Survival analysis of brackets and tubes

A twelve-month assessment

Min-Ho Jung*

ABSTRACT

Objective: To compare the clinical performance of brackets bonded to anterior and posterior teeth, including second molars.

Materials and Methods: One operator, using the straight-wire technique, bonded metallic brackets to the teeth of 127 consecutive patients. All patients were observed for 12 months during their regular orthodontic appointments. Bracket failures were recorded and summarized for statistical analysis. The Cox proportional hazards regression analysis was performed to evaluate bracket failure rates.

Results: Statistically significant differences in survival rates were observed between molar tubes and anterior brackets \( (P < .05) \). Twelve-month failure rates of incisor, canine, premolar, and molar brackets were 3.6, 1.6, 4.8, and 11.6%, respectively. The first and second molar did not show significant difference in bond failure. Young patients (age <18 years) showed a higher failure rate than old patients (≥18 years).

Conclusions: Brackets directly bonded to the buccal surfaces of molars failed significantly more often than those directly bonded to anterior teeth or premolars, but showed acceptable failure rate especially in adult patients. Bonding on second molars seems to be as reliable as bonding on the first molars. \((\text{Angle Orthod.} \ 2014;84:1034–1040.)\)

KEY WORDS: Bracket failure; Molar tube; Bonding

INTRODUCTION

Since the introduction of direct bonding of orthodontic brackets to enamel surfaces in the 1960s, many studies have investigated the clinical applicability of various materials and equipment. It has been shown that etching with 30%–50% phosphoric acid and light-cured adhesives can produce sufficient bond strength\(^1\) and an acceptable bracket survival rate.\(^2\)

Brackets bonded to posterior teeth tend to have a higher failure rate than those bonded to anterior teeth.\(^2,3\) For that reason, although previous research has shown that banded molars show a significantly greater loss of attachment during orthodontic treatment than bonded molars\(^4\) and bands can increase gingival inflammation,\(^5\) many clinicians still use bands\(^6\) to achieve a reliable adhesive bond. Although considerable advances have been made in the quality of adhesives and light-curing units, few recent studies have explored the clinical efficiency of bracket bonding on posterior regions.

It is believed that anchorage of the posterior teeth could be reinforced by adding the second molar to the posterior unit.\(^7\) For this reason, second molars are bonded from the beginning of the treatment in moderate or maximum anchorage cases when it is possible. But until now, information regarding second molar bonding is insufficient.

The aims of this prospective cohort study were to investigate the time to first failure and total failure rate of stainless steel orthodontic brackets and molar tubes including second molar over a 12-month period, and to assess whether this was related to the position of the tooth, gender, and/or age at the start of treatment.

MATERIALS AND METHODS

The Seoul National University Dental Hospital Institutional Review Board approved this clinical study.
One hundred twenty-seven consecutive patients (Table 1) from one orthodontic practice who met the inclusion criteria were recruited. Subjects were considered eligible for the study if they (1) required two-arch fixed appliance therapy using metal brackets; (2) all second molars had erupted and brackets were bonded to them at the beginning of treatment; and (3) did not have craniofacial anomalies, developmental defects involving enamel, or impacted teeth. Patients who needed rapid maxillary expander or fixed functional appliance were excluded. Sex, age, and race differences were ignored, and there was no restriction on the type of malocclusion. Teeth with fillings, hypoplasia, white spots on the buccal surface, or a prosthetic crown were excluded. Before the beginning of treatment, all patients were instructed in oral hygiene.

A total of 3061 brackets and tubes bonded to the enamel surface by a single operator were evaluated. Two hundred ninety-two teeth were extracted for orthodontic purposes and 203 teeth had a buccal filling, enamel hypoplasia, white spots, or a prosthetic crown. Enamel surfaces were cleaned with fluoride-free pumice with a rubber polishing cup and then etched with 37% phosphoric acid for 30 seconds (incisors, canines, molars) or 60 seconds (molars). After thorough washing, the enamel surfaces were dried with an oil-free air syringe and .022-inch slot metal brackets and molar tubes (Victory Series, 3M Unitek, Monrovia, Calif) were bonded with composite adhesive (Transbond XT, 3M Unitek) according to the manufacturer's guidelines. After applying primer to the etched enamel, a small amount of adhesive was placed on the mesh pad of the bracket base. The bracket was positioned on the labial surface with sufficient pressure to squeeze excess adhesive, which was removed from the margins of the bracket base with an explorer. The adhesive was then cured with plasma arc light (Flipo, LOKKI, Les Roches, France) for 9 seconds per bracket (3 seconds mesially, 3 distally, and 3 occlusally) according to the previous study.6

To ensure that light intensity did not change significantly during the experiment, we used a radiometer (Model 100, Demetron, Danbury, Conn) to determine the initial reading, which was 1370 mW/cm². We measured light intensity each month and adjusted it if needed during the experiment.

