made with a Gill AC potentiostat, the measurement of the galvanic current and potential difference in relation to time and current are recorded and the results are tabulated in Table 1.

Table 1: Current/Time

Groups	*N*	*Mean (mA)*	*SD*	*F-value*	*p-value*
AD	5	0.000051	0.0009	11.64	0.0001 S
BD	5	0.000061	0.0004		
AC	5	0.000082	0.0002		
BC	5	0.000091	0.0004		

S: Significant

The collected data were subjected to statistical analysis by using SPSS package for windows using one-way analysis of variance (ANOVA) to find out if there was any significant difference in value recorded.

Decreased current/time causes increased corrosion resistance. Results show that MIM bracket with copper nickel-titanium shows better corrosion resistance than conventional bracket with copper nickel-titanium (Table 1).

Decreased potential/time causes increased corrosion resistance. Results show that MIM bracket with copper nickel-titanium shows better corrosion resistance than conventional bracket with copper nickel-titanium. MIM bracket with nickel-titanium shows lesser corrosion resistance than conventional bracket with nickel-titanium archwire (Table 2).

Increased potential/time causes increased corrosion resistance. Result shows that MIM bracket with copper nickel-titanium shows better corrosion resistance than conventional bracket with copper nickel-titanium (Table 3). MIM bracket with nickel-titanium shows better corrosion resistance than conventional bracket with nickel-titanium.

Table 2: Potential/time

Groups	*N*	*Mean (mV)*	*SD*	*F-value*	*p-value*
AD	5	136.00	86.49	125.43	0.0001 S
BD	5	232.56	23.37		
AC	5	433.00	5.50		
BC	5	422.70	21.68		

S: Significant

Table 3: Potential/Current

Groups	*N*	*Mean (mV)*	*SD*	*F-value*	*p-value*
AD	5	114.50	46.68	2.52	0.05 S
BD	5	89.00	80.89		
AC	5	42.00	66.01		
BC	5	21.65	106.66		

S: Significant

EDS analysis pre- *vs* postcorrosion, EDS analysis postcorrosion showed that there is no statistical significant difference between the groups.

But MIM bracket with copper nickel-titanium release fewer ions than the conventional bracket with copper nickel-titanium and also conventional bracket with copper nickel-titanium release fewer ions than MIM with nickel-titanium wire.

The overall findings from the groups shows that MIM bracket with copper nickel-titanium has better corrosion resistance potential. Both MIM and conventional bracket shows similar potential difference to nickel-titanium archwires (Graph 1). Both brackets are more compatable with copper nickel-titanium wire than nickel-titanium archwire.

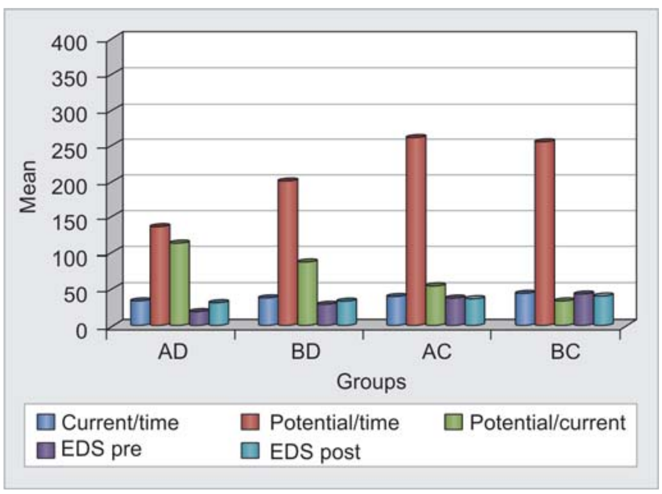
DISCUSSION

Corrosive resistance of the appliances is important for the prevention of ion release[3] into the oral cavity. Some of these ions, such as nickel (Ni),[12] chromium (Cr)[9] have been associated with allergic, cytotoxic or carcinogenic[14] effect when taken up by the human body.[7]

The present study was carried out on a Gill AC potentiostat, the electrochemical measurement galvanic current and potential difference in relation to time and potential difference in relation to current were recorded. The electrochemical measurement was based on the previous work in literature by Bakthari et al[1] in which the galvanic current and amount of charge transferred for each pair were monitored with a zero resistance ammeter for 10 hours.

