RadioMatrix
Lab Report

This document specifies the tests, analysis and observations in the RadioMatrix™ development process.

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Method

Printing and scanning

All models were printed on Stratasys Digital Anatomy™ Printers (DAP). 4 different printers were used (designated Bio 1/2/3/5), 2 different modes (High Mix and High Speed) and 2 different batches of RadioMatrix resin (internal and production). The materials used were RadioMatrix (RM), TissueMatrix™ (TM) and VeroClear™ (VC).

All models were scanned in a clinical Philips CT iCT 256 scanner, which undergoes a weekly IQ test by a certified technician and quarterly preventive maintenance. The scanners' software version was iCT by iPatient v4.1.10.19210, OS version - 5.0.0.1026, EBW - V4.8.5.65126, Scanner - V5.0.0.10181.

Analysis method

The results were analyzed in MATLAB software using the intrinsic DICOM reading functions of MATLAB (dicomCollection, dicominfo, dicomreadVolume). After reading the DICOM set, the following analysis steps were performed:

1. The range of slices in which the models appear were determined manually. The slice range was chosen such that slices near the edges were not analyzed. The goal is to avoid noise caused by the air and the mixing layer of support material.

2. In the 1st slice elements in the frame were found with their bounding boxes. The bounding box was eroded by 7 pixels in order to avoid edge effects.

3. For each slice, the average and standard deviation of each element were found using the bounding boxes found in step 2.

4. The overall value was the average on all slices (i.e. average on the volume of the model). The overall standard deviation was also calculated.

Results

Test 1: Baseline tests of different PolyJet™ materials

Cubes of most base materials available in DAP were printed and scanned.

- Most materials were around ~100HU

- Exceptions:

  - VeroUltraWhite™: ~200HU

  - TissueMatrix: ~ - 50HU

  - GelMatrix™ and MED625™: ~50HU

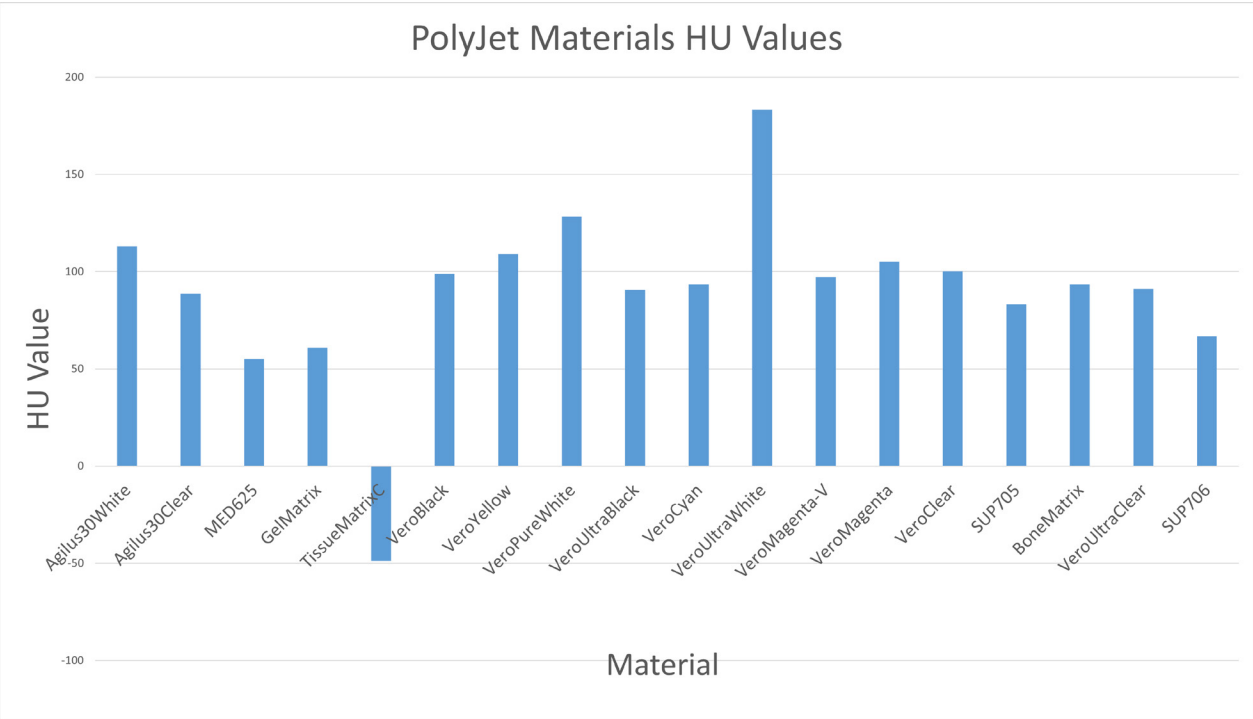- Standard deviations were around 15-20HU

