Original Article

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Survival analysis of an orthodontic bracket bond subjected to cyclic tensile and shear forces

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Abstract:

OBJECTIVES: The objective of this study was to evaluate the use of survival analysis in cyclic fatigue testing in orthodontic bracket bonding.

MATERIALS AND METHODS: We used 100 extracted bovine lower incisors (50 orthodontic brackets and 50 eyelet brackets). Each set of brackets was further divided by etching technique (25 total-etch and 25 self-etch). Cyclic fatigue testing was performed at a crosshead speed of 2 mm/min using an up-and-down method. Kaplan–Meier survival data analyses and Cox regression analyses were performed.

RESULTS: Survival analysis proved to be a simple methodology and revealed that the etching technique was not a statistically significant predictor for survival of orthodontic bracket bonding with either tensile or shear cyclic forces at $P > 0.05$. In tensile cyclic loading, high mechanical loading after controlling for the etching technique is a statistically significant predictor for lower survival of the orthodontic bracket bond at $P < 0.001$.

CONCLUSIONS: Both etching techniques (total-etch and self-etch) are equally efficient in bonding orthodontic brackets. High mechanical loading is an important predictor of bond failure when applying tensile cyclic forces. Finally, survival analysis is a simpler alternative method to analyze orthodontic bracket bonding subjected to cyclic tensile and shear forces and gives similar results to other complicated methods.

Keywords:

Cyclic shear, cyclic tensile, survival analysis

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Introduction

Orthodontic brackets are commonly attached to the enamel surface using phosphoric acid etching. This requires rinsing and drying after application of the etching reagent. Therefore, this technique is called the etch-and-rinse or total-etch (TE) technique. Although it remains the most effective approach to bonding to enamel, it does have some drawbacks.[1] The procedure is technique-sensitive, requires proper moisture control,[1] and causes enamel loss during etching and debonding.[2-4] Thus, there is increasing interest in a self-etch system—a bonding system that etches, primes, and bonds in one step. This technique produced a more conservative etch pattern and is less destructive to the enamel surface.[2-6] Although it has many advantages over the conventional TE approach, the bracket bond strength of resin cements using self-etching had lower bond strengths than TE bonding.[3,4,6] On the contrary, some studies have reported that the shear bond strength of the self-etch was not significantly different from the TE system.[2,7,8] However, in these studies, only the static bond strength was evaluated.

Clinically, bonding systems are more likely to be subjected to repeated small

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loads. With time, this can cause cyclic fatigue.[9] Cyclic fatigue occurs when a structure eventually fails after being repeatedly subjected to loads that are so small that one application would not affect the component.[10] Therefore, for accurate *in vitro* testing of materials used in the oral cavity, it is essential to subject these materials to cyclic loading using cyclic fatigue testing rather than static testing.[11-14] However, there are only a few papers that have evaluated self-etch bonding. In one example, Mansour *et al.*[11] evaluated the cyclic shear bond strengths of self-etch compared to TE bonding and concluded that the TE had a greater bond strength than the self-etch bonding system.

There is not much research analyzing orthodontic bonding subjected to cyclic fatigue using survival analysis. In this article, we present the use of survival analysis—a statistical procedure used to analyze the time to event outcome of interest to evaluate the orthodontic bracket bonding. The event in this study is the cyclic fatigue failure of the orthodontic bond. In the survival approach, the bond strengths of different materials and different testing methods are compared by analyzing their times to failure. The survival analysis approach allows us to estimate the likelihood that failure of the bond strength does not occur beyond a specific time. Therefore, the aim of this study was to evaluate the use of survival analysis in cyclic fatigue of the orthodontic bracket bond.

Objectives

1. To compare the survival of orthodontic bracket bonding of the self-etch technique to the acid-etch technique when subjected to cyclic tensile loading or cyclic shear loading
2. To compare the survival of orthodontic bracket bonding under different mechanical loading levels when subjected to cyclic tensile loading or cyclic shear loading.

Materials and Methods

We studied 100 extracted bovine lower incisors to which orthodontic brackets were attached using different bonding systems. The teeth had no caries, obvious defects, or attrition. For the experiment, the teeth were embedded in auto-polymerized acrylic resin (Vitacryllic®, Fricke Dental Manufacturing Co., Villa Park, IL) in a rubber mold (25 mm in diameter × 20 mm deep) such that the flat surface of the enamel was parallel to the base of the acrylic mold. The surfaces were polished with medium grit pumice (Great Lakes Orthodontics Co., Tonawanda, NY) and washed with water. The mounted teeth were then randomly divided into two groups.

