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Research Paper

Characterisation of breast implant surfaces and correlation with fibroblast adhesion

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ABSTRACT

Introduction: Capsular contracture formation is a common complication following breast augmentation surgery. Breast implant shells have either a smooth or a textured surface. Smooth surfaces demonstrate a higher incidence of contracture formation. The 3-dimensional surface of textured implants is thought to disrupt contractile forces and reduce capsular contracture rates.
Aim: To investigate the interaction of fibroblasts with silicone breast implant surfaces through characterization of their unique features.
Method: Surfaces of smooth and textured breast implants were characterized using a confocal laser scanning microscope, a microtest 5 kN tensile testing device, and a contact angle goniometer. The kinetics of fibroblast interaction with these surfaces was further analysed.
Results: The textured surfaces were rough, and nodular containing high peaks and deep crevasses with roughness (Sa) values in the range 8.88–18.83 μm and contact angles between 130° and 142°. The smooth implant surfaces were less rough, more regular and repetitive with 0.06–0.07 μm surface roughness, and contact angles between 110.9° and 111.8°. The textured surfaces displayed higher bending stiffness than the smooth surfaces (0.19 and 0.26 N mm). Significant ($p<0.05$) numbers of fibroblasts were attached to the textured surfaces compared to the smooth surfaces which had higher levels of cell adhesion with surface roughness above 8 μm and contact angles above 130°.
Conclusions: In summary, surfaces with arithmetical mean deviation of greater roughness and reduced hydrophilicity with high water contact angles enhanced cell adhesion. These features aid design of improved surfaces, which may help, in prevention of breast capsular formation.

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1. Introduction

Capsular contracture is an abnormal hardening and tightening of the capsule around a breast implant, which is a common complication of augmentation mammoplasty (Kjoller et al., 2001). Symptoms, including pain and/or firmness, may be so severe that further surgery is required (Marshall et al., 1989, Spear et al., 2003). A variety of aetiologies have been proposed (see for example, Lavine, 1993, Handel et al., 1995, Burkhardt et al., 1986, Adams et al., 2006) that may predispose to capsular contracture formation including the implant surface topography (Hakelius and Ohlsen, 1997, Ersek, 1991).

Texturing silicone in a pre-determined pattern can alter the host's response to wound healing, so that tissue ingrowth may produce a host prosthesis interface that is more stable, compatible and thinner, that remains softer for longer and promotes decreased capsular contracture (Ersek et al., 1990, Barr and Bayat, 2011). The irregular surface characteristics of textured surfaces promote the growth of fibroblasts into and around the interstices of the surface resulting in an environment where contractile forces tend to cancel each other out. This contact inhibition may result in a thinner capsule formation (Margaret and Ulrich, 2010).

Conversely, smooth surfaces tend to elicit a fibrous reaction wherein all of the collagen fibrils are aligned cumulatively in a connective-tissue capsule adjacent to the implant (Batra et al., 1995). Contractile forces are then parallel to the surface of the prosthesis (Wyatt et al., 1998), which may prevent any attachment of the scar capsule to the prosthesis. Therefore, any movement of the host creates a shearing effect on any microscopic surface irregularity, resulting in a chronic inflammatory, thickly scarred pseudo-bursa around the smooth implant (Emery et al., 1994).

Investigations into the topography, chemical structure and mechanical properties of breast implants have been previously undertaken in order to characterize these implant surfaces in greater detail. Light microscopy, scanning electron microscopy (SEM) and fluorescence optical microscopy have been used to analyze the topography of a range of commercially available breast implants (Barr et al., 2010, Danino et al., 2001, Abramo et al., 2010). These studies have involved both smooth and textured implant surfaces and have revealed the distinct micro- and nano-scale topographies of the sample surfaces considered.

