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3D Printing Research

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THE EFFECT OF PRINT ANGULATION ON SURFACE ROUGHNESS AND DIMENSIONAL REPRODUCIBILITY OF 3D-PRINTED MODELS

BACKGROUND

- When optimizing print space on the build plate, angling the orientation of the printed object is a common practice.
- However, angulation requires auxiliary supports that significantly affect the dimensional accuracy of the item, create additional work in their removal, increase the volume of resin consumed, and affect the surface smoothness and detail reproduction.
- So how does print angulation affect surface roughness and dimensional accuracy when you are using different types of resins and printers?

PURPOSE OF STUDY

- Evaluate the effect of print angulation on Surface Roughness and Dimensional Accuracy of 3D printed models using a wide variety of 3D printers and resins.

MATERIALS AND METHODS

- Random maxillary cast
- Digitally scanned Medit T500
- 5 vertical pillars added to master STL (Standard Triangle Language) file as measurement points.
- The same STL file was sent to different manufacturers requesting the fabrication of 6 replications using 3 angulations:
    - Horizontal (0°)
    - 30°
    - Vertical (70° to preclude supports on pillars)
- In all digital fabrication processes, the object to be fabricated was placed in a Cartesian coordinate system consisting of closed, triangular spaces.
- The 3D object was deconstructed into 2D file “slices” that are sequentially produced using layer-by-layer strategy.

- Some manufacturers used **Fused Deposition Modelling (FDM)** – an extrusion process of layering successive heights of warmed filament that fuse to each other as they are deposited and form the final product when cooled.
- A variety of active polymerization processes were also used:
    - **Steriolithography Apparatus (SLA)** – uses a bath of unpolymerized resin and UV-based laser to trace out the features of each slice.
    - **Digital Light Projection (DLP)** – projects an image of an entire slide onto the bottom of the resin bath all at once.
    - **Polyjet Photopolymerization (PP)** – uses printing technology much like an ink jet printer.

EFFECT OF PRINT ANGULATION ON **SURFACE ROUGHNESS**

- A Nanovea ST400 non-contact optical scanner was used to measure the Surface roughness/waviness of the models.
- Model was positioned vertically in orientation jig.
- Scan information run through surface analysis software TalyMap Gold.
- **Surface Roughness vs Waviness**:
    - **Surface Roughness (Sa)** is determined by averaging roughness over a pre-defined area, not accounting for object form.
    - **Waviness** is surface roughness that takes into account object form. It is what you see with your eye. Often overlooked.

RESULTS, ANALYSIS & DISCUSSION

- A 2-Factor ANOVA was used to compare the effect of angulation on Sa and Waviness in multiple print/resin systems.
- Angulation as a factor did not significantly affect either Sa or waviness.
- Printer/Resin/Angulation interaction significantly affected Sa and Waviness.
- There was no significant difference in Waviness in majority of resin/printer combinations (average between 33 and 48 microns).
- Waviness of the same DLP printer (MR S100) with different resins produced similar values. However, the same resin with a different printer (SR Pro) produced significantly lower waviness.
- FDM and PP produced the roughest surfaces (Sa). Sa values of all others were between only 1 and 1.5 μm.

CONCLUSIONS

- Print angulation did not globally affect either surface waviness or Sa.
- Waviness values should be considered whenever surface smoothness is evaluated – variation in surface form left from the sequential layering fabrication process is much greater than Sa values, which only measure the smoothness of the surface of a layered strand, not between.
- Printer selection is much more influential on waviness than Sa.
- Relative ranking of resin/printers not similar for waviness and Sa.

EFFECT OF PRINT ANGULATION ON **DIMENSIONAL REPRODUCIBILITY**

- Wanted to know how the models differ anterior-posteriorly and cross-arch.
- Model placed on a desktop scanner along with calibrated scale.
- Scan was imported into image analysis software (ImageJ).
- Software measured and compared distances between printed pillars.
- The same measurements were done on the STL file to establish how accurately different print systems and angulations reproduced the dimensions of the STL file.

RESULTS, ANALYSIS & DISCUSSION

- Anterior-Posterior and Cross-arch dimensions showed <u>no overall trend</u> of print angulation on dimensional reproduction from the same STL file.
- The SLA, PPP, and some DLP printers reproduced dimensions in both directions not significantly different from the STL file control.
- Dimensions were affected by resin for the same printer:
    - SR Grey/MoonRay S100 models were shorter than the control (all clinically significant).
    - SR Tan Model/MoonRay S100 dimensions were not different from the STL control, but many values were clinically significant.
    - SR Tan Model resin, using a more recent model printer (SprintRay Pro), produced dimensions not different from the STL control, none of which were clinically significant.
    - Best reproducibility in the absence of clinically significant values independent of angulation, seen using PPP (Verodent/Eden 260) and DLP (SR Tan Model/SprintRay Pro).

CONCLUSIONS

- Ability to reproduce STL master dimension on printed models is not universally related to print angulation. It varies according to printer and resin combination.
- Dimensional reproducibility and provision of values considered to be clinically acceptable was found to be resin and printer-dependent.

OVERALL CONCLUSIONS

- The printer demonstrating the lowest effect of print angulation on surface roughness or dimensional accuracy was the Sprintray PRO (DLP) and the Objet Eden (PPP).
- However, results could also be dependent on selection of resin.
- Surface waviness is a much more appropriate parameter to compare surfaces than Sa.
- The biggest issue with dimensional measurement had to do with being within 0.25mm of the STL file dimensions.