Electrochemical measurement results show that current/time in which more amount of current consumption is for conventional bracket with nickel-titanium and the least for MIM with copper nickel-titanium. More amount of current consumption causes increase corrosion rate and galvanic susceptibility. Statistical result shows that there is a significant difference among the groups.

Potential/time shows that lowest potential differences were found for MIM with copper nickel-titanium wire and the highest for MIM with nickel-titanium wire. Conventional brackets with copper nickel-titanium has lesser potential difference than MIM copper nickel-titanium but has lower potential difference with MIM nickel-titanium wire. Higher potential difference has increased galvanic susceptibility. According to the results conventional bracket has higher



Graph 1: Comparison of all groups

potential difference than MIM bracket and might have greater corrosion susceptibility. Statistical result shows that there is a significant difference among the groups, in which MIM with copper nickel-titanium shows the lowest value. Barbara Siargos et al[3] reported that highest potential difference were found for MIM-nickel-titanium and the lowest for MIM copper nickel-titanium with corrosion susceptibility decreasing from the former to the latter couple.

Results for potential/current shows that the value is higher for MIM with copper nickel-titanium. The lowest for conventional bracket with nickel-titanium wire. Conventional bracket with copper nickel-titanium has higher E-Corr value than MIM with nickel-titanium wire but has lesser value than MIM with copper nickel-titanium. Higher E-Corr value has decreased corrosion susceptibility. Statistical results show that there is a significant difference regarding potential/current among the various groups. It shows that MIM with copper nickel-titanium is superior to other groups.

SEM with elemental analysis showed that the conventional bracket consist of two parts (base and wing) (Fig. 10) joined together with a silver (Ag)-based brazing alloy, whereas MIM bracket is a single-unit fabrication, which is free of brazing alloy (Fig. 9).

The elemental composition of the MIM bracket has slight differences from that of the conventional bracket, this might be due to the different company uses, different materials for the manufacturing of their brackets, and thus the biological, corrosive, physical and clinical properties can vary among the available products.

Precorrosion SEM of MIM bracket shows that it has large granular structure than conventional bracket and there are increased amount of internal porosity (Fig. 7). In contrast conventional brackets have less porosity and have smaller granular structure (Fig. 8).

Postcorrosion SEM shows that there is increased amount of corrosion on conventional bracket with nickel-titanium wire (Fig. 14) when compared to that of MIM