The surface roughness of silicone breast implants has been studied qualitatively using SEM (Schmidt and Von Recum, 1991, Prasad et al., 2010, Mirzadeh et al., 2003) and quantitatively using a variety of techniques including atomic force microscopy (AFM), optical profilometry and scanning mechanical microscopes (Prasad et al., 2010, Lampin et al., 1997). Prasad et al. (2010) measured the surface roughness of polydimethylsiloxane (PDMS) samples using AFM and an optical profilometer. Lampin et al. (1997) obtained surface roughness values when characterizing poly(methyl methacrylate) (PMMA) surfaces using a scanning mechanical microscope. In addition, water contact angles were also obtained for the surfaces.

Mechanical, electromechanical and dynamic testing devices have also been employed in order to provide information regarding implant properties for surface characterization. Necchi et al. (2011) obtained the shell mechanical properties of silicone gel-filled breast implants by means of tensile, dynamic mechanical and tear tests. Prager-Khoutorsky et al. (2011) measured the rigidity of PDMS substrates with an Instron (Instron Ltd, UK) universal testing machine. De Bruijn et al. (2009) undertook tensile strength and pliability testing on a polyester mesh implant used for mastopexy.

Fibroblast growth on breast implant material surfaces has been investigated in an attempt to elucidate the relationship between wound healing and surface topography and consequently the conditions under which capsular contracture could be averted. Prasad et al. (2010) investigated the growth of 3T3 fibroblasts on silicone elastomer samples of varying roughness. Fibroblast growth was found to decrease with increasing surface roughness. A variety of additional techniques have also been applied to provide insightful information, including infrared thermography (Park and Ha, 2009), Fourier transform infrared/attenuated total reflectance (FTIR/ATR) spectroscopy (Persichetti et al., 2009) and differential scanning calorimetry (Mirzadeh et al., 2003) amongst others.

Kolind et al. (2010) studied human fibroblast proliferation and mechanical response of 169 distinct topographies. Fibroblasts proliferated the least and elongated strongly disrupting the actin cytoskeleton anchored to focal adhesions between the pillars on 4–6 μm inter-pillar gap surfaces. Grinnell and Ho (2013) studied the human fibroblast morphological response to substrate stiffness ranging from 0.5 to 40 kPa. They found that high substrate stiffness resulted in strong substrate interactions. Hu et al. (2011) studied the interaction of C2C12 myoblasts and human bone marrow stem cells (hMSCs) with silk-tropoelastin biomaterials. A combination of low surface roughness ($Ra = 22.8$–41.4 nm) and high elastic modulus (20–28 MPa) was favourable for proliferation and differentiation of C2C12 cells. In contrast, hMSCs showed enhanced proliferation at higher surface roughness ($Ra = 90$ nm).

Brown et al. (2010) explored the effect of tissue stiffness on platelet-derived growth factor (PDGF) signalling in vascular smooth muscle cells (VSMCs) using engineered substrates with different mechanical properties. Cell area increased significantly with increased substrate stiffness. Cell area on the 84 kPa substrates was 180% larger than on the 31 kPa substrates ($p < 0.01$). Ranella et al. (2010) investigated NIH/3T3 fibroblast cell adhesion on silicon surfaces of gradient roughness ratios and wettabilities. The number of attached cells per unit area decreased as the roughness ratio and wetting angle increased. Huang et al. (2004) investigated the effect of surface roughness of ground Ti on the initial adhesion of osteoblast-like U-2 OS cells. Ti specimens ($Ra = 0.05$ and 0.07 μm) had a surface roughness less optimal for initial cell adhesion (30 min to 24 h), while Ti specimens with Ra of 0.15 μm had the optimal cell adhesion behaviour. Tamada and Ikada (1993) studied the effect of surface wettability on mice fibroblasts adhesion. The optimal water contact angle for cell adhesion was found to be approximately 70°.

It is clear from these studies that the topographical features of the interfaces (surface morphology and surface roughness), and the mechanical properties of the extracellular materials (elastic modulus and rigidity) can have an