Biomechanical Testing of Bioabsorbable Cannulated Screws for Slipped Capital Femoral Epiphysis Fixation

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Abstract

This study compared cannulated 4.5-mm bioabsorbable screws made of self-reinforced poly-l-actotic acid to cannulated 4.5-mm steel and titanium screws for resistance to shear stress and ability to generate compression in a polyurethane foam model of slipped capital femoral epiphysis fixation. The maximum shear stress resisted by the three screw types was similar (self-reinforced poly-l-actotic acid 371±146 MPa, steel 442±43 MPa, and titanium 470±91 MPa). The maximum compression generated by both the self-reinforced poly-l-actotic acid screw (68.5±3.3 N) and the steel screw (63.3±5.9 N) was greater than that for the titanium screw (3±1.4 N, P<.05). These data suggest cannulated self-reinforced poly-l-actotic acid screws can be used in the treatment of slipped capital femoral epiphysis because of their sufficient biomechanical strength.

Slipped capital femoral epiphysis is a common hip disorder in adolescents. The goal of treatment is to stabilize the proximal femoral epiphysis and prevent progression of the deformity. In the United States, the standard of care for slipped capital femoral epiphysis is fixation, in situ, with a single metal screw placed under fluoroscopic guidance.1 The slipped capital femoral epiphysis screw fixation is designed to resist the shear stress across the physsis and incite early physeal closure.2-8 However, one potential limitation of metal fixation is the need for hardware removal at a later date.

Bioabsorbable materials are suited for slipped capital femoral epiphysis fixation as they are completely resorbable and thus preclude the problems of stress shielding and hardware removal. Bioabsorbable implants are also compatible with magnetic resonance imaging and, as a result, enable the surgeon to closely follow the revascularization and remodeling of the femoral head after fixation.9-12 In addition, Otsuka et al13 have shown bioabsorbable fixation crossing the growth plate can promote early physeal closure, which could be an advantage in the treatment of slipped capital femoral epiphysis through screw fixation.

Cannulated, self-reinforced poly-l-actotic acid screws have recently been made available (Bionix Corp, Malvern, Pa). The biocompatibility of self-reinforced poly-l-actotic acid screws in the treatment of fractures and osteotomies is well established.9,14,15 This study demonstrated the mechanical strength and ability of these screws to resist the deforming forces needed for slipped capital femoral epiphysis fixation.

Materials and Methods

Cannulated 4.5-mm steel, titanium, and self-reinforced poly-l-actotic acid screws were evaluated for their resistance to shear stress in a polyurethane foam model of cancellous bone (Last-A-Foam; General Plastics, Tacoma, Wash) (Figure 1). Foam was used in this study to circumvent the inherent variability associated with cadaver material. Also, the complex geometry of the femoral neck makes the detection of small differences in biomechanical performance difficult.4,16 This rigid foam model has already been shown to have mechanical properties similar to cancellous bone and provides reproducible bio-

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mechanical testing results. Three different foams with densities of 0.16 g/cm³, 0.24 g/cm³, and 0.32 g/cm³, which have been shown to approximate the range of density of human cancellous bone, were used. Different densities of foam were used to evaluate the effect of increased bone density on shear strength and compression ability.

**Shear Strength**

All screws tested were 40-mm long and inserted according to the manufacturers’ recommended technique. The screws were inserted across two foam blocks with 30 mm of the screw in the proximal block and 10 mm of the screw in the distal block. The proximal block containing the head of the screw was mounted firmly to the base of a materials testing machine (MTS, Minneapolis, Minn) so that the loading axis was perpendicular to the axis of the screw.

Load was applied to the distal block, and the resistance to shear stress was measured via a load cell mounted on the MTS machine (Figure 2). The peak force generated was designated as the shear strength of the screw/foam composite. Three trials were performed with each screw in each of the three densities of foam for a total of 27 trials. The foam blocks also were examined to determine the mode of failure—screw bending, screw breakage, or foam failure. The results were compared and evaluated for statistical significance using analysis of variance (ANOVA) with post-hoc Student Neuman-Keuls test.

**Compression Strength**

The maximum interface compression stress that could be achieved with the steel, titanium, and self-reinforced polyethylacetic acid screws also was determined. The screws were inserted through a steel spacer into a foam block so that 10 mm of screw was engaged in the distal foam block, but not in the proximal block. A load cell was placed between the spacer and the distal block to measure the compressive force generated (Thru Hole Load Washer Compression Only Load Cell; Transducer Techniques, Temecula, Calif) (Figure 3).

Force was recorded every quarter turn until maximum force was achieved and the screw was stripped. Three trials were performed with each screw in each density of foam for a total of 27 trials. The foam blocks were examined to determine mode of stripping—thread breakage, screw breakage, or screw pullout. The compression results were analyzed for statistical significance using ANOVA test.