Figure 1: HU values of different PolyJet materials - 120KV

Test 2: Calibration curves & Benchmark repeatability

Two benchmark models were designed:

- First benchmark: Mixings of VeroClear and RadioMatrix in several percentages (0%-100% RadioMatrix)

- Second benchmark: Mixings of VeroClear and TissueMatrix in several percentages (0%-95% TissueMatrix).

Both benchmarks were printed in various conditions, as is described below.
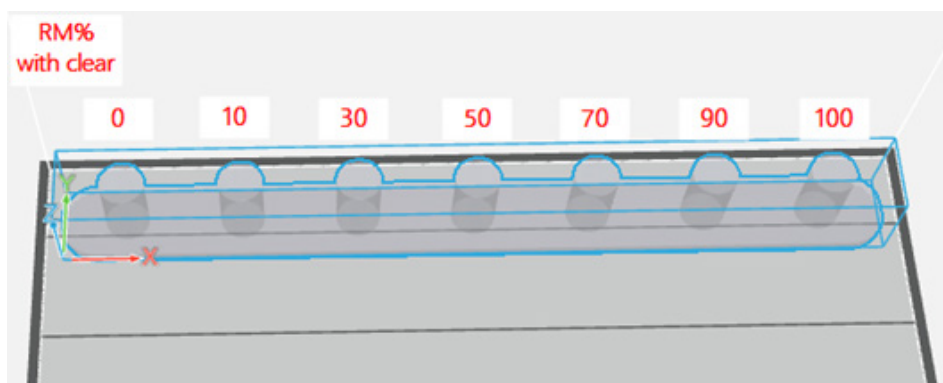The benchmarks consisted of cylinders with heights of 40mm and diameters of 25mm.

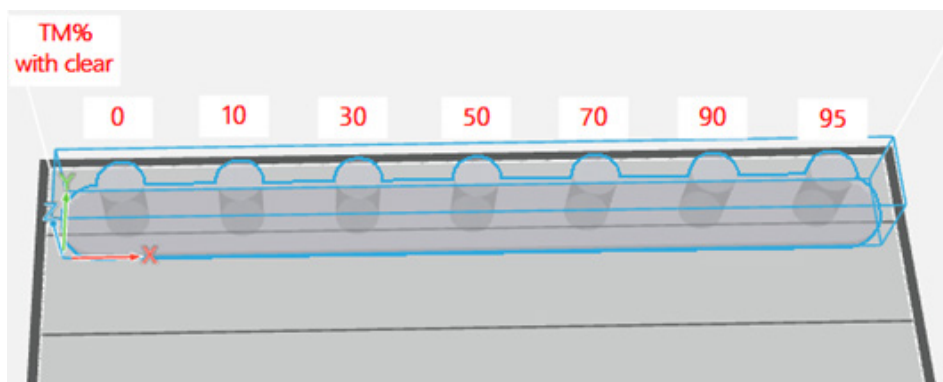**Figure 2:** RadioMatrix/VeroClear benchmark. The red numbers are % of RadioMatrix.