Every effort was made to minimize variation in the magnitude of orthodontic force applied to the brackets and teeth. The usual choice of initial aligning archwire was 0.014-inch nickel-titanium (NiTi) wire, followed by progressively thicker NiTi wires, and finally 0.019 × 0.025-inch stainless steel wire. In this study, the initial archwire was ligated for at least 10 minutes after the bonding procedure.

Verbal and written instructions were given to each patient regarding appliance care, and professional cleaning was carried out approximately every 4 weeks. In addition, each patient was specifically recommended to contact the orthodontic office as soon as possible if any bonded attachment became dislodged. During treatment, patients attended the office at 4-week intervals. Bond failures were recorded accurately in the patients’ record files for later statistical analyses. The date of bond failure was identified as the date when detachment was observed by the operator.

The bracket was replaced immediately after bond failure was detected; new bonded brackets were not included in the study because replacing a bracket could affect its bond strength. All patients were observed for 12 months.

The chi-square test was used to compare bracket failure rates in different tooth type. Then, a multiple comparison technique, the Marascuilo procedure, was performed to detect which proportions were significantly different from each other.

Cox proportional hazards regression models with time-to-event (bracket failure) in months as the time scale were applied to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) for the association of tooth type, gender, and age with bracket failure risk. The test for the proportional hazards assumption based on the scaled Schoenfeld residuals was also performed. Because the test for covariate age and global test showed the assumptions were not satisfied at $P < .05$, stratified Cox model was introduced with age (<18 and ≥18 years) as strata. Using this model, adjusted survival curves were plotted, and HRs and 95% CIs were calculated. Further Cox analysis for failure rates of molar tubes was performed with additional covariates that represented the type and position of molar tubes. All statistical analyses were

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Table 1. Sample Characteristics
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Age, mean (SD), y</td>
<td>18.6</td>
<td>(6.0)</td>
</tr>
<tr>
<td>Age, male/female, mean (SD), y</td>
<td>17.8</td>
<td>(5.6)/19.1 (6.1)</td>
</tr>
<tr>
<td>Male/female, N (%)</td>
<td>52</td>
<td>(40.9)/75 (59.1)</td>
</tr>
<tr>
<td>Extraction/nonextraction, N (%)</td>
<td>80</td>
<td>(63.0)/47 (37.0)</td>
</tr>
<tr>
<td>Old (&gt;18 y)/young, N (%)</td>
<td>49</td>
<td>(36.6)/78 (61.4)</td>
</tr>
<tr>
<td>Extraction in old /nonextraction in old, N (%)</td>
<td>30</td>
<td>(61.2)/19 (38.8)</td>
</tr>
</tbody>
</table>

Table 2. Number and Percentage of Failed Brackets
|          | Bonded, N | Failed, N | Failed, % *
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Incisor</td>
<td>996</td>
<td>36</td>
<td>3.6&lt;sup&gt;AB&lt;/sup&gt;</td>
</tr>
<tr>
<td>Canine</td>
<td>505</td>
<td>8</td>
<td>1.6&lt;sup&gt;A&lt;/sup&gt;</td>
</tr>
<tr>
<td>Premolar</td>
<td>726</td>
<td>35</td>
<td>4.8&lt;sup&gt;B&lt;/sup&gt;</td>
</tr>
<tr>
<td>Molar</td>
<td>834</td>
<td>97</td>
<td>11.6&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total</td>
<td>3061</td>
<td>176</td>
<td>5.7</td>
</tr>
</tbody>
</table>

* The same letters are not significantly different at $P = .05$ by multiple comparison, the Marascuilo procedure.

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**Angle Orthodontist, Vol 84, No 6, 2014**
performed with R programming language (R Development Core Team, Vienna, Austria).