SCANNING ELECTRON MICROSCOPE VIEW

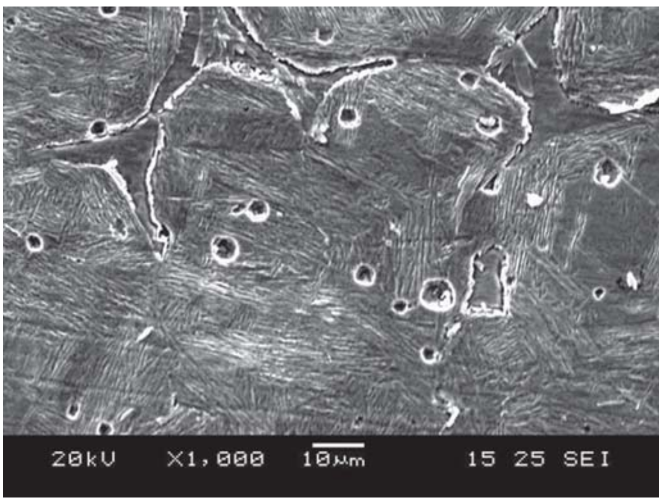


Fig. 7: Precorrosion MIM bracket

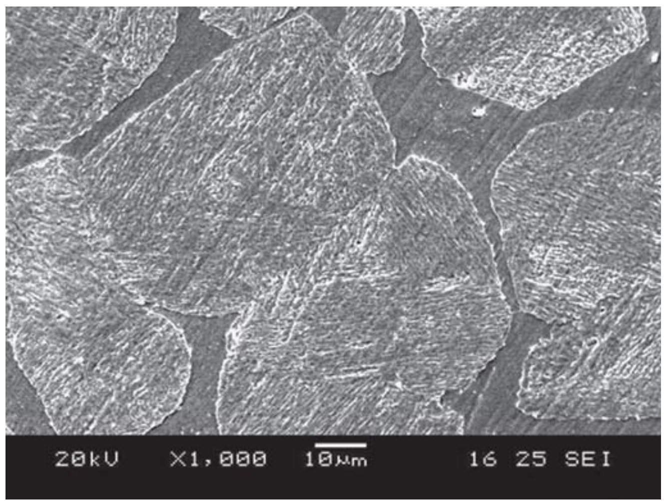


Fig. 8: Precorrosion conventional bracket

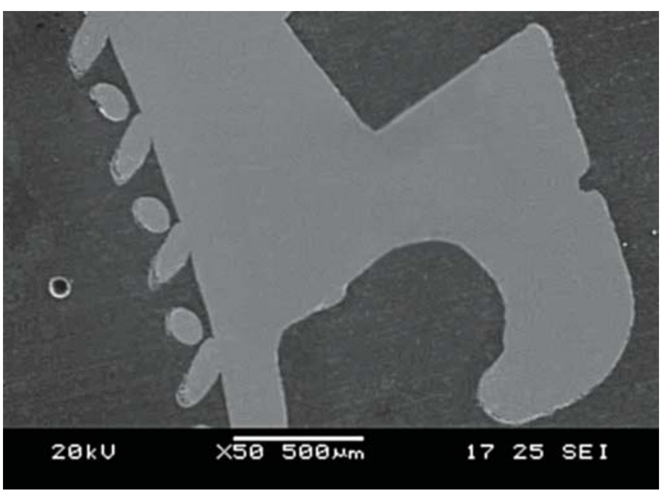


Fig. 9: Cross-section MIM bracket

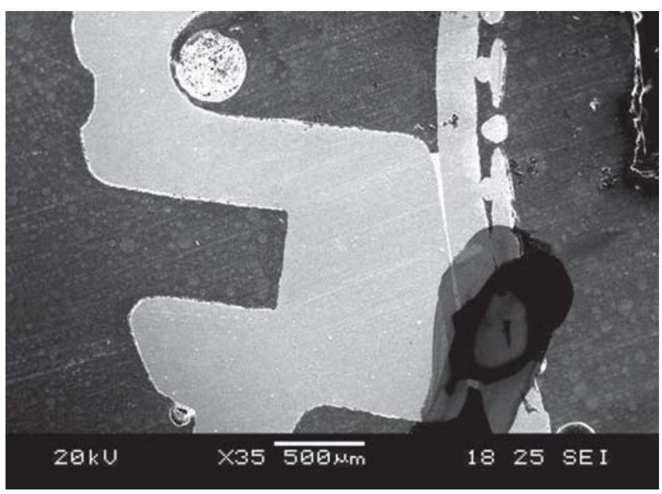


Fig. 10: Cross-section conventional bracket

with nickel-titanium wire (Fig. 13). The least amount of corrosion is seen in MIM with copper nickel-titanium wire (Fig. 11) whereas conventional bracket with copper nickel-titanium shows (Fig. 12) more corrosion than MIM with copper nickel-titanium but less than MIM with nickel-titanium.

Elemental analysis shows that in MIM bracket increased loss of metal ions take place in MIM with nickel-titanium wire than MIM with copper nickel-titanium, whereas in conventional bracket with nickel-titanium it has increased metal ion loss than conventional bracket with copper nickel-titanium.

Statistical result shows that there is no significant difference between pre- and postcorrosion EDS groups. The decreased ion loss with copper nickel-titanium wire is due to copper which is more noble [electrode potential (V) (+0.47)] than nickel [electrode potential (V) (–0.23)]. Skinners[13] explains the electromotive series of metal, so that the less noble metal causes more corrosion on the specific bracket.