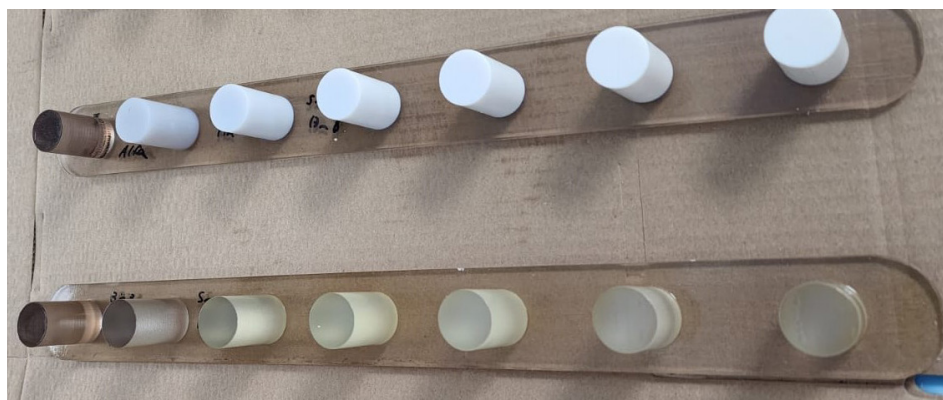**Figure 3:** TissueMatrix/VeroClear benchmark. The red numbers are % of TissueMatrix.

Figure 4: printed benchmarks. Upper: RadioMatrix/VeroClear. lower: TissueMatrix/VeroClear.

RadioMatrix/VeroClear benchmark results:

Table 1: RadioMatrix/VeroClear Benchmark- printing parameters

- Behavior was very linear across Kv values.

- The max difference between values through all different conditions is <20HU.

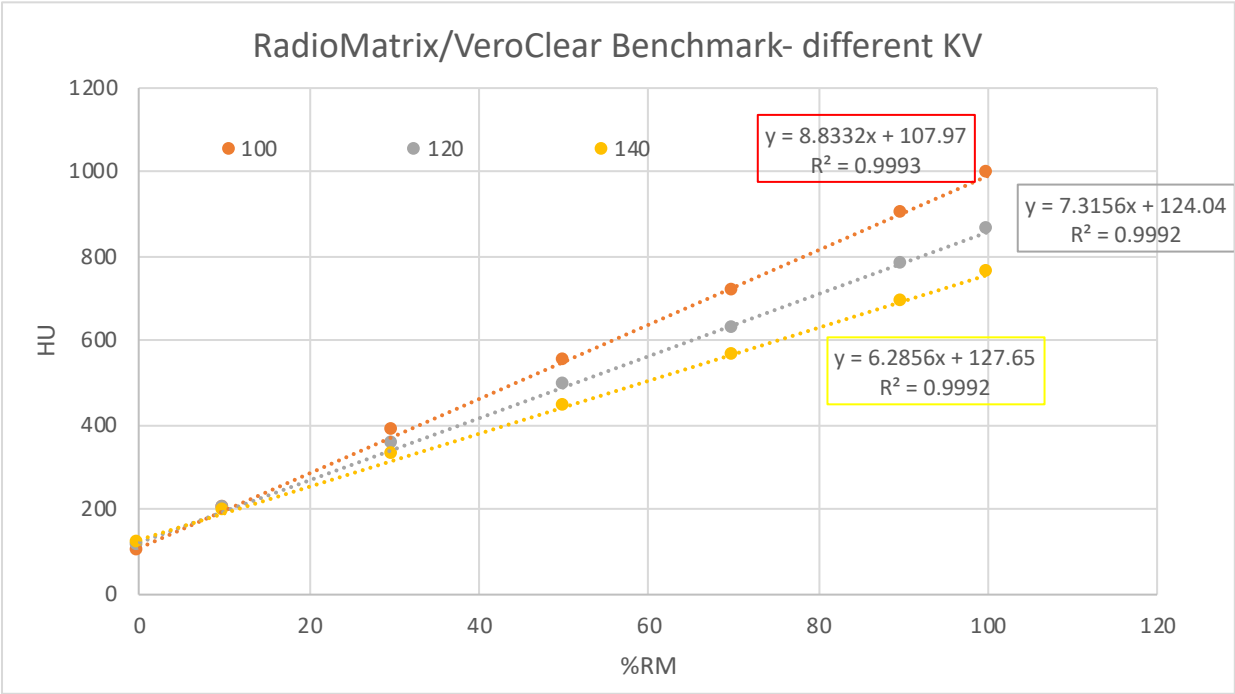- The standard deviation of all values in the graphs is ~10-20 HU.

