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AAO Foundation Final Report Form
(a/o 1/3/2018)

Type of Award
Biomedical Research Award

Name(s) of Principal Investigator(s)
F. Kurtis Kasper

Institution
The University of Texas Health Science Center at Houston

Title of Project
Mechanical and Color Stability of 3D-Printed Orthodontic Brackets

Period of AAOF Support
07-01-18 to 12-31-19
No Cost Extension 07-01-2019 to 12-31-19

Amount of Funding
$22,500

Summary/Abstract
Objectives: Recent advances in additive manufacturing technologies present the potential for fabrication of esthetic orthodontic brackets in-office via 3D-printing using materials cleared for intraoral use. Direct fabrication of esthetic brackets via 3D-printing could revolutionize orthodontics by enabling clinicians to design and fabricate customized brackets that satisfy patient demands for esthetics in an on-demand fashion. At the same time, in-office design and fabrication of brackets via 3D-printing would support increased clinician control and operational efficiency in orthodontic practices. As clinical cases of 3D-printed brackets emerge in the literature, a clear and urgent need exists to investigate key properties of 3D-printed brackets, including their mechanical and color stability as a function of time, to inform the orthodontic community regarding potential advantages and limitations. Accordingly, the overall objective of this project was to evaluate the mechanical and color stability of 3D-printed orthodontic brackets.

Materials and Methods: For the mechanical analyses, 80 de-identified extracted human premolars were divided into 4 groups of 20 each. Three different commercially available 3D printing resins were used to print premolar brackets based on a commercially available metal bracket. 20 Clear resin (C), 20 Dental LT resin (LT), 20 Dental SG resin (SG), and 20 metal (M) brackets were bonded to the extracted teeth. All brackets were bonded on the premolars using

Transbond XT. Half of the bonded teeth from each bracket group were thermocycled. Shear bond tests then were preformed on all samples with a universal testing machine, and the failure types were classified by the adhesive remnant index (ARI). For color stability analyses, disc-shaped specimens were fabricated via 3D-printing using 3 resins: LT, SG, and C. Five conditions were evaluated for each resin (n=10 per condition per resin) to assess its corresponding effect on color and translucency: immersion in (1) red wine, (2) coffee, (3) tea, and (4) distilled water (control), and (5) exposure to accelerated aging. Immersion took place over the course of seven days with daily solution change and rinsing of samples in distilled water. Accelerated aging was performed using a flatbed Suntest XXL+ Xenon Test Instrument, which exposed samples to light/dark and wet/dry cycles with conditions set forth in ISO Standard 4892-2:2006 to a dosage of 450 kJ/m^2. Spectrophotometric color and translucency measurements were made before and after exposure using an X-Rite Ci7600 Series benchtop spectrophotometer. Samples were measured against standard white calibration tiles for color evaluation and against white and black calibration tiles for translucency measurements. Color change and transparency were evaluated for each sample using the formulas: $\Delta E^* = [(L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2]^{1/2}$ and $TP = [(L_B^* - L_W^*)^2 + (a_B^* - a_W^*)^2 + (b_B^* - b_W^*)^2]^{1/2}$, respectively. Data from before and after conditioning was analyzed using a generalized linear model.

Results: Mean shear bond strengths for 3D-printed brackets ranged from 4.6 ± 1.3 to 15.6 ± 4.1 MPa. Shear bond strength differed significantly for the main effects of bracket material and thermocycling, with significant interaction between them manifesting most clearly in the thermocycled C resin. A Kruskal-Wallis rank sum test found the effect of ARI score by bracket material was significant (P=0.00011). Pairwise comparisons were then completed using Tukey-Kramer-Nemenyi all-pairs test with Tukey-Distribution approximation and revealed a significant difference in ARI scores between M and C (P= 0.0055), M and LT (P=0.044), SG and C (P=0.0027) and between SG and LT (P=0.025). No other statistically significant differences were observed among pairs. ΔE*, ΔL* and ΔTP values showed a gamma distribution and a statistically significant effect (P>0.001) of the condition (aging or staining) on ΔE*, ΔL*, and ΔTP dependent on the resin material via a generalized linear model. The most dramatic changes in ΔE* were a result of the extrinsic staining effects of wine on all three resins. Changes in ΔE* due to the intrinsic effects of aging on C resin and SG resin were also high. Coffee and tea led to changes in ΔE* either within or slightly beyond the clinical thresholds for acceptability and perceptibility.

Conclusions: The data collectively demonstrate the proof-of-concept of applying biocompatible resins toward the fabrication of orthodontic premolar brackets via 3D-printing and the feasibility of the methods applied in characterizing the shear bond strength of the brackets bonded to enamel and the color stability of the printed materials. The data suggests that clinically sufficient shear bond strengths can be achieved with 3D-printed brackets, and that the shear bond strength depends on the material used in the fabrication. Additionally, the data suggests that the color stability of the materials investigated may not be suitable for application in fabrication of esthetic orthodontic brackets.

