A Comparison of Metallographic Evaluation of Pore Morphology Using the Manual and Digital Methods Following ASTM F1854

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INTRODUCTION: The success of biological fixation of an orthopaedic implant depends on the pore size and porosity of the porous surfaces [1]. However, researchers rarely report the exact method used to measure pore size and porosity or employ non-standard methods [2]. Currently ASTM F1854-15 is the only consensus standard recognized by the US FDA to measure pore size and porosity of cementless implants. The ASTM standard provides options of using digital or manual method to measure pore size and porosity. The standard also recommends ensuring automated technique results are comparable to manual techniques. The goal of this study was to compare these different methods on a spherical beaded porous surface.

METHODS: Four spherical Ti bead coated Ti-6Al-4V samples with different lengths were evaluated. Images were taken using an optical microscope at 1.6 micron/pixel resolution and stitched together for each sample. The same set of stitched images (n=4) were used for percent porosity and pore size measurements independently by the two senior authors, one using the manual and one using the digital methods per ASTM F1854-15. *Porosity:* In manual method, an array of equally spaced points was superimposed onto the stitched image. The space between the points was <50 µm, and the grid size was 12 x 81 to 12 x 279 to cover the coating area with an original length between 3994 µm to 13891 µm for the four samples. At a magnification of 110x, the actual length of the images for manual measurement was between 44 cm to 153 cm, and the grid space was <5.5 mm. Porosity was measured by dividing the manually counted points on the void by the total number of points covering the coating area. In digital method, porosity was calculated by dividing the number of pixels in voids by the total number of pixels in the image using computer software, Image-Pro (Media Cybernetics). *Pore size or mean void intercept length (MVIL):* Two manual and two digital methods were used. The manual method follows Clause 9.3 of ASTM F1854 using an array of equally spaced grid lines (line space <50 µm) superimposed on the stitched image at 110x magnification. MVIL was calculated using the porosity value (manual), the evaluation length, and the number of intercepts manually counted either on both sides (Clause 9.3.3.1, method 1) or on one side (Clause 9.3.3.2, method 2) of the solid features. In digital method, an array of equally spaced grid lines was superimposed onto the image using the Image-Pro software. MVIL was calculated following Clause 9.3.5 of the standard using the porosity value (digital), the evaluation length, and auto-counted number of intercepts per Clause 9.3.3.1 (digital method 1), or following Clause 9.3.6 by averaging all the lengths of void in the field of measurement (digital method 2).

RESULTS AND ANALYSIS: *Porosity:* The mean (±SD) porosity for the four samples was 41.0 ±3.8% measured using the manual point count method (M) and 43.7 ±2.8% using the digital pixel count method (D). The digital method resulted in a higher porosity value than the manual method, with a mean (±SD.) difference of 2.7 ±2.0% (range 0.1% to 4.7%), Table 1. *Mean void intercept length (MVIL):* The MVIL measured using the manual method 2 (M2) was lower than that using method 1 (M1), with a mean (±std.) difference (ΔM) of -9 ±8 µm (range -1 to -19 µm). The MVIL measured using the digital method 2 (D2) was lower than that measured by digital method 1 (D1) in general, with a mean difference (ΔD) of -15 ±14 µm (range 0 to -30 µm), Table 2. When average of the two digital results and average of the two manual results was compared for each sample, the digital method resulted in a higher MVIL, with a mean difference (ΔDM) of 7 ±7 µm (range 1 to 16 µm). Among all four (2 digital and 2 manual) results measured for each sample, the maximum difference (ΔMax) was in the range of 14 µm to 30 µm, and the mean was 21 ±7 µm for the four samples.

DISCUSSIONS: *Porosity:* In principle, porosity values measured using the standard manual point count and digital pixel count method should match. A factor that may contribute to the observed difference between the two methods used in this study could be the different brightness/contrast settings used independently by the two investigators. It can be expected that a change of brightness/contrast of a grayscale image can affect the point or pixel count particularly in the boundary between the void and the solid feature, thus affecting the measured porosity value. Standardization of image brightness/contrast setting may reduce the uncertainty for porosity measurement using different methods. *Mean void intercept length (MVIL):* The difference between the two manual methods, and between the two digital methods is mainly reflected by the different ways of counting the intercept at the two ends of the grid lines. This edge effect is expected to be smaller with increased evaluation length. Likely for this reason, the longest sample B4 had little (1 µm) or no (0 µm) difference in MVIL between the two manual or between the two digital methods, Table 2. On the other hand, the difference between the digital and manual method (ΔDM) was larger for sample with a longer length. This may have been caused by the systematic difference between the two methods, such as different image contrast setting, which is amplified with increasing evaluation length.

SIGNIFICANCE: Optimal pore size and porosity is essential for bone growth and long-term fixation of orthopaedic implants. A consistent method to compare different porous surfaces is critical to compare the performance of such implants.

REFERENCES: [1] Bobyn JD, et al, CORR, 1980(150),263-270. [2] Chang B et al., Acta Biomaterialia, 2016 (33),311-321.

ID	Length (µm)	Porosity %		
		M	D	Δ
B1	4755	40.7	45.4	**4.7**
B2	3994	38.0	40.2	**2.2**
B3	11523	46.4	46.5	**0.1**
B4	13891	39.0	42.7	**3.7**
Mean		41.0	43.7	2.7
SD		3.8	2.8	2.0

Table 1: Summary of porosity. M is manual result (percentage of point count), and D is the digital result (percentage of pixel count). Δ=D-M represents the difference between the two methods.

ID	Manual MVIL (µm)				Digital MVIL (µm)				ΔDM (µm)	ΔMax. (µm)
	M1	M2	M	ΔM	D1	D2	D	ΔD		
B1	200	181	191	**-19**	205	182	194	**-23**	**3**	**24**
B2	142	135	139	**-7**	155	125	140	**-30**	**1**	**30**
B3	201	193	197	**-8**	207	201	204	**-6**	**7**	**14**
B4	165	164	165	**-1**	181	181	181	**0**	**16**	**17**
Mean	177	168	173	-9	187	172	180	-15	7	21
SD	29	25	27	8	24	33	28	14	7	7

Table 2: Summary of MVIL. M1 and M2 are results by manual method 1 and 2, M=(M1+M2)/2, and ΔM=M2-M1. D1 and D2 are results by digital method 1 and 2, D=(D1+D2)/2 and ΔD=D2-D1. ΔDM=D-M represents the difference between the digital and manual result. ΔMax is the maximum difference among the 4 results (2 manual and 2 digital) measured for each sample.