Developing 3D-Printed Peri-Implantium to Establish Periodontal Hygiene Efficacy

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Abstract

Objectives: Currently, there is no consensus of how to best maintain dental implants. With over 2 million dental implants placed annually, there is an urgent need for objective ways to measure plaque removal from peri-implant surfaces. Here, we developed a cost effective, fast and accurate way to measure the effectiveness of various oral hygiene products to maintain health of the implant and surrounding oral tissues using a 3D printer.

Methods: Digitizations of dentoform teeth and jaws provided the basis for 3D-printed custom models. Simulated gingiva and genuine dental implants were incorporated to maximize clinical relevance. Fabricated model teeth were analyzed for consistency of cusp heights, inter-cusp distance and mass. Mass was remeasured following water immersion. An artificial plaque substrate (APS) was applied to 3D-printed and porcelain surfaces to ensure consistent performance. A standard by which toothbrush mediated APS removal from the interproximal and subgingival areas was developed, with varying brushing angle, force and toothbrush design.

Results: The 3D-printed models had higher dimensional accuracy than the resolution of the 3D printer (X/Y<400µm, Z<100µm). Immersion in water yielded an increase in mass that was correlated linearly with time (r^2 = .9365) and could be reversed upon desiccation. APS behaved similarly on the 3D-printed surface as porcelain.

Conclusions: Lack of commercially available dentoforms with accurate dental implant anatomy limited the ability to simulate implant systems *in vitro*. However, the advent of low-priced commercial grade 3D printers enables individuals to create such models rapidly and at low cost. We developed highly accurate, anatomically correct, 3D-printed dental implant model systems, which mitigated flaws in extant designs and devised a high-throughput method for assessing *in vitro* plaque removal that is superior to existing methods. In the future, digital model files can be included in an electronic library for rapid manufacturing of identical models anywhere in the world.

Background

- Dental implants are susceptible to disease, with approximately 50% of all implants affected by peri-implant mucositis. Peri-implantitis is present at 12-43% of all dental implant sites.
- The microbiota found in the peri-implant space do not differ in composition from those found at adjacent natural dentition and overall periodontal status of natural dentition determines the implant microbial composition.
- Plaque biofilm can form and accumulate on restorations, abutments and implant fixtures. A four year retrospective study of dental implants showed that 60% of proximal implant surfaces had plaque accumulation and 45% had inflammation.
- Peri-implantitis is rare with proper plaque control, while inadequate plaque control is associated with peri-implant lesions.
- The elimination of at least 85% of plaque on a daily basis is critical to the maintenance of implant health, while long term failure of dental implants is associated with high levels of plaque.
- The only widely accepted option for proper implant care is regular professional implant hygiene. Neither the American Dental Association nor the American Academy of Periodontology recommends any special treatment for implants during brushing, even though implants represent unique oral surfaces that are inherently different from natural dentition.
- A number of *in vitro* methods have been developed to assess plaque removal from interproximal and subgingival surfaces of teeth, using models that approximate natural dentition.
- 3D printers have been used to produce orthotics and assistive devices for disabled children and even surgical instruments.
- Therefore, we sought to 3D print usable dental implant models that were anatomically correct and mitigated flaws in extant designs and methods for assessing plaque removal.