RESULTS

The average age of male and female patients was not significant according to the independent $t$-test ($P = .05$).

The overall failure rate was 5.7%. The failure rate of upper and lower arches over 12 months was 6.3% and 5.2% and did not show significant difference. When we compared the failure rate of each tooth type (incisor, canine, premolar, and molar), there was also no significant difference between upper and lower arch. The distribution and rate of bracket failures at the end of the study are shown in Table 2. The differences of bracket failure rates among groups were statistically significant ($\chi^2 = 78.93$, $df = 3$, $P = .000$). The Marascuilo multiple comparison revealed that statistically significant differences in bracket failure rates were found in various tooth types, except between incisor and canine, and between incisor and premolar. Canines showed significantly lower failure rates, and molars showed significantly greater failure rates than the other tooth types. The distribution and rate of bracket failures are shown in Tables 2 and 3, respectively.

Table 4 shows adjusted HR and 95% CI for bracket failure rates in relation to tooth type and gender. Molar had 8.16 times greater hazard compared with the reference category, canine. Premolar had higher risk of bracket failure by 173% compared with canine. Failure risk for incisor was not statistically significant ($P = .052$). Bracket failure rate was significantly associated with gender. Male patients had greater failure risk than female patients (HR = 1.56, $P = .002$).

Since age was not satisfied with the proportional hazards assumption, each age group (young and old, <18 and \geq 18 years) had their own baseline hazards functions and different survival curves. Figure 1 shows adjusted survival curve for each tooth type. Young male patients had the lowest survival rate, while old female patients had the highest survival rate. Young patients showed a higher failure rate (7.6%) than old patients (2.7%).

Additional Cox regression analysis was performed. Gender, age, molar position (upper or lower molar), and molar type (first or second molar) were used as covariates. The differences between gender, molar position, and molar type were not statistically significant (gender, $P = .582$; position, $P = .417$; type, $P = .431$). Because this model was not satisfied with the proportional hazards assumption (global $P = .000$), molar position and molar type were stratified. Table 5 shows hazard ratios and 95% CIs of the final stratified Cox model for molar tube. There was no statistically significant difference in hazard ratio for gender. Age was the only determinant factor. Young patients had greater risk than old patients (HR = 3.19, $P = .000$). Figure 2 shows the adjusted survival curve for molar tube. There was no significant difference in failure tendency according to molar position and molar type. The failure rates of first molar and second molar tubes were 10.6% and 12.4%, respectively. In old and young

Table 3. The Pattern of Bracket Survival Rate (%) Changes of Each Tooth Type by Months 1 to 12*

<table>
<thead>
<tr>
<th>Tooth Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incisors</td>
<td>99.6</td>
<td>99.3</td>
<td>98.6</td>
<td>98.2</td>
<td>98.0</td>
<td>97.7</td>
<td>97.5</td>
<td>97.4</td>
<td>97.0</td>
<td>96.9</td>
<td>96.9</td>
<td>96.4</td>
</tr>
<tr>
<td>Canines</td>
<td>100.0</td>
<td>100.0</td>
<td>99.6</td>
<td>99.6</td>
<td>99.6</td>
<td>99.6</td>
<td>99.6</td>
<td>99.6</td>
<td>99.0</td>
<td>98.6</td>
<td>98.6</td>
<td>98.4</td>
</tr>
<tr>
<td>Premolars</td>
<td>99.2</td>
<td>98.6</td>
<td>98.5</td>
<td>98.5</td>
<td>97.7</td>
<td>97.5</td>
<td>97.0</td>
<td>96.4</td>
<td>96.0</td>
<td>95.7</td>
<td>95.5</td>
<td>95.2</td>
</tr>
<tr>
<td>Molars</td>
<td>98.1</td>
<td>96.5</td>
<td>95.2</td>
<td>93.9</td>
<td>92.2</td>
<td>91.5</td>
<td>91.2</td>
<td>90.5</td>
<td>89.0</td>
<td>89.3</td>
<td>88.6</td>
<td>88.4</td>
</tr>
<tr>
<td>First molar</td>
<td>97.8</td>
<td>97.0</td>
<td>95.9</td>
<td>95.4</td>
<td>93.2</td>
<td>92.6</td>
<td>92.4</td>
<td>91.8</td>
<td>91.3</td>
<td>91.0</td>
<td>89.9</td>
<td>89.4</td>
</tr>
<tr>
<td>Second molar</td>
<td>98.3</td>
<td>96.1</td>
<td>94.6</td>
<td>92.7</td>
<td>91.4</td>
<td>90.6</td>
<td>90.4</td>
<td>89.5</td>
<td>88.9</td>
<td>88.0</td>
<td>87.6</td>
<td>87.6</td>
</tr>
<tr>
<td>Total</td>
<td>99.2</td>
<td>98.5</td>
<td>97.8</td>
<td>97.3</td>
<td>96.6</td>
<td>96.3</td>
<td>96.0</td>
<td>95.7</td>
<td>95.2</td>
<td>94.8</td>
<td>94.6</td>
<td>94.3</td>
</tr>
</tbody>
</table>

