

## Formation of porous ultrahigh molecular weight polyethylene using subcritical water

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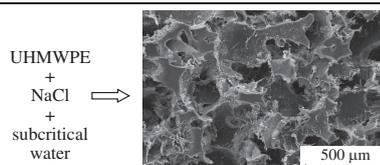
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**An effective method based on the leaching of NaCl from the bulk samples of ultrahigh molecular weight polyethylene was developed for the formation of multilayer porous scaffolds for bone defect replacement.**



The reconstruction of bone defects is a problem of considerable current interest in the implant surgery. In particular, the reconstruction of bones of the locomotor system is an extremely important and relevant part of orthopedics, oncology, traumatology and medicine in general.

The bone can be considered as a composite material consisting of two structural layers formed of cortical and cancellous bones. The role of the cortical tissue is to resist twisting, bending and compression. Cancellous bone provides the delivery of nutrients, ingrowth of tissues and tissue vascularization. The replacement of a bone defect would occur most efficiently with the use of implants that mimic the structure of the restored bone.

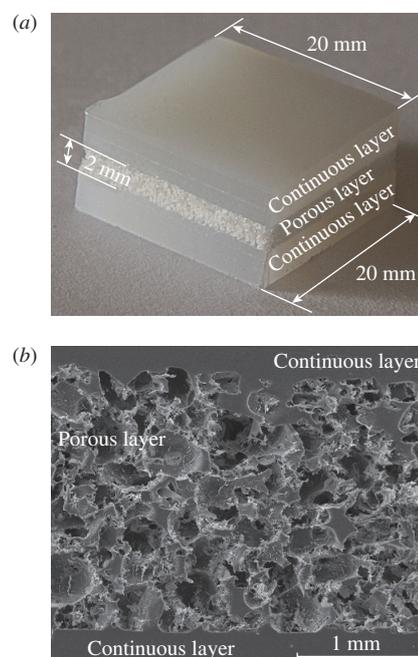
The replacement of a bone defect would occur most efficiently with the use of implants that mimic the structure of the restored bone.<sup>1,2</sup> Ultrahigh molecular weight polyethylene (UHMWPE) is a promising non-resorbable polymeric material for applications in implantology.<sup>3–7</sup> Previously, we developed a method for producing porous materials based on UHMWPE.<sup>8</sup> The aim of this study was to obtain multilayer porous scaffolds for bone replacement based on UHMWPE.

Figure 1(a) shows the architecture of the samples obtained. Multilayer porous scaffolds have a three-layer (sandwich) structure formed by two solid UHMWPE layers and a 2 mm thick porous UHMWPE layer between them. The selected geometry of the implant can be used to restore flat bones such as a pelvis. The porous osseoconductive layer promotes bone repair processes: the active adhesion and proliferation of bone cells *in vivo* with a minimal toxicity.<sup>9</sup> The solid layers are monolithic to mimic the cortical bone tissue to provide mechanical strength.

Due to a small contact area between the porous layer and water, there are serious difficulties in carrying out the process of salt leaching from the entire sample volume during the preparation of a porous layer from UHMWPE powder and salt. Salt residues may lead to a change in cytotoxicity.

In this work, a long and energy-consuming step of salt removal by boiling the samples was replaced by processing in water

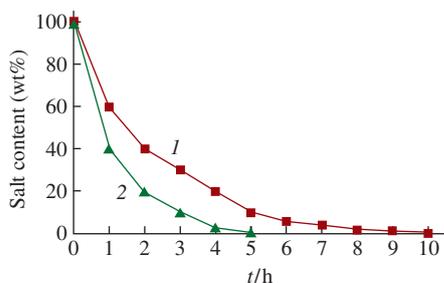
at elevated pressure and temperature (subcritical state).<sup>†</sup> It is well known that water in the subcritical state (temperatures of 100–374 °C) possesses significantly lower polarity, viscosity and surface tension, as compared with the corresponding characteristics of water under normal conditions.<sup>10,11</sup> Subcritical water can dissolve not only polar but also medium-polarity and even nonpolar substances<sup>12,13</sup> as an efficient, environmentally friendly and cheap solvent. Raising the pressure and temperature promotes an increase in the ion product of water,<sup>14</sup> which positively affects the dissolution rate of the salts. The salt leaching conditions were



**Figure 1** (a) Photo of a multilayer porous scaffold for bone replacement and (b) SEM image of a porous layer in the multilayer scaffold.

<sup>†</sup> UHMWPE with an average molecular weight of  $5 \times 10^6$  g mol<sup>-1</sup> was used to form the multilayer porous scaffolds. NaCl with a particle size of 80–700 μm was used as a pore-forming filler. The size of pores formed in the polymer was adjusted by the size distribution of the salt. The initial

components were 10 wt% UHMWPE and 90 wt% NaCl. UHMWPE and NaCl powder were mixed using a Fritsch Pulverisette 5 planetary ball mill in ceramic grinding bowls. The multilayer porous scaffolds were formed by thermopressing at 180 °C and 40 MPa.



**Figure 2** Curves for NaCl extraction from the porous layer of the experimental samples. Water temperature, 95 °C; pressure, 250 atm; and flow rate, (1) 4 and (2) 20 ml min<sup>-1</sup>.

as follows: water temperature, 95 °C; pressure, 250 atm; and flow rate, (i) 4 or (ii) 20 ml min<sup>-1</sup>.

The NaCl solution (washed-out from a sample) was collected in a separator and measured every hour. Based on the data of three parallel experiments, the curves of NaCl extraction from the porous layer of UHMWPE were obtained (Figure 2). The graph shows the complete washing of the salt sample within 10 h at a flow rate of 4 ml min<sup>-1</sup> and a pressure of 250 atm. An increase in the flow rate up to 20 ml min<sup>-1</sup> shortened the salt removal process to 5 h. The leaching of salts from UHMWPE by boiling under standard conditions can take more than 30 h, and it does not guarantee the complete removal of the salt from the polymer. Thus, based on the results, we concluded that the use of subcritical water can significantly accelerate NaCl removal from the polymer matrix, which is extremely important in a scaling-up process: from laboratory scale to industrial one.

The structure of multilayer porous scaffolds was studied using a VEGA 3 TESCAN scanning electronic microscope [Figure 1(b)]. According to SEM data, a porous scaffold layer has a system of interconnected pores with a size of 80–700 μm. The porous layer with a decreased number of fusion defects has no individual UHMWPE particles because of complete sintering between individual polymer particles in a point contact. Previously, we found that the porous UHMWPE with such a structure had a very high plasticity.<sup>8,15</sup>

In our opinion, the formed porous structure of UHMWPE provides optimal conditions for the regeneration of bone tissue

and the formation of a new network of blood vessels, which determines the integration of the implant with the surrounding tissues. The porous structure formed allows the attachment of cells to proceed due to the developed surface microrelief of the pore walls. The orthotopic implantation of porous UHMWPE samples was reported previously.<sup>15</sup>

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