The enamel surface was prepared, and the brackets were bonded to the teeth in one of two methods: (1) TE group (82 teeth) using a 37% phosphoric acid gel following manufacturer instructions and a thin layer of the liquid unfilled resin of the Transbond XT (3M Unitek). (2) The orthodontic one-step self-etch bonding solution Transbond Plus (TBP) (82 teeth) was used following manufacturer's instruction.

Bracket bonding

Fifty eyelet large metal brackets (3M Unitek, Monrovia, CA, USA) with a base surface area of 12.6 mm^2 were used for the tensile tests. Fifty stainless steel upper right central incisor brackets (Victory series, 3M Unitek, Monrovia, CA, USA) with a base surface area of 12.6 mm^2 were used for the shear tests. Transbond XT light-cured composite (3M Unitek Monrovia, CA, USA) was used for bonding the brackets, and excess resin was removed with an explorer prior to polymerization of the resin. The resin was cured for 10 seconds from the mesial and distal sides using a light-emitting diode light source (Ortholux LED, 3M Unitek Orthodontic Products, Monrovia, CA, USA). All samples were stored in distilled water at 37°C for 24 h.

Cyclic fatigue testing

Cyclic fatigue testing was carried out at a crosshead speed of 2 mm/min with an up-and-down method according to the compressive fatigue method used by Draughn.[15] The value of the initial load was 60% of the mean obtained from the static testing results in each group. The test was then run for 1,000 cycles or until bond failure occurred. When a bracket survived the 1,000 cycles, the load for the following sample was increased by 20 N. However, if the bracket did not survive the 1,000 cycles, then the load for the following sample was reduced by 20 N. The procedure of increasing the load by 20 N or reducing it by the same amount following each sample was continued for each subsequent sample until all samples in each group were assessed.

This "up-and-down" method provides a good measure of the mean fatigue limit and allows the standard deviation of the mean to be calculated.[15] Here, the number of each sample group was 25. The survival data analysis was based on the event that occurred (bond failures {censored 1} and no bond failures {censored 0}).

Statistical analysis

Data analyses were performed using Statistical Package for the Social Sciences (SPSS) version 24 IBM. We generated a histogram to describe the data distribution of the survival cycles (TIME) for shear and tensile forces. A censoring variable was created to show the survival time or the failure of the bracket bond (Censoring variable: 0–1). The Kaplan–Meier survival data analyses evaluated the bonding strength of the different types of etching techniques and different levels of mechanical loading with shear and tensile forces. Cox regression was also performed on the survival of the bonding with shear and tensile forces controlling for the etching technique and the level of mechanical loading.

Results

The sample was distributed evenly between the TE and the self-etch. We divided the sample into a high load or a low load based on the mean of the mechanical loading level. The distribution of the survival of orthodontic bracket bonding subjected to shear and tensile cyclic forces is presented in Figure 1, and the histograms showed that the data are not normally distributed.

The Kaplan–Meier test [Table 1] showed that the mechanical loading level was a statistically significant predictor of survival of orthodontic bracket bonding subjected to tensile cyclic forces. A high mechanical load in tensile cyclic forces is associated with lower survival.

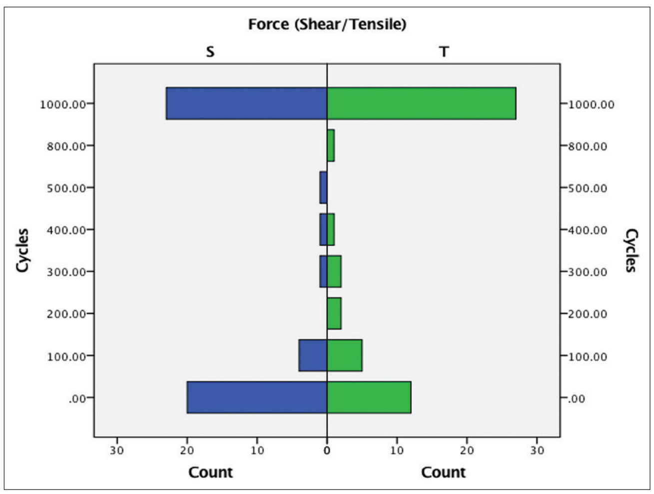

Figure 1: Histogram for the distribution of the survival cycles with shear and tensile forces

However, this predictor was not significant for shear cyclic forces. Survival plots of bracket bonding using high and low mechanical loading with shear and tensile cyclic forces are presented in Figure 2.