The findings are comparable with studies done by Barbara Siargos et al[3] where copper nickel-titanium archwire produces lower potential difference than nickel-titanium archwire with conventional and MIM brackets and thus are less susceptible to galvanic corrosion.

Postcorrosion EDS analysis shows that MIM with copper nickel-titanium has least ion release. Whereas conventional bracket with copper nickel-titanium has less ion release than MIM with nickel-titanium conventional bracket with nickel-titanium has more amount of ion release than MIM with nickel-titanium. Statistical result shows that there is no significant difference between postcorrosion groups.

Although the MIM bracket exhibit comparable galvanic potential to the conventional bracket, the study mainly focused on the initial aligning wires like nickel-titanium

SEM VIEW

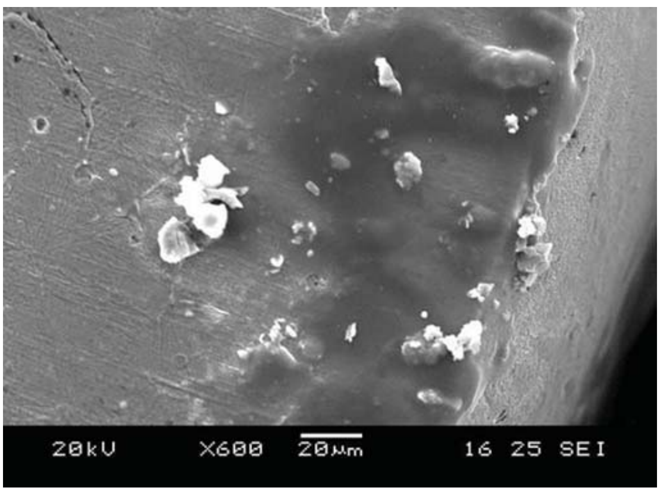


Fig. 11: Postcorrosion MIM bracket with Cu NiTi wire

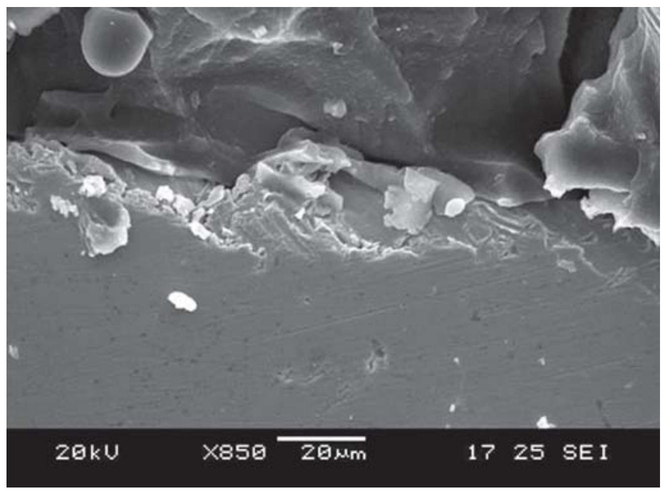


Fig. 12: Postcorrosion conventional bracket with Cu NiTi wire

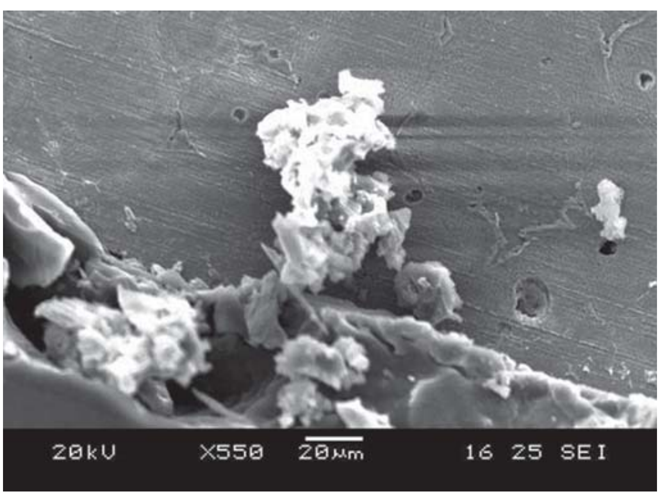


Fig. 13: Postcorrosion MIM bracket with NiTi wire

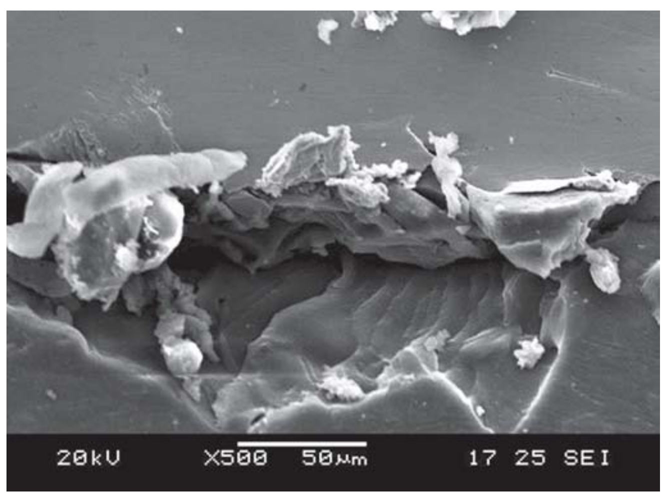


Fig. 14: Postcorrosion conventional bracket with NiTi wire

and copper nickel-titanium. Between these two wires copper nickel-titanium archwire shows lower potential difference than nickel-titanium archwire suggestive of less corrosion potential. The combinations with superior corrosion resistance are as follows: MIM with copper nickel-titanium, conventional bracket with copper nickel-titanium, MIM with nickel-titanium and conventional bracket with nickel-titanium.

Although the conventional bracket has smaller granular structure than MIM bracket it also has similar corrosion resistance rate, as confirmed with the EDS analysis which shows that there is no statistically significant amount of difference. In clinical situations both MIM and conventional brackets behave similarly in terms of there respective corrosion resistance. In order to decrease the corrosion potential of MIM brackets, more precise manufacturing technique should be improved to get a more smoother surface finish.

SUMMARY AND CONCLUSION

