EFFECT OF PRINT ANGULATION, MODEL RESIN, AND PRINTER ON DIMENSIONAL ACCURACY OF 3D PRINTED MODELS

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INTRODUCTION

Recent advances in the application of digital imaging of oral tissues and three-dimensional, additive fabrication techniques have led to a burgeoning industry in dentistry. Over a very short period of time, this technology has greatly improved in terms of level of surface detail reproducibility and dimensional accuracy of printed forms.

Initially, thermoplastic extrusion of warmed filaments of various plastic material was used. However, the layer thickness was quite large, and surface feature reproduction was low. With advances in use of photocurable monomer resins and controlled application of photo-activating light wavelengths to provide polymerization of very thin slices of the form image, the reality of providing stoneless models of a patient's dentition became a physical, and financial reality in private dental practices.

CONVENTIONAL DENTAL STONE REPRODUCTION

MODELS BEING PRINTED HORIZONTALLY

BANK OF 3D PRINTED MODELS PRINTED AT AN OFFSET ANGULATION

When using additive manufacturing processes, the operator orients individual items within the printing area to maximize the total number of forms that can be made during a single printing cycle. In order to accomplish this task, the items will be tilted to help facilitate optimal use of the printing surface area. In addition, often times a structure needs to be developed within an image slice that is not currently connected to the main body of the form (it is free-hanging – unsupported). To alleviate this problem, the software inserts "supports" that act to anchor such initially free-hanging material. After fabrication, the supports are removed, leaving the final form only. As the angulation of fabrication increases, often times, the number of supports increases.

Currently, there is little-to-no knowledge of how printing angle or the specific resin/printer combination affects the dimensional accuracy of a 3-D printed dental model.

METHODS

SAME MASTER STL FILE OF MAXILLARY MODEL HAVING EMBEDDED, STRATEGICALLY PLACED PILLARS PRINTED

DENTAL 3D PRINTING RESINS TESTED

TYPE PRINTER	PRINTER MODEL	MANUFACTURER	RESIN USED	LIGHT SOURCE	POST-CURING PROCESS	RESOLUTION (µm)	PRINTED THICKNESS (µm)
FILAMENT	Robox Dual	CEL Robox UK	PLA Polar White	N/A	N/A	XY 7.5 (positioning presicion)	50
SLA, DLP 405 nm	MOONRAY (S100)	SprintRay Los Angeles CA	Gray Resin	LED-based Light Source	15 min alcohol, 15 LED post processing	XY 100	50
SLA, LASER 405 nm	FORM 2	Formlabs, Inc Sommerville MA	Gray Resin	405 nm laser, 250 mW (Class 1)	15 min alcohol, 15 LED post processing	XY 140	50
DLP	OCTAVE R1	Profound3D Exton PA	White	LED-based Light Source	15 min alcohol, 15 LED post processing	XY 70 (per pixel)	50
FDM (Filament deposition Modeling)	Objet Eden260 VS Dental Advantage	Stratasys Valencia, CA	Dental ASA resin	FDM technology	No PP requiered (FDM	600 XY (dpi)	28

MODEL FABRICATION

Each type resin/printer combination printed 3D models from same STL file
Each resin/printer combination printed models at 0° (horizontal), 30°, and 90° (vertical)
All with similar layer thickness (50 microns)
3 replications made per each test condition

DIMENSIONAL CHANGE MEASUREMENT

Distances between the centers of the printed pillars within each model were determined

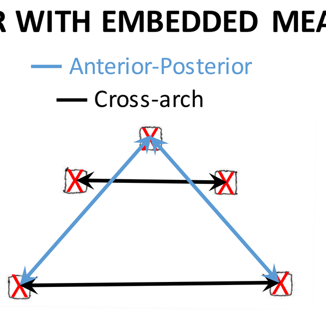
For each model:
Right and Left Ant/Post lengths determined, averaged into a single value

Upper and Lower cross-arch widths measured, averaged into a single value

MODELS PLACED ON FLATBED SCANNER WITH EMBEDDED MEASURE, IMAGE ANALYZED USING NIH IMAGE J

MODELS SCANNED

SCANNED IMAGE



PROCESSED IMAGE

ImageJ
Image Processing and Analysis in Java

X 2016

IMAGE PROCESSING DATA COLLECTION

SIGMAPLOT
Exact Graphs for Exact Science

STATISTICAL ANALYSIS

PURPOSE

The purposes of this research were to measure and compare the effect of print angulation 0° (horizontal), 30°, and 90° (vertical) on anterior-posterior and cross-arch dimensions among 3D printed maxillary models (all from the same STL file) using a variety of 3D printing resins and printers.