Using the Kaplan–Meier test [Table 2], we found that the etching technique was not a significant predictor of survival of orthodontic bracket bonding with either tensile or shear cyclic forces. Survival plots of brackets bonding using different etching techniques with shear and tensile cyclic forces are presented in Figure 3.

Cox regression analysis [Table 3] shows that the model global test is a significant predictor of orthodontic bracket survival at $P < 0.001$. The model factorial analysis showed that high mechanical loading—even after controlling for the etching technique—is a statistically significant predictor for lower survival of the orthodontic bracket bonding. Cox regression survival plots of brackets bonding with shear and tensile cyclic forces are displayed in Figure 4a-e. Figure 4a presents the survival plots for the global model. Figure 4b and c presents the etching techniques. Figure 4d and e presents mechanical loading levels.

Discussion

These findings suggest a simpler alternative method to analyze bonding in orthodontics. Survival analysis is rarely used to analyze orthodontic bonding studies. The results also suggest that the etching technique does not change the survival rate of the orthodontic bracket bonding. Similar results were found with both the TE and self-etch techniques. Furthermore, we found that the level of mechanical loading affects the survival of bracket bonding subjected to tensile forces. High mechanical loading (>60 N) of tensile cyclic forces caused a lower survival rate than brackets subjected to low mechanical loading (<60 N) during cyclic tensile forces.

Orthodontic bracket bond survival is influenced by many factors such as mechanical loading levels, types

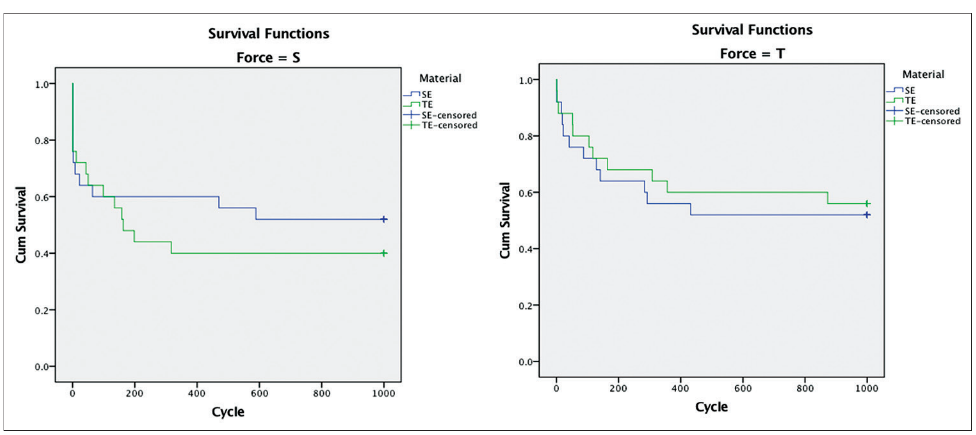

Figure 2: Survival plots of brackets bonding using different mechanical loading with shear and tensile forces

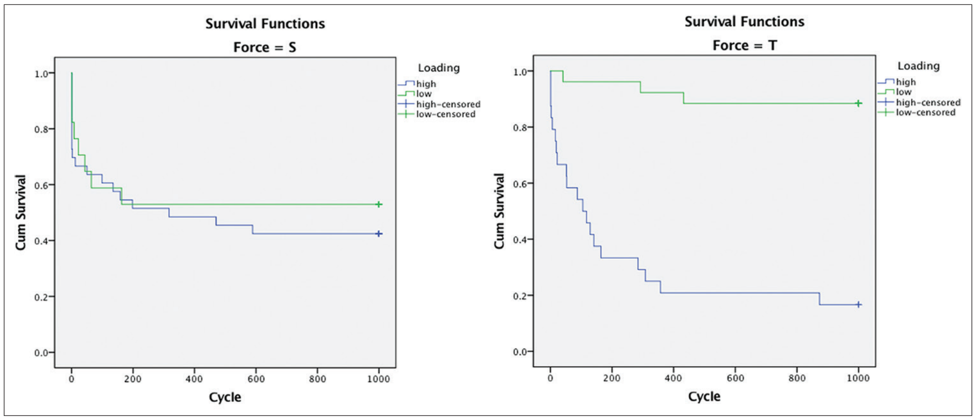

Figure 3: Survival plot of brackets bonding using different etching techniques with shear and tensile forces