Acknowledgements

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Results

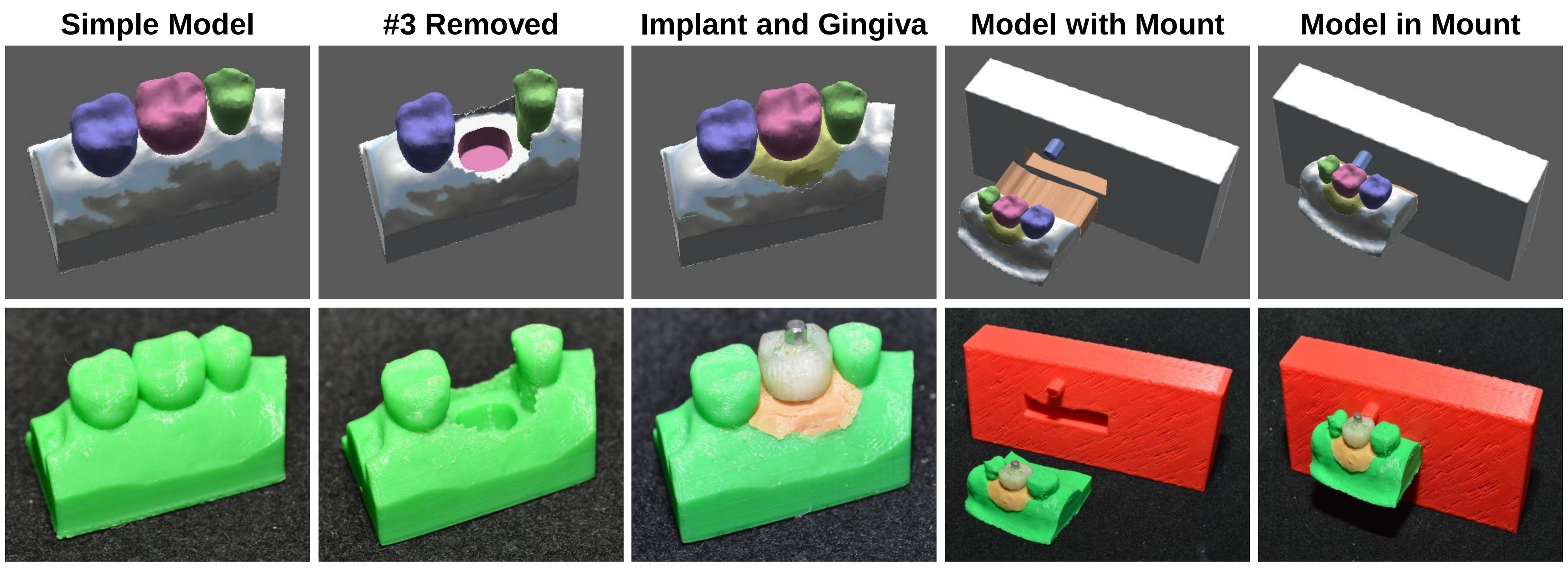

Fig 1. Stereolithographic renderings of models during various stages of development with the 3D printed results.