HYPOTHESES

Because there is no pre-exiting, similar data to base a hypothesis upon, it is anticipated that neither type of printer/resin nor printing angulation will have a significant effect on either Anterior-Posterior or Cross-arch dimensions among the various products tested.

RESULTS

STATISTICAL ANALYSES

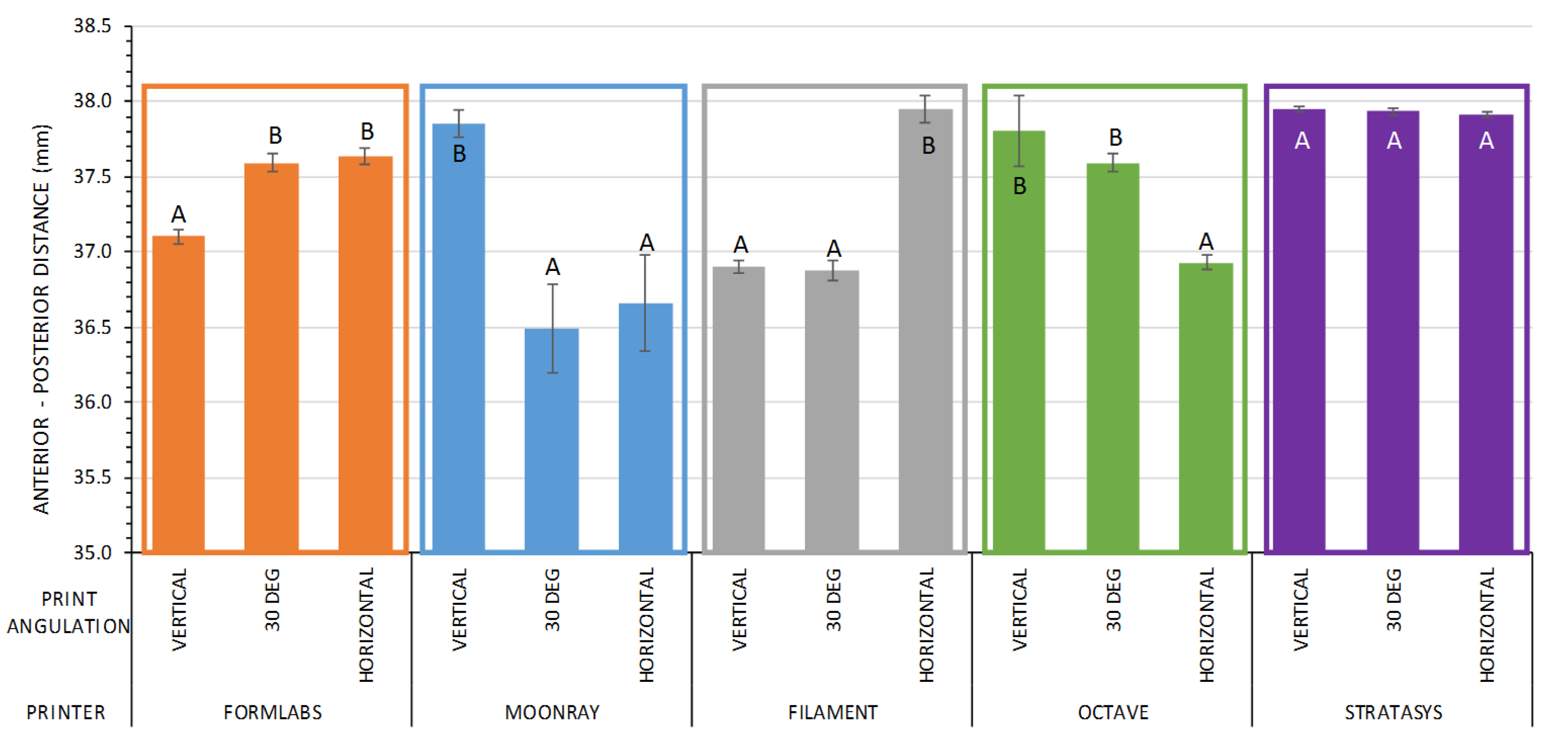
2-way ANOVA within each type Measurement category (Anterior/Posterior or Cross-Arch:

- ✓ Main effects cannot be properly interpreted if significant interaction is determined. This is because the size of a factor's effect depends upon the level of the other factor.
- ✓ The effect of different levels of PRINTER depends on what level of ANGULATION is present. There is a statistically significant interaction between PRINTER and ANGULATION. (P = <0.001)