This study was conducted to investigate the galvanic corrosion of MIM and conventional brackets with nickel-titanium and copper nickel-titanium archwires and to evaluate whether the MIM bracket has improved corrosion resistance potential when compared to that of conventional brackets.

From the results of the above investigation, it was concluded that the MIM bracket yielded better electrochemical measurements than conventional bracket with copper nickel-titanium wire, suggestive of decreased corrosion susceptibility. Both MIM and conventional bracket showed similar corrosion resistance potential in association with nickel-titanium archwires.

Based on the results of the present study, it seems that both brackets are more compatible with copper nickel-titanium archwires regarding the decrease in the consequences of galvanic reaction.

According to the EDS analysis the MIM bracket with copper nickel-titanium released less metal ions than conventional bracket with copper nickel-titanium. At the same MIM bracket with nickel-titanium wire released more metal ions than conventional bracket with copper nickel-titanium. As per the statistical analysis the results showed that there is no significant difference among the various groups.

Due to the number of variables like the number of samples tested, types of orthodontic archwires tested, duration of the study, it is suggested to have further extensive clinical and laboratory research to characterize the safety and efficiency of these orthodontic brackets.

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ABOUT THE AUTHORS

D Praveen Kumar Varma (Corresponding Author)

Professor, Department of Orthodontics, Vishnu Dental College Bhimavaram-534202, Andhra Pradesh, India, e-mail: dpkvarma@yahoo.com

S Chidambaram

Professor, Department of Orthodontics, Rajah Muthiah Dental College and Hospital, Chidambaram, Tamil Nadu, India

K Baburam Reddy

Professor, Department of Orthodontics, Vishnu Dental College Bhimavaram, Andhra Pradesh, India

M Vijay

Professor and Head, Department of Orthodontics, CSI Dental College Madurai, Tamil Nadu, India

D Ravindranath

Professor, Department of Periodontics, Sibar Institute of Dental Sciences, Guntur, Andhra Pradesh, India

M Rajendra Prasad

Professor and Head, Department of Periodontics, Lenora Institute of Dental Sciences, Rajahmundry, Andhra Pradesh, India