RadioMatrix/VeroClear Benchmark- different KV

Legend: ● 100   ● 120   ● 140

$y = 8.8332x + 107.97$
$R^2 = 0.9993$

$y = 7.3156x + 124.04$
$R^2 = 0.9992$

$y = 6.2856x + 127.65$
$R^2 = 0.9992$

Y-axis: HU (0 to 1200)
X-axis: %RM (0 to 120)

Figure 5: RadioMatrix/VeroClear benchmark scanned in several KV settings

RadioMatrix/VeroClear Benchmark- 120KeV

Figure 6: RadioMatrix/VeroClear benchmark at 120 Kv in different conditions (see table below for details)

	Mode	Printer	Batch	Date
1	High Mix	Bio5	Internal	28/3
2	High Speed	Bio5	Internal	28/3
3	High Speed	Bio3	Internal	28/3
4	High Mix	Bio2	Production	18/4

Table 1: RadioMatrix/VeroClear Benchmark- printing parameters

TissueMatrix/VeroClear benchmark results:

Table 2: TissueMatrix/VeroClear Benchmark- printing parameters

- Behavior was very linear in all KV values.
- The max difference between the values of all different conditions is <5HU.
- The standard deviation of all values in the graphs is ~10-20 HU.

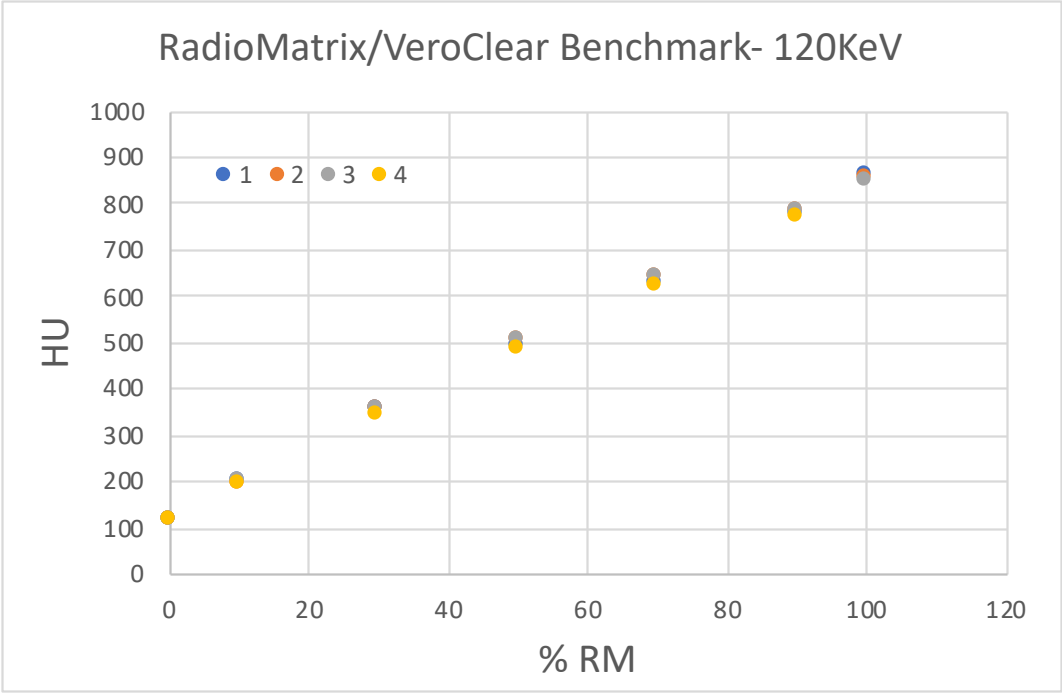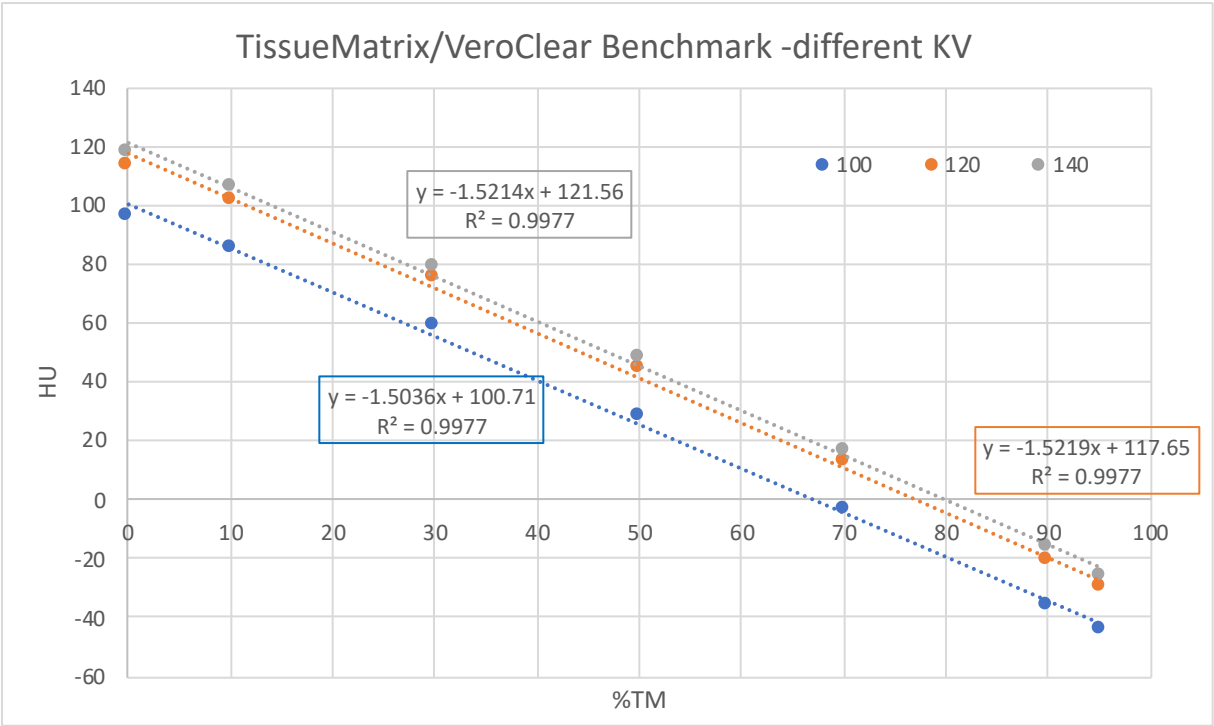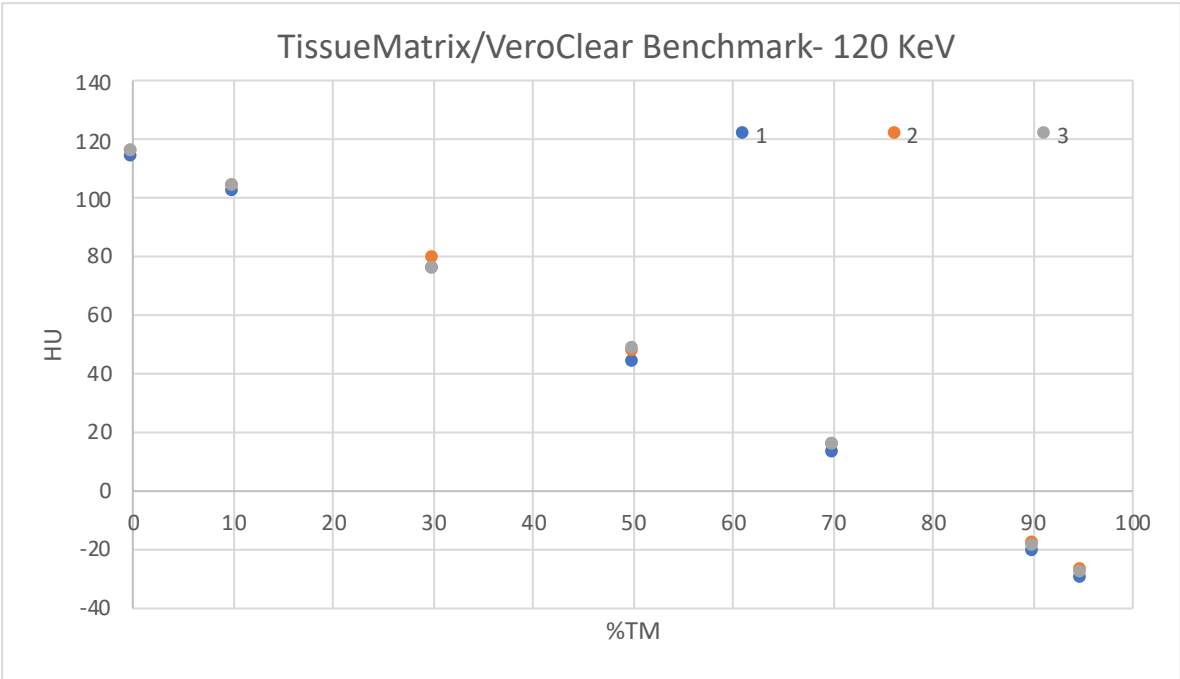**Figure 7:** TissueMatrix/VeroClear benchmark scanned in several KV settings