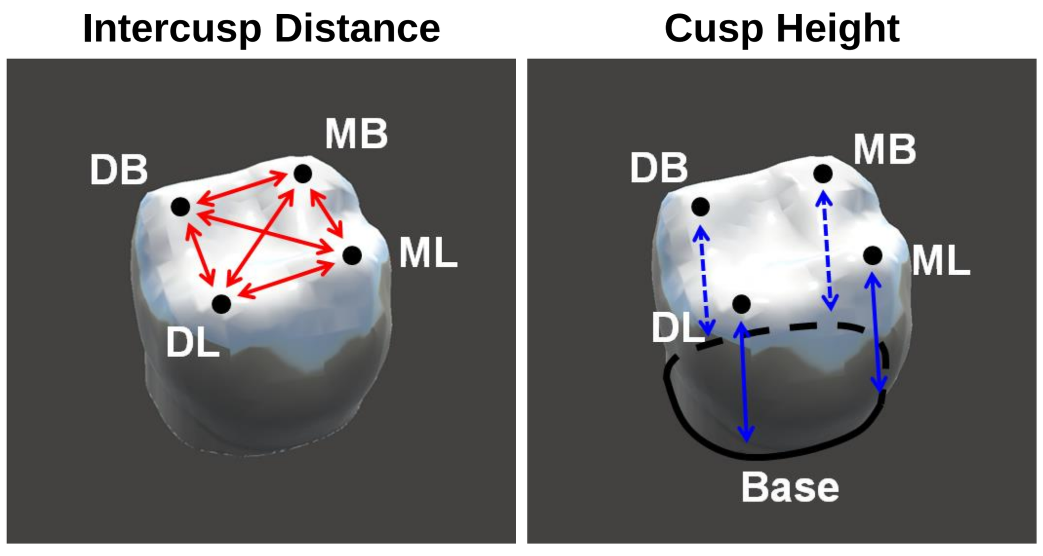

Fig 2a. Depiction of the 10 dimensions measured on 3D printed teeth. Distance between each cusp (MB-ML, MB-DL, MB-DB, DB-ML, DB-DL, ML-DL) and height of each cusp (DB, DL, MB, ML).

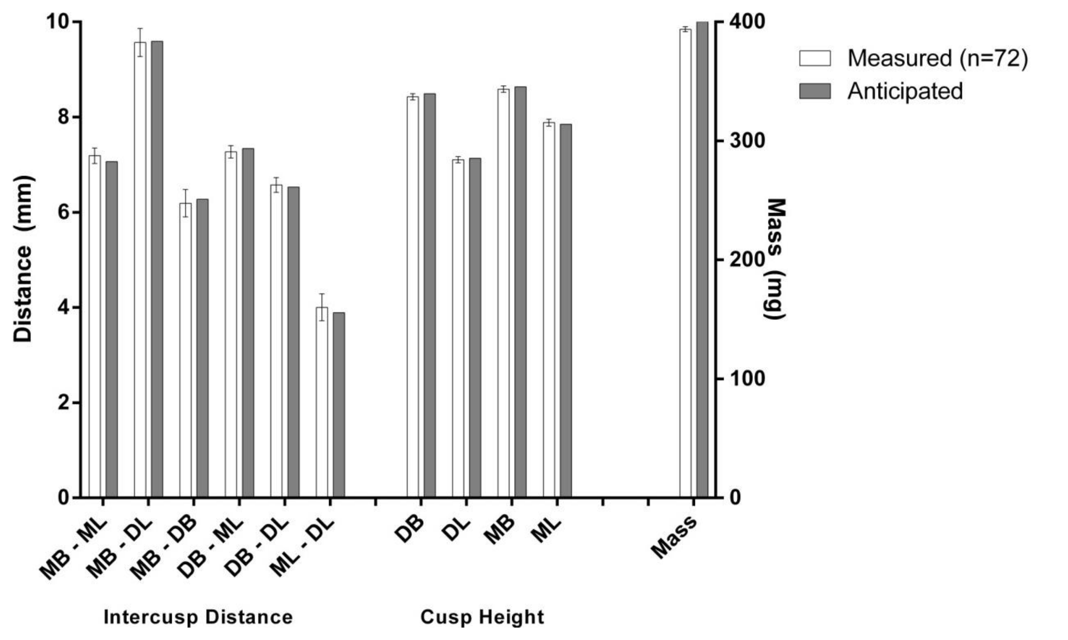

Fig 2b. Comparison of 10 measured dimensions and mass between stereolithograph files and the 3D printed results (n=72).