**RESULTS**

The resistance to shear stress increased with foam density for all screws. For the two less dense foams (0.16 g/cm³ and 0.24 g/cm³), there was no statistically significant difference in resistance to shear stress between any of the screws tested (Table 1). In the less dense foams, the foam uniformly failed before the screws, and none of the screws demonstrated any deformation or damage. In the most dense foam (0.32 g/cm³), the self-reinforced polyethylacetic acid screw showed significant plastic deformation and failed at an average of 370 MPa.

The maximum compression force was achieved as the threads of the screws ripped through the foam. In the compression strength testing, the foam failed before the screws in all foam densities. None of the screws demonstrated deformation or damage after the compression test.

The steel and self-reinforced polyethylacetic acid screws demonstrated an increased compressive strength with increasing foam density. The steel and self-reinforced polyethylacetic acid screws demonstrated no statistically significant difference in compressive force in all densities of foam for average maximum values of 63.3 N and 68.5 N, respectively. The titanium screw generated average maximum compressive forces from 2.7 N to 5.6 N, which was significantly less than steel and self-reinforced polyethylacetic acid screws. The titanium screw maximum compressive force was achieved at the intermediate foam density (0.24 g/cm³) (Table 2).

**DISCUSSION**

The demonstrated shear strength of the cannulated self-reinforced polyethylacetic acid screw was 371 MPa. This value is consistent with other biomechanical studies of self-reinforced polyethylacetic acid screw shear strength. The shear strength of these 4.5-mm cannulated self-reinforced polyethylacetic
acid screws is significantly greater than the average shear strength of cancellous bone, which is 210 MPa.9

The average resistance to shear stress demonstrated by the steel and titanium screws was greater than or equal to the shear strength of the foam in all densities. These findings suggest the shear strength demonstrated in these trials was limited by the foam itself, rather than the screws.

The self-reinforced poly-lactide acid screws performed similarly to the steel and titanium screws in the less dense foams (0.16 g/cm³ and 0.24 g/cm³). The self-reinforced poly-lactide acid screws demonstrated significant plastic deformation in the densest foam (0.32 g/cm³), indicating the screw was the limiting factor rather than the foam.

The 4.5-mm self-reinforced poly-lactide acid cannulated screw had a shear strength of 371 MPa (371 × 10⁶ N/m²). The diameter of the screw is 4.5 mm, and using the formula area = π × (radius)², the total cross-sectional area is 1.59 × 10⁻⁵ m. Multiplying 371 MPa by the cross-sectional area of the screw (1.59 × 10⁻⁵) translates into a force of 5900 N.

The shear strength of the screw is important in resisting the deforming shear forces across the physis in slipped capital femoral epiphysis.12-16 Chung et al17 measured the strength of the physis with and without the perichondral ring in cadaveric specimens from children ranging in age from 5 days to 15 years. They found that the strength of the physis increased with age and the perichondral ring became attenuated as the physis closed. They concluded that a combination of a slowly closing (maturing) physis combined with the normal attenuation of strength of the perichondral ring enabled the physis to slip in large children. The maximum load for physisal failure (Salters Harris I type fracture) was 1705 N in a 10 year, 9 month child.2

Litchman and Duffy7 performed a finite element analysis of the femoral neck to determine the effect of version on the forces seen by the proximal femoral physis. They found that the maximum force seen in normal gait was 1.25 times bodyweight, and the force can increase up to 6.5 times bodyweight in jumping.7

Litchman’s analysis can be used to predict the forces seen at the physis in a heavy child of 100 kg. Given acceleration due to gravity at 9.8 m/s², the child’s mass is 98 N. If all of his force is taken as shear force perpendicular to the physis, the maximum shear forces seen at the physis are 2450 N in gait and 6370 N with jumping. The shear strength of the screw at 5900 N is close to the maximum load seen across the physis in a jumping, 100-kg child.

The steel and self-reinforced poly-lactide acid screws demonstrated equivalent maximum compression, because they have similar thread geometry: the outer diameter, inner diameter, thread depth, and pitch are nearly identical.

Pullout strength (and hence compression force) increases with length of engaged thread.19 The titanium screws are self-tapping with a cutting portion at the tip measuring 4.05 mm. This leaves only 5.95 mm of thread engaged in the foam for compression testing. The cutting portions of the steel and self-reinforced poly-lactide acid screws measured 2.42 mm and 2.05 mm, respectively. Thus, the weakness of the titanium screws in the compression test can be accounted for by the paucity of engaged thread compared to the steel and self-reinforced poly-lactide acid screws. In addition, the fine pitch of the titanium screws was a disadvantage in the soft, porous foam model of cancellous bone.18

Data indicate that cannulated 4.5-mm self-reinforced poly-lactide acid bioabsorbable screws have strength equivalent to steel and titanium screws of the same size both in resistance to shear force and compression. Presently, 6.5- and 7.3-mm steel screws are used for slipped capital femoral epiphysis fixation.20 The 4.5-mm screws were tested due to ease of availability. One can project that larger self-reinforced poly-lactide acid screws would have even greater shear strength and compression strength due to the increased size.