Table 1: Kaplan-Meier survival of brackets bonding using different mechanical loading with shear and tensile forces

Force		Survival estimates		*n*	No. of events	Censored		*P*
		Mean	SE			*n*	Percentage	
Shear	High load	486.03	79.99	33	19	14	42.4	0.56
	Low load	547.24	116.79	17	8	9	52.9	
Tensile	High load	280.75	75.41	24	20	4	16.7	<0.001*
	Low load	914.04	47.91	26	3	23	88.5	

*Significant at $P<0.05$

Table 2: Kaplan-Meier survival of brackets bonding using different etching techniques with shear and tensile forces

Force		Survival estimates		*n*	No. of events	Censored		Chi-square log-rank *P* value
		Mean	SE			*n*	Percentage	
Shear	Total-etch	447.24	91.41	25	15	10	40	0.47
	Self-etch	566.44	94.24	25	12	13	52	
Tensile	Total-etch	641.52	87.21	25	11	14	56	0.71
	Self-etch	578.60	89.71	25	12	13	52	

SE – Standard error

Table 3: Cox regression for survival of brackets bonding controlling for multiple factors

Cox model	Estimate	SE	*P*
Etching technique	–0.42	0.30	0.156
Mechanical loading	0.78	0.19	<0.001*

SE – Standard of error. *Significant at $P<0.05$. Global model $P<0.0001$

of forces (shear or tensile), and etching techniques. Our findings show that the mechanical loading levels were a statistically significant predictor of orthodontic bracket bond survival when subjected to tensile cyclic forces. However, this finding was not observed with shear cyclic forces. A high mechanical load in tensile cyclic forces was associated with lower survival. In addition, Cox regression analysis showed that high mechanical loading even after controlling for the etching technique was a statistically significant predictor for lower survival of the orthodontic bracket bonding. Kumar *et al.*[16] compared the shear and tensile bond strength of three different adhesive systems used for bonding brackets. They concluded that the tensile bond strength was less than that of the shear for all tested materials. Valletta *et al.*[17] suggested that applying tensile forces during debonding would be a better clinical option.

The etching technique investigated here was not a significant predictor of orthodontic bracket bond survival when subjected to tensile or shear cyclic forces. We also tested for similarity using the Kaplan–Meier survival curve and the log-rank test. The results demonstrated no significant differences in survival distribution of the self-etch and TE techniques.[7] Other studies reported no significant differences in shear bond strengths of the self-etch compared to the TE system.[2,7,8] On the contrary, other studies showed that the self-etch system had lower bond strengths compared to the TE system.[3,4,6] Only one study investigated the effect of cyclic loading on the shear bond strength of the TE and self-etch techniques and concluded that cyclic loading reduces the bond strengths of both bonding systems. Both of these were clinically acceptable despite the lower bond strengths of the self-etch system relative to the TE system.