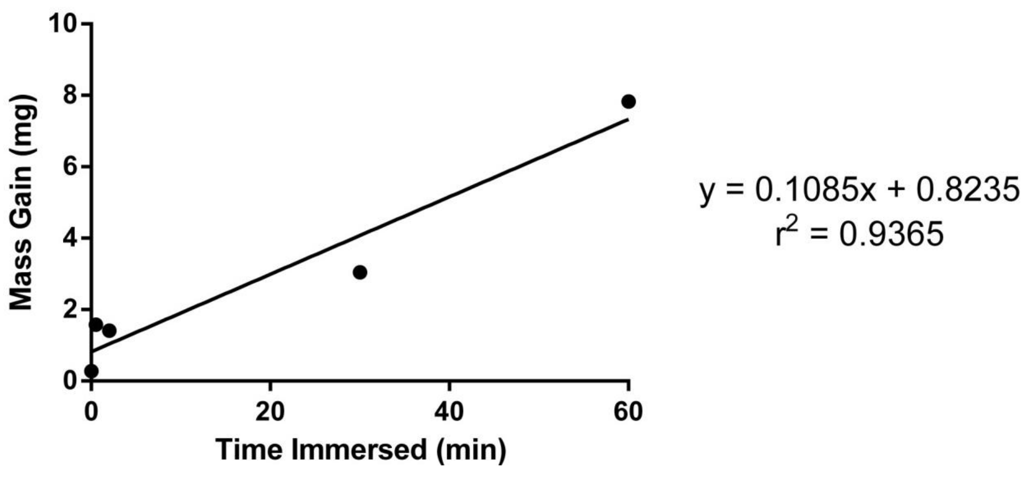

Fig 3a. Mass gained by 3D printed teeth after immersion in water for various periods of time.

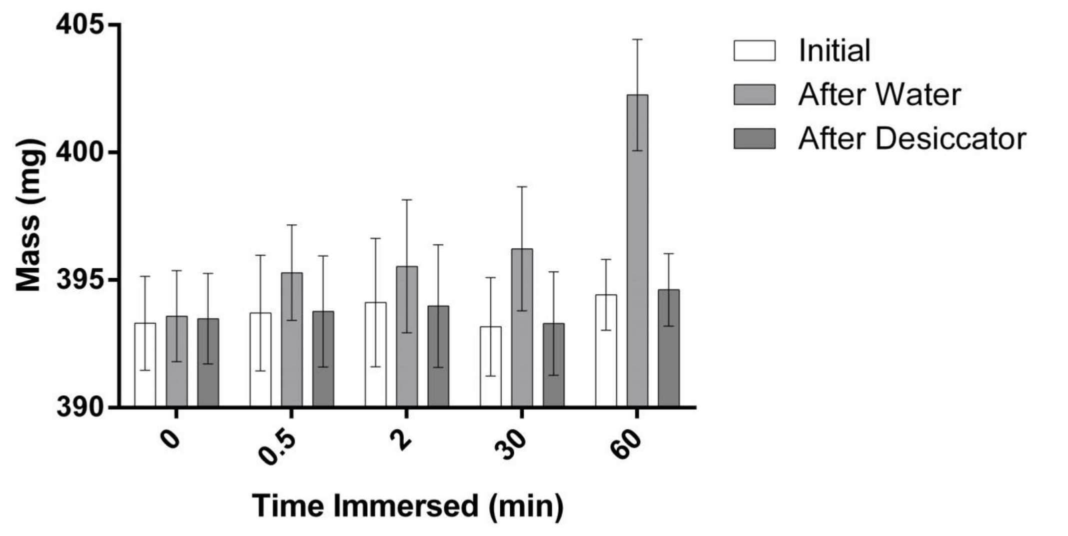

Fig 3b. Comparison of 3D printed tooth mass dry, after water immersion for various periods of time and after desiccation.