Figure 8: TissueMatrix/VeroClear benchmark at 120 Kv in different conditions (see table below for details)

	Mode	Machine	Batch	Date
1	High Mix	Bio1	Internal	28/3
2	High Mix	Bio2	Production	18/4
3	High Mix	Bio3	Production	18/4

Table 5: HU values for different sizes

Test 3: Dependence on printing position/angle/size

Angle and position in x

A tray with cylinders with similar geometry to the benchmark's cylinders was printed and scanned, using various angles positioned along the X-direction of the tray. The tray was printed again, but with a different arrangement of the angles. Both scans of the trays were compared to see if a correlation of HU to angle or position was seen.

Two comparisons between the scans were made: a comparison between models in the same position and comparison between models with the same angle.
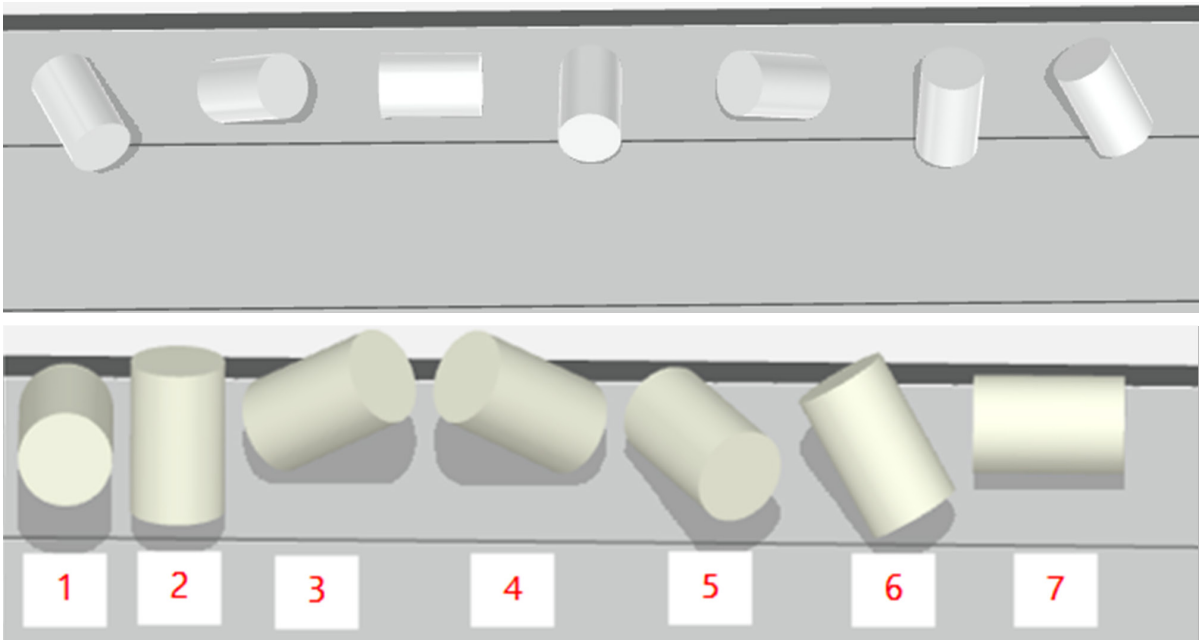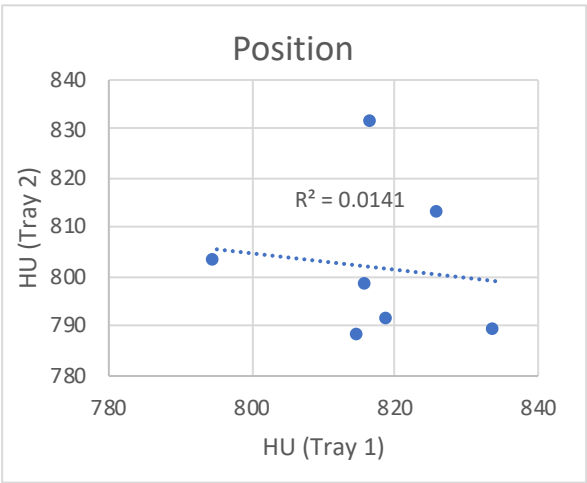

Figure 9: Trays for angle testing, upper: 1st tray, lower: 2nd tray

Table 3: HU values for different positions

| Position	Tray 1	Tray 2
1	795	803
2	817	831
3	816	798
4	815	788
5	819	791
6	826	813
7	834	789

Table 3: HU values for different positions

Figure 10: position comparison tray 1 and 2

Table 4: HU values for different angles

- The range of HU values was ~40HU.
- No correlation is seen between prints when comparing either position or angle. This strongly indicates that the differences seen between prints are due to noise in the scan.