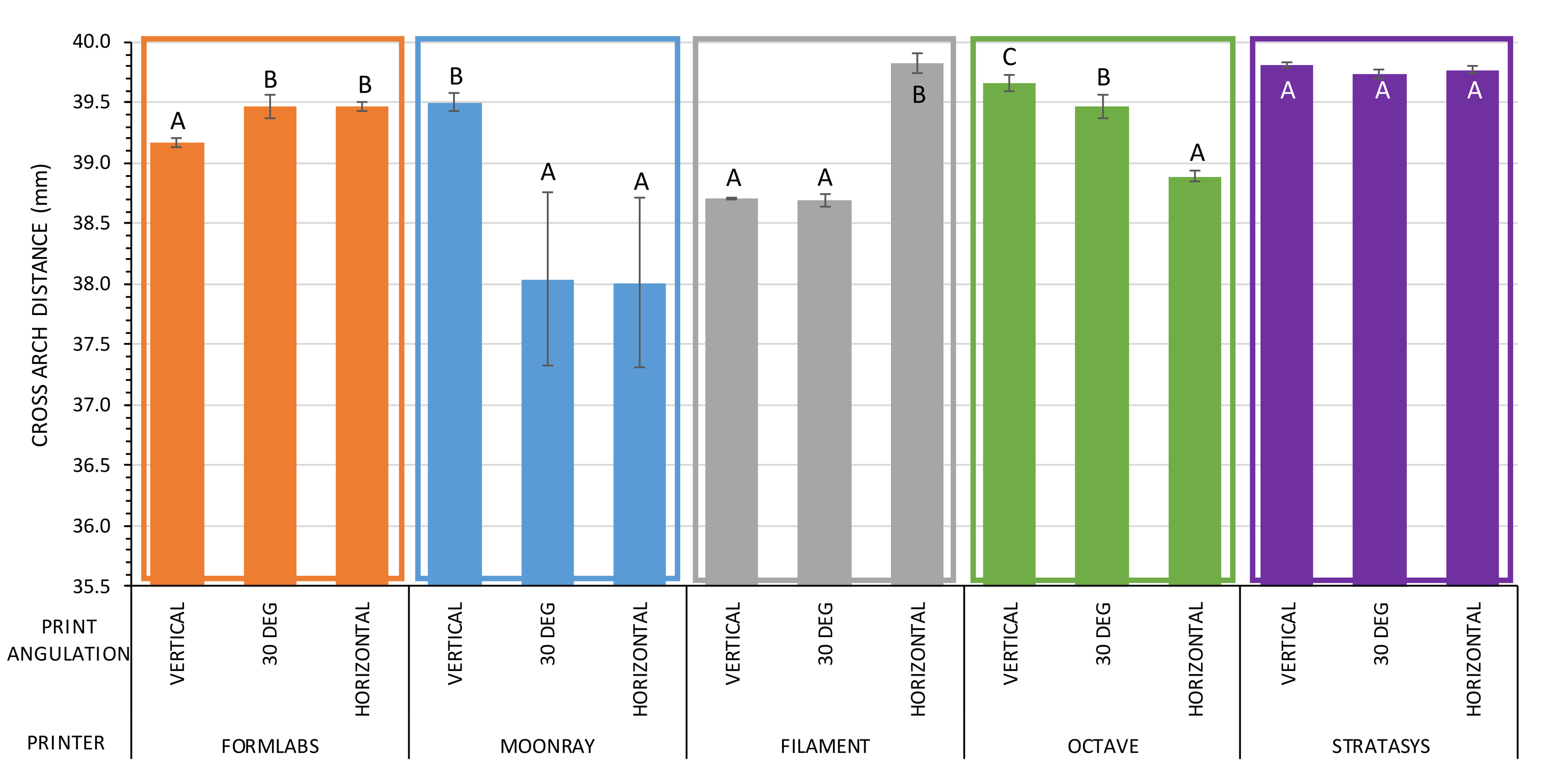
THEREFORE . . . .

1-Way ANOVAs were performed to test the effect of angulation among printer/resin types for each type of measurement classification

ANTERIOR-POSTER DIMENSIONAL DIFFERENCES



CROSS-ARCH DIMENSIONAL DIFFERENCES



1-way ANOVA within each type Printer/resin combination to test the effect of print angulation on Ant-Post dimension and Cross-arch measurement
Tukey post-hoc, pair-wise means comparison
Pre-set alpha 0.05
N=3 specimens per experimental group
Within a printer/resin combination, values correlated with same upper case letter are not significantly different.

CONCLUSIONS

1. Significant interaction among Printer/resin types and printing angulation on Anterior-Posterior as well as on Cross-arch dimensions
2. Effect of print angulation trends were similar for a given type printer/resin for anterior-Posterior and Cross-Arch dimensions
3. Formlabs and Filament printing dimensions tended to increase with print angulation; Moonray and Octave tended to decrease with angulation
4. Best dimensional consistency with angulation for both measurement classifications was Stratasys