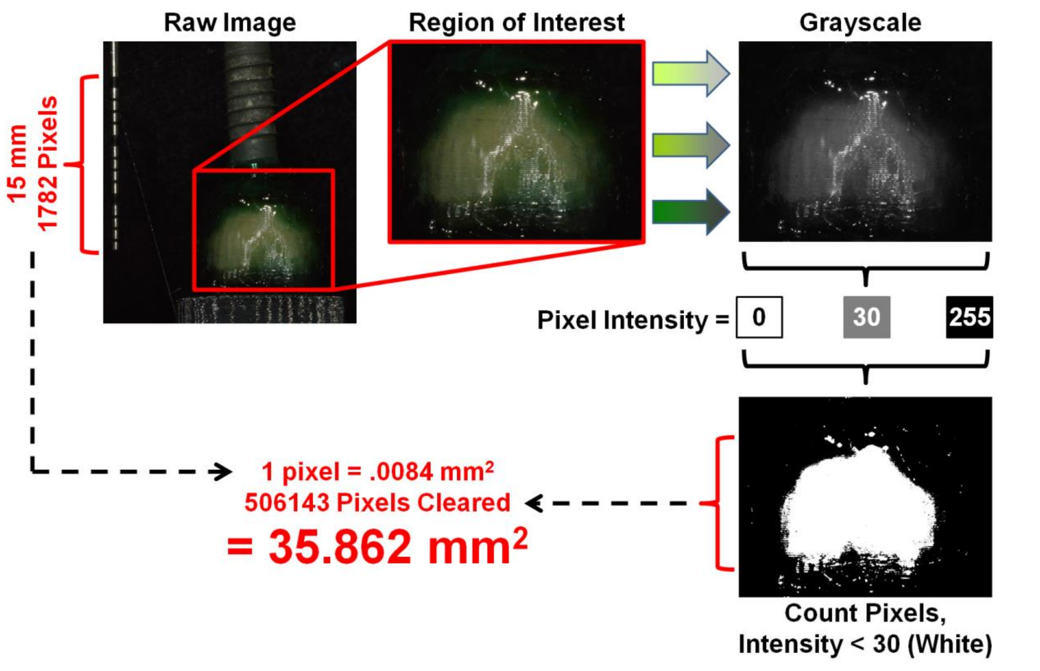

Fig 4a. Determination of surface area of plaque removed from a tooth by brushing required isolation of the region of interest, conversion to grayscale and compilation of pixel intensity values to evaluate whether plaque remained in any given pixel.

