Fixation strength of Swelling Co-Polymeric Anchors in Artificial bone

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INTRODUCTION: The primary function of a suture anchor is to attach tissue at the proper site and maintain its position without loosening or excessive tension until physiologic healing is accomplished. Several anchor materials have been introduced to maximize pull-out strength and minimize iatrogenic damage. The anchor composition varied from metal to bioabsorbable to polyetheretherketone (PEEK). They achieve their fixation at the implant-bone interface through the shear of the bone located between the threads. Their main goal is to provide long-term fixation. Metallic bone anchors have a higher modulus of elasticity compared to bone which, overtime can lead to stress-shielding and bone resorption, and are associated with complications such as loosening, migration, incarceration of the metal implant within the joint, chondral damage, and interference with imaging studies. Furthermore, the mismatch of mechanical properties, specifically in low-density bones, negatively impacts bone remodeling and osteointegration leading to implant failure. To address the problems associated with conventional bone anchors, a porous swelling co-polymeric material made of Methyl Methacrylate (MMA) and Acrylic Acid (AA) has been developed [1]. This co-polymeric anchor swells in a controlled manner by absorbing interstitial fluids, producing radial stresses in the bone that leads to initial mechanical fixation followed by bone remodeling and osteointegration resulting in a long-term biological fixation. Importantly, the swelling characteristics lead to improved mechanical fixation in low density bone[2]. The goal of this study was to evaluate the effect of the amount of porosity in swelling anchors on fixation strength in artificial bone of various densities.

METHODS: The polymer resin was a combination of 80% of MMA, 20% of AA, and DEGDMA as the cross-linker agent that polymerized and achieved a swelling ratio of 4-6% by volume in saline solution. The porosity was achieved by adding NaCl crystals during the polymerization process and then dissolving the crystals via desalination in water. The resulting porosity had an average pore size of 300 microns, suitable for bone ingrowth. All anchors were cylindrical, 8mm in diameter and length. Three levels of porosity were produced, including 0 porosity (solid), partial porosity (hybrid), and fully porous (Fig 1). The free-swelling properties in saline solution and the compressive mechanical properties of the anchors were obtained. For the pull-out tests, a 2 mm metal threaded rod was fixed in the center of each anchor before the polymerization. The metal rod provided the means of pull-out tests. Testing was conducted on 120 swelling bone anchors consisting of 40 anchors in each group (solid, hybrid, porous). Ten anchors in each group were press-fitted into pre-drilled holes in artificial bone cubes with four different densities (8, 15, 30, and 40 PCF) (Fig 2). The samples were immersed in 0.9% saline solution for one week at a temperature of 37˚C. Mechanical pull-out tests were conducted using a tensile testing machine (Mark-10 ESM 1500).

RESULTS: Fully porous swelling anchors had the highest swelling ratio, followed by the hybrid anchors, and the solid anchors presented with the lowest swelling ratio. The ANOVA statistical analysis indicates that these differences were statistically significant. An opposite trend was observed in the compressive mechanical properties, with porous anchors having the lowest mechanical properties followed by the hybrid anchors, and the solid anchors exhibited the highest mechanical strength. The pull-out strength significantly increased with an increase in artificial bone density for each anchor group, except for the lowest bone density (PCF 8), in which the pull-out strength of all three anchor groups was approximately the same. For the intermediate bone density groups, there was a significant difference between porous and other groups. For the highest bone density, a significant difference in pull-out strength was also observed between all three groups (Fig 3). Examination of the artificial bone tunnels indicated no visible damage. The average tunnel diameter following pull-out increased by 3.7%. Tunnel diameter following pull-out was noted to decrease with an increase in bone density.

DISCUSSION: It was concluded that as the porosity of the anchor increased the fixation strength decreased. In contrast to conventional cancellous bone screws, pull-out of the swelling anchors produced no detectable damage to the bone tunnel. The radial stress produced by the swelling copolymer at the anchor-bone interface results in friction-based resistance to pull-out forces. This friction-based mechanism is advantageous in low-density bone such as in osteoporotic patients. Additionally, the radial stresses are expected to stimulate adaptive bone remodeling and osteointegration, converting the initial mechanical fixation into a long-term biological fixation. The porous swelling copolymeric material may be used for developing bone fixation devices for various clinical applications such as suture anchors and interference screws. Bone fixation devices with osteoconductive properties may be particularly beneficial in older patients with low-density bone. These bone regions are known to be difficult to produce strong fixation by conventional anchors. Further studies are ongoing to optimize the swelling ratio along with mechanical properties to best match its specific intended clinical application.

SIGNIFICANCE/CLINICAL RELEVANCE: The porous swelling co-polymeric anchor provides an initial mechanical fixation followed by bone remodeling and osteointegration resulting in a long-term biological fixation, importantly, in low density bone.

REFERENCES: 1. Siegler, S., et al., A porous swelling copolymeric material for improved implant fixation to bone. J Biomed Mater Res B Appl Biomater, 2023. 111(7): p. 1342-1350.
2. Sadighi, A., et al., Numerical analysis of the mechanical response of novel swelling bone implants in polyurethane foams. J Mech Behav Biomed Mater, 2023. 143: p. 105871.
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IMAGES AND TABLES:

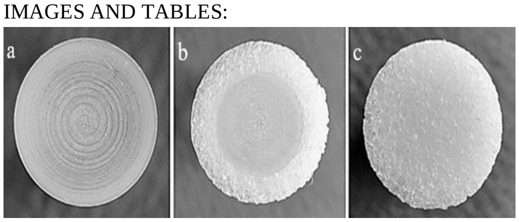

Figure 1. Three types of co-polymeric swelling implants (a) solid swelling anchor, (b) hybrid swelling anchor, (c) porous swelling anchor.

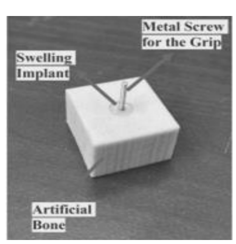

Figure 2. Implanted swelling bone anchor in an artificial bone.

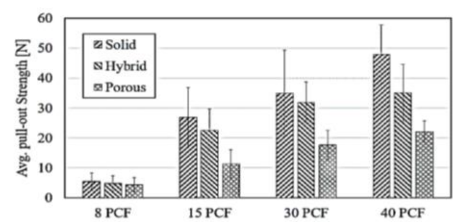

Figure 3. Comparison of average pull-out strength of solid, hybrid, and porous swelling anchors in 4 different densities.