* The brackets that detached in the first 4 weeks were considered instances of bracket failure in the first month.

Table 4. Hazard Ratio by Cox Proportional Hazards Model for Bracket Failure*

<table>
<thead>
<tr>
<th>Tooth Type</th>
<th>Coefficient $\beta$</th>
<th>Hazard Ratio</th>
<th>95% CI</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canine (ref)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Incisor</td>
<td>0.72</td>
<td>2.06</td>
<td>0.99–4.27</td>
<td>.052</td>
</tr>
<tr>
<td>Molar</td>
<td>2.10</td>
<td>8.16</td>
<td>4.14–16.09</td>
<td>.000**</td>
</tr>
<tr>
<td>Premolar</td>
<td>1.01</td>
<td>2.73</td>
<td>1.31–5.70</td>
<td>.007*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gender</th>
<th>Coefficient $\beta$</th>
<th>Hazard Ratio</th>
<th>95% CI</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female (ref)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>0.44</td>
<td>1.56</td>
<td>1.17–2.07</td>
<td>.002*</td>
</tr>
</tbody>
</table>

* Cox model was stratified by age, effect modified by tooth type and gender. Canine and female was used as reference value.

* $P < .01$; ** $< .001$.
patients, failure rates of molar tubes were 5.2% and 15.3%, respectively.

DISCUSSION

The reported incidence of bracket bond failure is higher for posterior teeth than anterior teeth. Various reasons have been proposed to account for this difference, including the greater masticatory forces in the posterior region of the mouth. Incisal biting forces in the 13 to 15 kg range have been reported, and forces generated in the posterior quadrants are generally higher than 30 kg. During mastication, force transferred through the food pathway, especially in the case of hard food impinging upon the bracket, may account for most bond failures, and this might be expected to increase posteriorly. Other reasons for bracket bond failure of posterior teeth include different etching patterns

Figure 1. Adjusted survival curves for four tooth types. (A) For old (age ≥18 years) female patient. (B) For old male patient. (C) For young (age <18 years) female patient. (D) For young male patient.
produced on different teeth by acid conditioning\textsuperscript{14}; the difficulty of maintaining a dry field posteriorly (gingival fluid and saliva)\textsuperscript{15}; and inadequate adaptation of the bracket to the tooth surface due to attrition by malocclusion and the diverse morphology of buccal grooves, which weakens bond strength due to different rates of polymerization shrinkage or thermal expansion.\textsuperscript{16}

Because of such higher failure rates, many orthodontists use bands on molars\textsuperscript{6} or do not bond brackets to the second molars until the finishing stage.\textsuperscript{17} But, if greater anchorage is needed in an extraction case, the second molar should be included before the retraction stage.\textsuperscript{18}

The xenon plasma arc lamp was introduced for high-intensity curing of composite resin and can be used for bracket bonding.\textsuperscript{19} Previous research has shown that there are no significant differences in bond failure rates\textsuperscript{2} and bond strength\textsuperscript{8} between brackets cured with conventional halogen light and a high-intensity light-curing unit. The advantage of using high-intensity light is that the same amount of total light energy can be delivered to the composite adhesive over a much shorter period. Thus, maintaining a dry field became easier, but the clinical impact of such a change has not been tested.

The failure rates in our patient population were within the range of those reported in other clinical trials, that is between 2.95% and 23.0%.\textsuperscript{20–24} However, it is difficult to directly compare bracket failure rates between studies due to variation in operators, bonding techniques, adhesives, research designs, and observation periods.