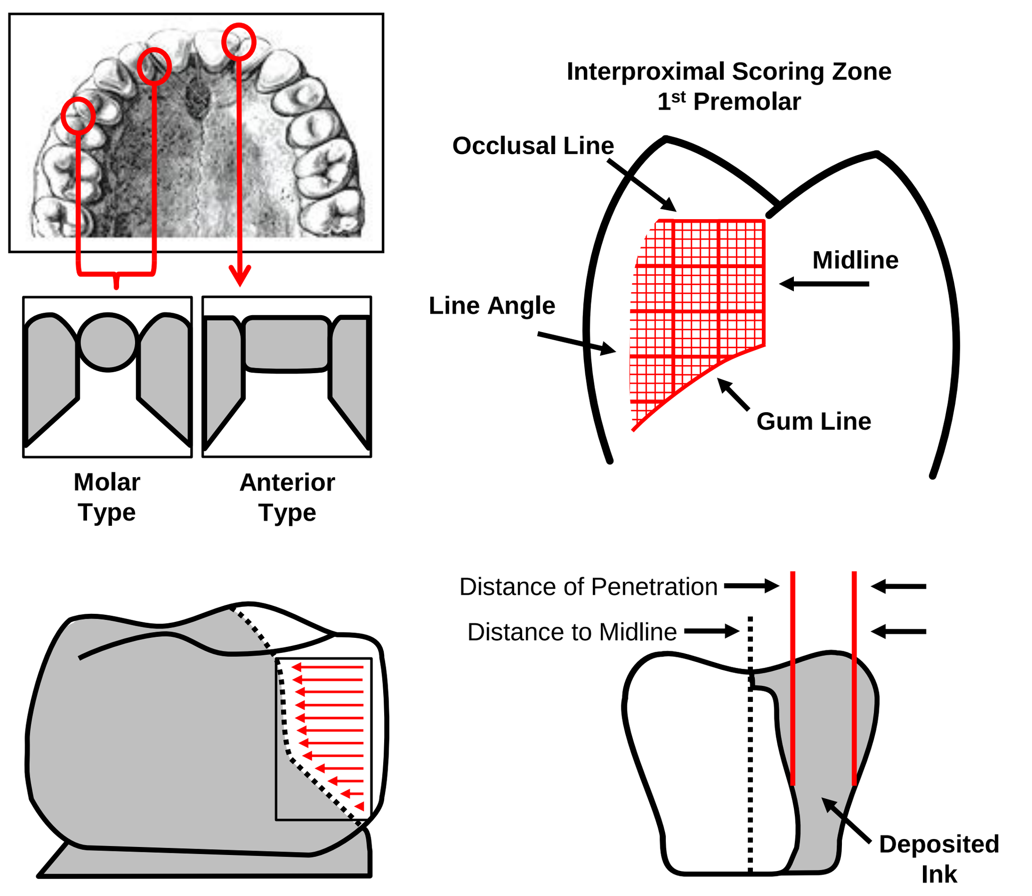

Fig 4b. Previously published methods to directly or indirectly assess surface area of plaque removed from a tooth.

Models were designed and successfully 3D printed (Fig. 1). Characteristics incorporated include anatomically correct dental structures, removable implant fixtures with crowns, simulated gingiva and a mount which allows for placement of models into a brushing machine to assess plaque removal.

Similarity Between Models: 72 identical maxillary first molar crowns were 3D printed concurrently, to evaluate the accuracy of the 3D printing hardware. All crowns were measured in 11 dimensions: 4 cusp heights, 6 intercusp distances and mass (Fig. 2a). Compared to the values within the stereolithography file that was printed, average intercusp measurements ranged from .084 mm smaller to .125 mm larger than expected, while cusp height measurements ranged from .065 mm smaller to .032 mm larger than expected and the crown mass was 6.27 mg less than expected (Fig. 2b). The highest standard deviation for average intercusp measurements was .293 mm, for cusp height the highest standard deviation was .071 mm and the standard deviation for mass was 2.07 mg.

Water Absorption: Minimal mass change over time was observed for 3D printed crowns that remained dry, however immersion in water yielded an increase in mass that had a positive linear correlation with time immersed (r^2 = .9365) (Fig. 3a). This mass increase was found to be fully reversible via desiccation (Fig. 3b).

Porcelain Comparison to 3D Printed Plastic: Under the same brushing conditions, an average of 100.006 mm^2 of artificial plaque was removed from a porcelain surface, while an average of 97.205 mm^2 of artificial plaque was removed from a 3D printed surface.

Digital Analysis of Plaque Removal: Photographs were taken of brushed crowns placed next to a periodontal probe which were converted to grayscale yielding an intensity value between 0 (white) and 255 (black) for each pixel and a cutoff value was used while assessing plaque removal to include crown surfaces (off-white) while excluding surfaces covered by plaque (Fig. 4a). This method allowed for measurements with precision greater than .01 mm^2.

Conclusions

- We developed an accurate, objective working model for peri-implantium hygiene that mimics clinical conditions and can be used as a standardized simulation.
- Novel 3D printing hardware and materials were characterized and found to be suitable for the quantification of plaque removal from implants.
    - Models are highly accurate with average dimensional variations in an acceptable range and smaller than the resolution of the 3D printer used (X/Y = 400µm, Z = 100µm).
    - The models are porous and can absorb water. Since water is integral to the oral cavity, accurate simulations must include it. If mass is being measured, we recommend placing the models in a desiccator after water exposure.
    - Artificial plaque behaves similarly on porcelain discs and 3D printed discs, therefore 3D printed crowns can accurately simulate plaque removal from porcelain implant restorations.
- The artificial plaque substrate used has the same tenacity on 3D printed teeth as plaque biofilm has on enamel, *in vivo* allowing for successful modelling of clinical conditions.
- A high throughput measurement system was devised that can reliably evaluate the surface area of artificial plaque with precision exceeding .01 mm^2. This measurement system is far superior to other systems described in literature, which used imprecise, subjective measurements that were collected by hand and often performed on anatomically incorrect tooth analogs (Fig. 4b).
- A brushing machine was used to reproducibly simulate both subgingival and interproximal plaque removal.
- The digital system used facilitates collaboration via sending stereolithograph files which the recipient can print at little to no cost.