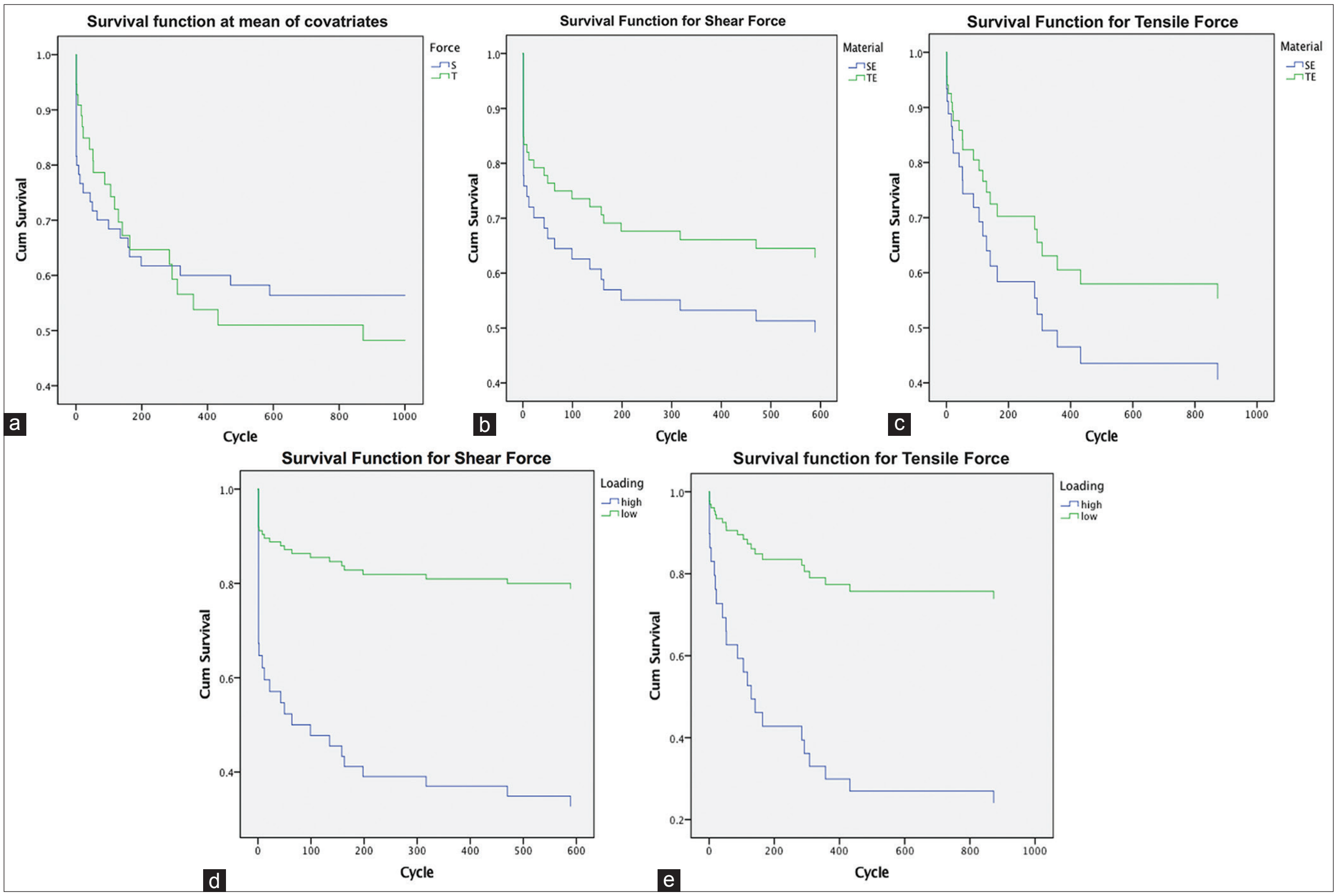

Figure 4: (a) Cox regression survival plots for shear and tensile cyclic forces-global model. (b) Cox regression survival plots for shear cyclic force-etching techniques. (c) Cox regression survival plots for tensile cyclic force-etching techniques. (d) Cox regression survival plots for shear cyclic force-loading levels. (e) Cox regression survival plots for tensile cyclic force-loading levels

All previous studies reported the bond strengths of orthodontic bracket bonding where the unit was transferred from force to stress. Eliades and Brantley[18] argued that the proper transformation from force to stress is difficult due to inaccuracies in the estimates of the actual contact area of the bracket base. Here, we used survival analysis to evaluate the orthodontic bracket bonding and thus the transformation of the unit from force to stress is not needed. In addition, survival analysis does not require normal distribution of the data. This emphasizes the small values at the tail of the distribution and consequently emphasizes the performance of the bonding system.[18]

Cyclic fatigue tests generate results that are much lower than their static counterpart.[11,14,19] This could explain why bracket failure takes place *in vivo* when teeth are subjected to forces of lower magnitude compared to their respective static magnitude.[18] Survival results of the orthodontic bracket bonding subjected to cyclic loading in the current study are more representative of *in vivo* clinical situations where low magnitude cyclic mechanical forces cause the failure.[18]

Conclusions

Survival analysis is a simpler alternative method to analyze orthodontic bracket bonding subjected to cyclic tensile and shear forces and gives similar results to other complicated methods. Orthodontic bracket bonding subjected to cyclic loading in the current study is more representative of *in vivo* clinical situations where low magnitude cyclic mechanical forces cause the failure. Both the TE and self-etch techniques are equally efficient in bonding orthodontic brackets. High mechanical loading level is an important factor affecting bracket bond failure when applying tensile forces.

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Conflicts of interest

There are no conflicts of interest.

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