In our study, the overall failure rate of bonded molar tubes was 11.6%, which was a little bit lower than previous studies. Zachrisson\textsuperscript{10} reported failure rates of 18.8% and 29.5% for upper and lower first permanent molars, respectively. Over a 3- to 15-month observation period, Geiger et al.\textsuperscript{25} reported a failure rate of 12.4% to 21.1% for bonded maxillary first molar tubes. Both of these previous studies used autopolymerizing adhesive. Another study that used a light-curing adhesive also reported a high failure rate\textsuperscript{15}—22% of upper and 20% of lower first molar tubes—even though rapid curing reduces moisture contamination.

This study is the first trial to investigate bracket failure rates of different tooth types, including second molars. If the failure rate is considered alone, one might infer that routine bonding on permanent molars

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**Table 5.** Hazard Ratio by Stratified Cox Proportional Hazards Model for Molar Tube\textsuperscript{a}

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Hazard Ratio</th>
<th>95% CI</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female (reference)</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>0.10</td>
<td>1.11</td>
<td>0.75–1.65</td>
<td>0.612</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Old (reference)</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young</td>
<td>1.16</td>
<td>3.19</td>
<td>1.87–5.54</td>
<td>(0.00^*)</td>
</tr>
</tbody>
</table>

\(^a\) Cox model was stratified by molar position and molar type, effect modified by gender and age.  
\(^*\) \(P < .001\).
is clinically unreliable. However, considering that the failure rate of first molar bands varied from 0.56%\textsuperscript{26} to 34.6%,\textsuperscript{27} bonding on molars can be substituted for bands without increasing the risk of failure. We expected to find a higher rate of bonding failure to second molars because of the shorter clinical crown, especially in adolescents, and more difficulties in maintaining a dry field, but there was no significant difference between first and second molar tube survival.

A 60-second etching time was to prepare the enamel of molars for bonding, as this has been shown to yield the optimal etch pattern.\textsuperscript{14} Therefore, it is unlikely that the etch pattern influenced the failure rate.

There was a significant difference between male and female patients in the survival of bonded brackets, but such a difference was not shown in the molar tubes. Gender difference was shown in the study of Millett and Gordon\textsuperscript{28} but not in the other studies.\textsuperscript{9,28} Although the greater maximum bite force in male patients\textsuperscript{30} can contribute to the gender difference in failure rate, our results did not show significant difference in the molar region.

The evidence in relation to patient age and bracket survival is equivocal.\textsuperscript{15,28,29} But we found a significant difference in bond survival between young (age <18 years) and old (age ≥18 years) subjects. Pandis and Eliades\textsuperscript{31} interpreted the differences in failure rates and contradictory evidence from studies testing identical materials in different populations to mean that culturally influenced dietary habits also affect the failure rate of brackets in vivo. Many popular Korean foods are relatively hard foods\textsuperscript{32} (white radish kimchi, parched anchovies, dried filefish, etc). Differences in patient compliance with instructions regarding avoidance of such hard foods may also account for this difference in failure rate.\textsuperscript{15} Therefore, it would be important to educate patients well, in particular the young (<18 years) patients, to reduce bond failure in the molar region.

We did not investigate failure rates according to type of malocclusion in this study. Although some researchers found significant differences in bracket failure rates among different malocclusion types,\textsuperscript{33} another study reported no significant differences.\textsuperscript{34} To minimize the effect of malocclusion type, we used the bonded bite plane when occlusal interference was observed. But, it would have been better to only include patients with the same type of malocclusion.

Because of the intrinsic limitations of in vitro studies and the inability to fully reproduce clinical conditions, various prospective clinical trials are required to determine whether certain bonding methods or conditions provide more clinically acceptable results than others.

CONCLUSIONS

- This prospective cohort study demonstrated that the failure rate of bonding to molars was greater than that of bonding to anterior teeth.
- But, direct bonding on the first and second molar had an acceptable failure rate, especially in adult patients.
- The failure rate was higher in young patients (age <18 years) than in old patients.

ACKNOWLEDGMENT

I am greatly indebted to Dr Yun-Sik Lee for proficient support and assistance in the statistical analysis for this manuscript.

REFERENCES