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Osteoclast resorption of thermal spray hydoxyapatite coatings is influenced by surface topography

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ABSTRACT

Coating characteristics such as composition, crystallite features and topography collectively impact the cell response. The influence from splats has not yet been assessed for hydroxyapatite (HAp) thermal spray coatings. The objective of this work is to (a) survey the topography on commercial implants, (b) ascertain topography formation from single splats, and (c) determine the osteoclast resorption pattern on a topographically refined coating compared to dentine. Coatings on dental implants, an orthopedic screw, a femoral stem and a knee implant were studied for reference. The effects of substrate pre-heat, roughness, spray distance and particle size on the coating roughness and topography were studied. Human-derived osteoclasts were placed on a coating with refined topography and compared to dentine, a polished coating and polished sintered HAp. A pre-heat of at least 200 °C on titanium was required to form rounded splats. The greatest influence on coating roughness and topography arose from particle size. A 2-fold increase in the mean particle size from 30 to 72 μm produced a significant difference ($P < 0.001$) in roughness from 4.8 and 9.7 μm. A model is shown to illustrate topography formation, nanostructure evolution on single splats, and the topography as seen in commercial implants. Osteoclasts showed a clear preference for activity on coatings with refined topography. A one-way ANOVA test revealed a significantly greater pit depth ($P = 0.022$) for dentine (14 μm) compared to the as-sprayed and polished coating (5 μm). Coatings with topography display a similar number of resorption pits with dentine, but a 10-fold greater number than polished coatings, emphasizing the importance of flattened droplet topography on implant surfaces.

1. Introduction

Orthopedic implants are exposed to osteoclasts, bone-resorbing cells, and osteoblasts, bone-forming cells. The individual contribution of both cell types dictates bone regeneration through the processes of resorption, and bone formation. Biomaterial surface characteristics impact the chain of biological events, leading to a successful clinical outcome. To date, there has been little or no attention on the topography of thermal spray hydroxyapatite (HAp) coatings. This work will survey the surface topography of implants and prostheses, investigate topography control from thermal spraying, and show the human osteoclast resorption of topographically improved HAp coatings.

In the past, attention has been focussed on providing a stable and strong interface with bone. The direct bonding capability of HAp was supplemented by mechanical interlocking of bone with porous surfaces made from sintered beads, wire-mesh or a titanium plasma coating bond-coat (Fig. 1). Pores larger than 100 μm allowed bone ingrowth or abutment into surface cavities. A study on thermally sprayed fluorhydroxyapatite with large changes in surface roughness (R_a of 6 μm vs. 21 μm) provided openings for interdigitation with bone, but did not show any difference in the osteoblast response [1], posing the question of whether more organized topography at the micro- and nano-scale could be important for cell response. The work developed here is motivated by the question, “Is it possible to control the surface topography with thermal spraying, and will this have any effect on the cell response?” This research is an extension of unpublished data from a Masters thesis that showed textured HAp coatings with a topography from flattened molten droplets [2].

Significant effort has been directed at improving the coating mechanical stability with approaches such as strengthening with a secondary phase or an increase in the HAp crystallinity. Inclusion of a second phase, such as zirconia, increases the fracture

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