In Vitro Structural Analysis and Bond Strength Evaluation of 3D Printed and Stainless Steel Space Maintainers

Watson L, Danley B, Versluis A, Tanbirojn D, Wells M

University of Tennessee, Memphis, TN, USA

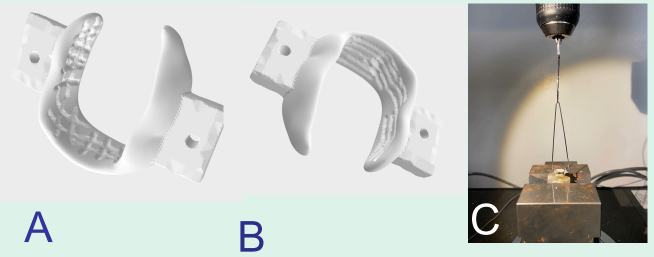
PURPOSE

To evaluate 3D printed space maintainers (SM) compared to stainless steel (SS). Three materials were evaluated and the material with the highest mechanical properties was further used to explore retention with various intaglio surface designs.

METHODS

Phase 1 testing determined preferred material and feasibility of 3D printed unilateral SMs. 7 extracted, caries-free primary second molars were used (IRB #18-06256-XP). Each tooth was mounted in SamplKwick Fast Cure Acrylic (Buehler, Lake Bluff, IL) and fitted with a SS general purpose molar band (Denovo Dental, Baldwin Park, CA). Mounted teeth were scanned with an intraoral scanner (3Shape TRIOS, Copenhagen Denmark). The Stereolithography (STL) files were imported into Meshmixer computer design software (Autodesk, San Rafael, CA) to design 3D bands with a modified claw design. Bands were printed via Prefactory® 3D printing software (ENVISIONTECH™) using ENVISIONTECH™ VIDA HD Printer. In Phase 2, the 3D printed bands consisted of three designs: plain printed, horizontal grooves, and crosshatch. All bands were modified to have buccal and lingual ledges (approximately 2x4mm). Bands were cemented to the teeth with GC FujiCEM 2 (GC America, Alsip, IL) and Transbond Plus (3M Unitek, Monrovia, CA) in randomized order and stored at 37°C in 100% humidity for 24 hr before retention testing. Each tooth was then secured in a universal testing machine (Instron 4467 Instron Corp, Norwood, MA) and loaded at 1mm/min until the band was completely removed from the tooth. (Figure 1).

Figure 1. A 3D printed band with crosshatch B. 3D printed band with horizontal grooves C. Instron apparatus for bilateral force for retention testing



RESULTS

E-Guard was determined to be the best material tested for this application due to its higher flexural modulus and strength. E-Guard bands possess sufficient flexure and strength qualities for intraoral use. Stainless steel bands require significantly more force to dislodge than any of the 3D printed bands, and the inclusion of intaglio surface designs does not significantly improve retention.

Phase I Max Sress (MPa)				
Material	Sample size	Flexural Strength Max (N)	SD	Anova
E-Guide	15	65	12.39	P<0.05
E-Dent400	15	90	13.14	
E-Guard	15	134	25.23	
Phase I Max Stress (MPa) "Post Hoc Analysis"				
Material	P-Value	Bonferroni variable	Statistical difference	
E-Guide vs E-Dent 400	<0.0001	0.0167	TRUE	
E-Guide vs E-Guard	<0.0001	0.0167	TRUE	
E-Dent400 vs E-Guard	<0.0001	0.0167	TRUE	
Phase I Flexural Modulus (Pa)				
Material	Sample size	ε(max)	SD	Anova
E-Guide	15	1540	399.54	P<0.05
E-Dent400	15	2489	144.13	
E-Guard	15	2653	889.80	
Phase I Flexural Modulus (Pa) "Post Hoc Analysis"				
Material	P-Value	Bonferroni variable	Statistical difference	
E-Guide vs E-Dent 400	<0.0001	0.0167	TRUE	
E-Guide vs E-Guard	<0.0001	0.0167	TRUE	
E-Dent400 vs E-Guard	0.49	0.0167	FALSE	

Table 1:Flexural modulus and flexural strength of 3D printed materials

ACKNOWLEDGEMENTS

Supported by UTHSC College of Dentistry Alumni Endowment Fund and TDA Foundation. Special thanks to Dr. Jeffrey Brooks and Dr. Wainscott Hollis

Type of Band	n	Mean Force (N)	Std. Dev.	Post hoc*
3D Printed – Plain	14	31.968	12.907	a
3D Printed – Crosshatch	14	42.536	13.066	a
3D Printed – Horizontal Grooves	14	42.978	15.736	a
SCC w/FujiCem2	14	126.464	26.511	b
SSC w/Transbond Plus	14	127.349	38.769	b

Table 2: Force required to remove bands of 3D printed and SSC bands
*One-way ANOVA followed by Student-Newman-Keuls post hoc test (significance level 0.05). Different letters identify statistically significant groups.

DISCUSSION

The aim of this study was to evaluate potential materials for 3D printing, propose a possible design, and compare retention strengths to traditional SS SM. Benefits of 3D printed SM would include the ability to design a loop custom fit to each patient's gingival architecture, allowing for flexure rather than displacement and improved esthetics. Of the materials tested, E-guard was determined to have superior material properties. When subjected to simulated occlusal forces, 3D SM were found to possess adequate failure strength and deflection under occlusal load to serve as a viable alternative for SM. Traditional SS SM were shown to have significantly higher retention strengths than 3D printed SM with failure noted at the tooth-cement interface. Failure with the 3D printed SM was observed to be at the cement-band interface, and the intaglio surface designs did not provide adequate mechanical retention to overcome bond failure. It is likely that the 3D bands demonstrate inferior retention because the claw design of the 3D band does not circumvent the tooth. As 3D technology continues to evolve, future designs with the ability to circumvent the tooth or bond to both teeth approximating the edentulous area may render 3D printed SM more clinically applicable.

CONCLUSION

Stainless steel bands require significantly more force to de-bond than 3D SM with either cement.