Angle (as in scan 4)	Tray 1	Tray 2
1	795	791
2	817	798
3	816	789
4	815	803
5	819	788
6	826	831
7	834	813

Table 4: HU values for different angles
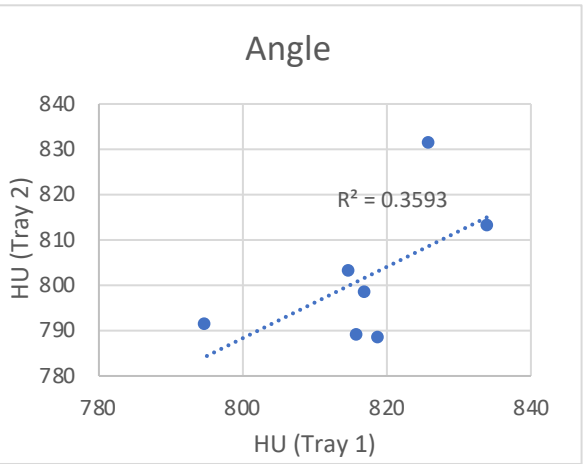
Figure 11: angle comparison of tray 1 and tray

Figure 12: size variation tray

Size Test

A tray of cylinders with varying diameters and heights was printed and scanned.

Table 5: HU values for different Size

- The range of HU is ~60.
- No correlation to diameter is seen.
- Some correlation is seen between the height of the model to HU value, where the value decreases with height.

Cylinder	Height	Diameter	HU
1	30	25	778
2	40	25	775
3	50	25	778
4	60	25	748
5	30	40	783
6	40	40	725
7	50	40	750
8	60	40	737
9	30	55	772
10	40	55	763
11	50	55	743
12	60	55	722

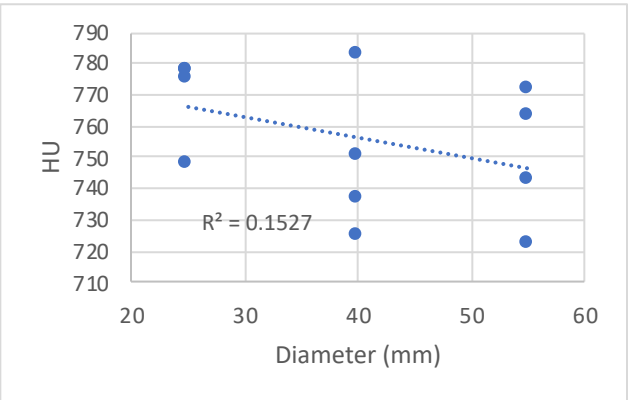**Table 5:** HU values for different Size

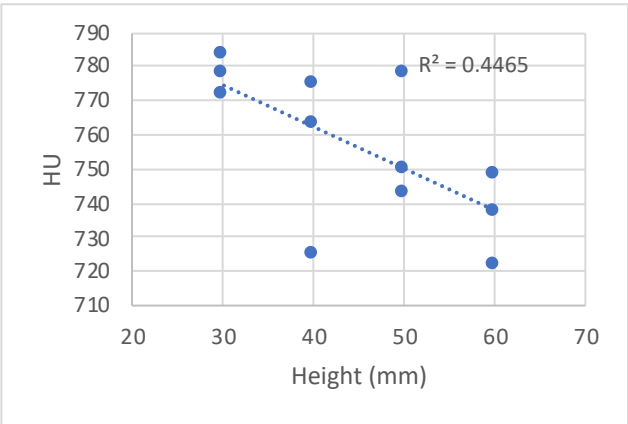**Figure 13:** dependence of HU on the diameter of the model

Figure 14: Dependence of the HU on the height of the model

Summary

- RadioMatrix/VeroClear and TissueMatrix/VeroClear mixings behave linearly with the RadioMatrix or TissueMatrix percentage.

- The calibration graphs are very repeatable over modes, printers, time, and resin batch (<20 HU difference),

- The HU values covered by DAP Radiology Materials is ~ -30 to 850 (scanning with 120KV) with a standard deviation of values around 10-20 HU.

- No correlation is seen between HU values and position on the print tray, angle or diameter of the model.

- Some correlation to height of the model is seen.

- It should be stressed that the results here are for a cylindric geometry. To get accurate predictions, a calibration curve should be completed for each geometry and scanning configuration (i.e., scanner model and parameters).

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