Rapid Fabrication Techniques for Complex-Shaped Calcium Polyphosphate Substrates of Implants to Repair Large Osteochondral Defects

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Introduction: Total joint replacement has enabled millions of people with severely damaged joints to live fuller and more active lives but in terms of function, the failures rates can be as high as 20% after 10 years [1]. Recent animal studies with sheep [2] demonstrated that small osteochondral defects could be repaired using 4 mm diameter plugs with cartilage grown *in vitro* from sheep cells on the surface of bone-substituting calcium polyphosphate (CPP) substrates. However, when the substrate and resulting cartilage surface of the implant did not match the joint surface contours, cartilage erosion occurred because tissue formation was sensitive to abnormal levels of strain and hydrostatic stress [3]. Thus, the surface geometry of the substrate was expected to have a major influence [4] when attempting to repair larger osteochondral defects. To achieve geometrical conformity, the original subchondral bone profile was obtained from a computer axial tomography (CAT) scan that was then used in freeform surface fabrication. The purpose of the present study was to explore the feasibility of two surface fabrication approaches: one involving computer numerically controlled (CNC) machining and the other one involving three-dimensional printing (3DP).

Methods: *CNC* machining was used directly to produce the required geometry from a sintered CPP block (Fig 1). The process is controlled to maintain minimal brittle fracture and proper porosity. The resulting surface properties were examined using scanning electron microscopy (SEM).

The 3DP utilized the ink-jet printer principle to bind ultra-thin layers of material successively to build up the desired object from a computer aided design (CAD) file. The process was employed to produce negative polymeric multi-segment molds with a "ZPrinter" (model 310 Plus®, Z-Corporation, Burlington, MA) and the CPP substrate was pre-shaped in the mold using a gelatin binder (Fig 1). The mold interior was covered with paint and then wax to isolate the mold material from the CPP thus avoiding possible adverse reactions. The final step would be to perform sintering of the pre-shaped part.

Results/Discussion: The CNC machined sample had good accuracy and reproducibility (Fig 1) and the SEM image (Fig 2) confirmed that it was possible to retain the open pores to facilitate cartilage formation and anchorage *in vitro* and bone ingrowth *in vivo* to achieve fixation of the biphasic (i.e. cartilage and CPP) implant. This approach could be further refined by developing a mechanistic cutting model for CPP to help predict and optimize the machining conditions and reduce both toolpath generation and machining time.

The 3DP process was performed to give a pre-shaped CPP part. In going from the CAD model of the mold to the 3DP finished mold, anisotropic scaling was needed to compensate for the very slight expansion inherent in the process. Unfortunately, at the next step, the pre-shaped part had some fine features that were not exactly replicated and sustained shrinkage, thus giving it a "near-net" shape. Better binding agents or further compensation might be able to solve this problem.

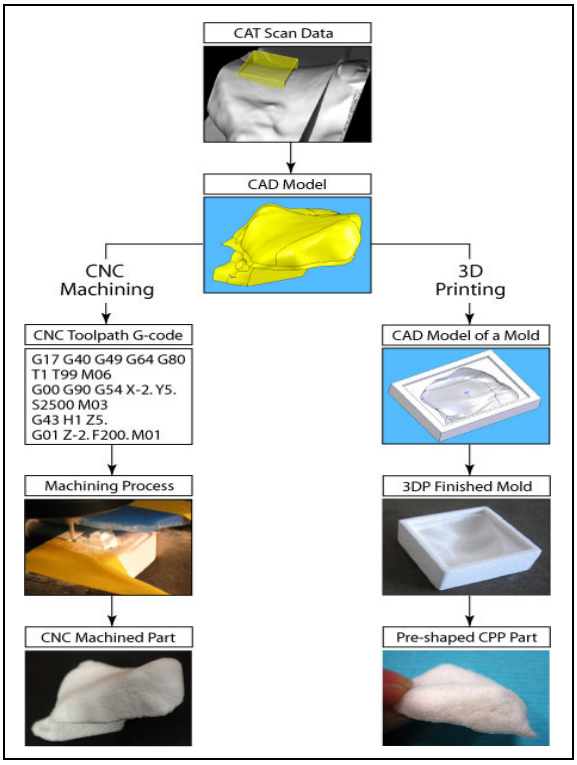

Fig 1: Process flowchart for 3DP and CNC machining.

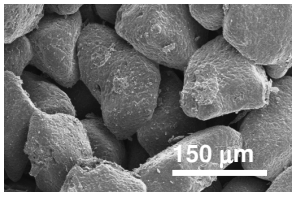

Fig 2: SEM of a CNC part.

Conclusions: CNC machining was a suitable approach for fabricating substrate with complex surface contours but further studies were advocated to reduce machining time. The 3DP made near-net shape parts and thus precision was compromised. Future research will consider improving the 3DP process or combining the fabrication procedures by producing a near-net shape parts with 3DP, followed by CNC machining to obtain a precise replication.

Reference: [1] Soderman P. Acta Orthop Scand. 2001; 72(2):113-19. [2] Kandel RA. Biomat. 2006;27:4120-31. [3] Carter DR. Clin Orthop. 1998;355(suppl):S41-S55. [4] Simmons CA. J Orth Res. 2000;19:187-94.