1. **Were the original, specific aims of the proposal realized?**
   Yes

2. **Were the results published?**
   a. **If so, cite reference/s for publication/s including titles, dates, author or co-authors, journal, issue and page numbers**
      1. Larson N. "Mechanical Stability of 3D-Printed Orthodontic Brackets," Masters of Science in Dentistry Thesis, Department of Orthodontics, The University of Texas School of Dentistry at Houston, Houston, Texas, ProQuest Dissertations Publishing, 2019. 22617446.

      2. Kasper FK, Haynie A, Abu Al Tamn M, English JD, and Paravina R, "Color Changes of Resins Applied in the Fabrication of 3D-Printed Orthodontic Brackets," Trans Soc Biomater, 40:663, 2019.

   b. **Was AAOF support acknowledged?**
      Yes, as appropriate, AAOF support was acknowledged in each publication.

   c. **If not, are there plans to publish? If not, why not?**
      Yes, the project involved contributions from two residents in partial completion of the requirements of the degree of Masters of Science in Dentistry. Some project results were published in a thesis detailed above and other results will be published in a planned thesis, as follows:

      1. Haynie A. "Color Stability of 3D-Printed Orthodontic Brackets," Masters of Science in Dentistry Thesis, Department of Orthodontics, The University of Texas School of Dentistry at Houston, Houston, Texas. (in preparation)

      In addition, two research manuscripts based on the results of the project are presently under preparation for submission to peer-reviewed journals. In each case, the submissions will acknowledge AAOF support, as appropriate.

3. **Have the results of this proposal been presented?**
   a. **If so, list titles, author or co-authors of these presentation/s, year and locations**
      1. "Color Stability of 3D-Printed Orthodontic Brackets," Haynie AS, Abu Al Tamn MA, English JD, Paravina RD, Kasper FK*. 2019 UTSD Student Research Showcase, The University of Texas School of Dentistry at Houston, Houston, Texas. (October 29, 2019) [Best Oral Presentation Award – Resident Category]

      2. "Evidence-based Guidance for 3D Printing Applications in Dentistry," Kasper FK*. Greater Houston Dental Society, Tale and Ale Program, Braeburn Country Club, Houston, Texas. (September 24, 2019)

      3. "Mechanical Stability of 3D-Printed Orthodontic Brackets," Larson N*. Masters of Science in Dentistry Thesis Defense, Department of Orthodontics, The University of Texas School of Dentistry at Houston, Houston, Texas. (June 19, 2019)

      4. "Evidence-based Guidance for 3D Printing Applications in Dentistry," Kasper FK*. The Houston Center for Biomaterials and Biomimetics (HCBB) Seminar Series, The University of Texas School of Dentistry at Houston, Houston, Texas.

(June 6, 2019)

5. "Color Changes of Resins Applied in the Fabrication of 3D-Printed Orthodontic Brackets," Kasper FK*, Haynie AS, Abu Al Tamn MA, English JD, Paravina RD. The Rolanette and Berdon Lawrence Bone Disease Program of Texas 2019 Scientific Retreat, Houston, Texas. (May 10, 2019)

6. "Color Changes of Resins Applied in the Fabrication of 3D-Printed Orthodontic Brackets," Kasper FK*, Haynie AS, Abu Al Tamn MA, English JD, Paravina RD. 2019 Annual Meeting of the Society For Biomaterials, Seattle, Washington (April 3 – 7, 2019)

7. "From Stone to Bone: Emerging Applications of 3D Printing in Orthodontics," Kasper FK*. The Rolanette and Berdon Lawrence Bone Disease Program of Texas Bone Research Club, Third Coast Restaurant, The Texas Medical Center, Houston, Texas. (February 13, 2019)

b. Was AAOF support acknowledged?
Yes, in each presentation

c. If not, are there plans to do so? If not, why not?
The results will continue to be included in presentations, as appropriate, with proper acknowledgement of support from AAOF for the work.

4. To what extent have you used, or how do you intend to use, AAOF funding to further your career?

As a bioengineer, I am thrilled to explore exciting new frontiers at the intersection of engineering and orthodontics, and funding from the AAOF has been vital to enable my investigations in these areas that traditionally are not targets for funding from federal sources. The funding from AAOF provides me with opportunities to expand my exposure to the challenges of clinical orthodontics, to collaborate with clinicians and researchers in the field, to increase my research profile, and to broaden my professional network. The benefits enabled by AAOF support provide a firm foundation upon which I plan to continue to build my research program in topics of relevance to orthodontics.