APERTURE AND PORE SIZE DISTRIBUTION OF TITANIUM FOAM IMPLANTS

T. Imwinkelried[1], P.D. Lee[2].
[1]Synthes GmbH Oberdorf (Switzerland), [2]Imperial College, London (UK).

Statement of Purpose: Titanium foam is attractive for implants where bone in-growth is essential. The combination of bone-like mechanical properties with an interconnected porosity may lead to excellent biological fixation [1]. However, even if an ideal pore size for bone in-growth is chosen, the apertures between pores (i.e. the pore throats or interconnects) may not be large enough to sustain complete bone penetration, thereby potentially limiting the osseous integration of the implant. The objective of this study was to characterize these relevant internal geometries of a commercially available implant material using x-ray microtomography.

Methods: Titanium foam implants are net-shape sintered using a powder metallurgical process (space holder method) [2]. The pore size is controlled by using the desired grain size fraction of the space holder powder (ammoniumbicarbonate). A total porosity of 62.5±1% is obtained by mixing the adequate amount of space holder powder to fine grained titanium powder.
Two cylinders of 5 mm diameter and 10 mm length are cut out of OPTINIUM™ (Synthes, Switzerland) titanium foam using wire electro-discharge machining (EDM). Sample 1 is produced from material used for an animal study [1], Sample 2 is cut out of a PlivioPore™ implant (Synthes, Switzerland, see Fig. 1) chosen at random from validated production.
A commercial X-ray microtomography (XMT) unit (nano-focus, Phoenix x-ray Systems and Services GmbH) with a resolution of 5.75 µm is used for the scanning. Appropriate mathematical morphological operators to identify individual pores and to quantify the size of the pores and of the apertures are used [3, 4].

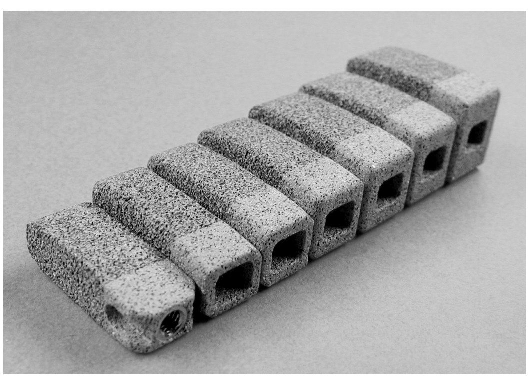

Figure 1. Titanium foam implants for posterior lumbar interbody fusion (PlivioPore™)

Results/Discussion: The distribution of the equivalent pore diameter (diameter of a spherical pore of equal volume) is given in Figure 2 for both samples. It is best approximated by a log normal distribution with a mean of 6.02±0.19. In micrometers, this corresponds to a mean value of 411 µm with +84 µm as the higher and -70 µm as the lower one sigma standard deviation.
The distribution of the equivalent aperture diameter (aperture bounding box diagonal) is given in figure 2 for both samples. It is best approximated by a log normal distribution with a mean and one sigma standard deviations of 4.4±0.92. This corresponds to a mean value of 81 µm (+122 /-49 µm). However, this result is unduely weighted by the very small interconnects. They contribute to less than 5% of the aperture area. If the total area of interconnects is taken instead, more than 90% of the area interconnecting the pores in apertures are greater than 100 µm.
The narrow size distribution of the pores contrasts with the wider distribution of apertures. Additionally, the pores appear to be in the upper range for good bone in-growth while the corresponding apertures fall in the lower range. A dog study [1] confirms that complete bone growth across a 5 mm cylinder can be achieved in less than 12 weeks.

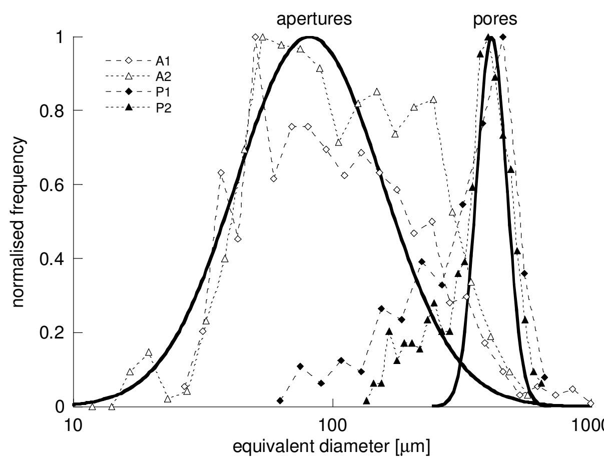

Figure 2. Equivalent diameter of pores (P) and of apertures (A) for sample 1 (A1, P1) and for sample 2 (A2, P2) with corresponding log normal distributions.

Conclusions: On average, the apertures in the OPTINIUM™ titanium foam are smaller than the pores themselves. However, pore and aperture size distributions appear to be within a range that allows complete bone in-growth.

References:

1. Steffen T, et al. 51st Ann. Meet. Orth. Res. Soc., Washington DC 2005; 30: 1396
2. Laptev A, et al.. Powder Metallurgy 2004; 47: 85-92
3. Atwood RC, et al. Scripta Mat. 2004; 51 (11): 1029-1033
4. Jones JR, et al. Roy Soc A 2006; 364 (1838): 263-281