These biomechanical tests and calculations suggest self-reinforced poly-lactide acid screws have sufficient biomechanical strength for slipped capital femoral epiphysis fixation. The bioabsorbable implant material gives self-reinforced poly-lactide acid screws

### Table 1

<table>
<thead>
<tr>
<th>Foam Density (g/cm³)</th>
<th>Steel</th>
<th>Titanium</th>
<th>SR-PLLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.16</td>
<td>122±26</td>
<td>176±72</td>
<td>184±21</td>
</tr>
<tr>
<td>0.24</td>
<td>308±38</td>
<td>357±52</td>
<td>260±78</td>
</tr>
<tr>
<td>0.32</td>
<td>442±43</td>
<td>470±91</td>
<td>371±146</td>
</tr>
</tbody>
</table>


*Shear strength of foam was 121 MPa.
‡Shear strength of foam was 278 MPa.
§Shear strength of foam was 420 MPa.

### Table 2

<table>
<thead>
<tr>
<th>Foam Density (g/cm³)</th>
<th>Steel</th>
<th>Titanium</th>
<th>SR-PLLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.16</td>
<td>16±1.0</td>
<td>2.7±0.3</td>
<td>13.3±1.5</td>
</tr>
<tr>
<td>0.24</td>
<td>30±8.6</td>
<td>5.6±2.1</td>
<td>30±0.9</td>
</tr>
<tr>
<td>0.32</td>
<td>63.3±5.9</td>
<td>3.0±1.4</td>
<td>68.5±3.3</td>
</tr>
</tbody>
</table>

distinct advantages over metal implants for slipped capital femoral epiphysis fixation.

One proposed advantage is the avoidance of a second operation for hardware removal. Metal implants have been shown to cause osteopenia secondary to stress shielding, and the retention of metal implants may impede local remodeling after fracture healing. Other indications that have been proposed for slipped capital femoral epiphysis screw removal include bursitis, ion toxicity, late infection, and future hip operations. However, complications are common with any type of hardware removal and are seen in up to 30% of cases. Specific complications related to removal of slipped capital femoral epiphysis screws include bleeding, infection, and failure to extract the screw.

The use of biodegradable screws for the fixation of slipped capital femoral epiphysis would avoid the morbidity associated with the second operation for hardware removal. In addition, elimination of slipped capital femoral epiphysis screw removal could result in significant economic benefits by avoiding the cost of a second operation.

Bioabsorbable materials have been used safely for orthopedic applications in adults and children for >10 years. Self-reinforced poly-levolactide acid screws, in particular, have an exceptionally low incidence of foreign body or osteolytic reaction compared to polyglycolic acid or polydioxanone.

Bioabsorbable implants also have been shown to be safe when used to cross the physis in the treatment of fractures. In addition, Otsuka et al. demonstrated that biodegradable pins placed across the physis can increase the incidence of bone bridge formation in rabbits. A biodegradable screw that promoted early physis closure would be advantageous in the treatment of slipped capital femoral epiphysis.

At present, self-reinforced poly-levolactide acid implants retain their strength for 12 months and take 5 years to fully degrade, which is sufficient time for physis closure. However, further in vivo and biomechanical testing is needed to evaluate the use of culated self-reinforced poly-levolactide acid screws in the fixation of slipped capital femoral epiphysis before recommending them for general use.

REFERENCES


**EDITORIAL DISCUSSION**

ORTHOPEDICS: Please describe the next steps.

Kroeger et al: Further in vivo studies are required to better understand the biology of bioabsorbable cannulated screws for fixation of slipped capital femoral epiphysis. Previous studies in a miniature swine model have demonstrated that this model can be used successfully to study the pathology of femoral neck fractures.¹

A follow-up study adapted this model to juvenile animals. A Salter-Harris type I fracture could be created through the proximal femoral physis and fixed with cannulated steel, titanium, and self-reinforced poly-l-levolactic acid screws. After healing, the animals could be sacrificed and the proximal femora evaluated radiographically, microscopically, and biomechanically.

Bioabsorbable screws have been shown to hasten growth plate closure in transphyseal applications, which would be advantageous in the treatment of slipped capital femoral epiphysis.²

In addition, self-reinforced poly-l-levolactic acid implants have been used successfully in the treatment of children's fractures for many years.³ Therefore, it is reasonable to consider a clinical trial in humans for fixation of slipped capital femoral epiphysis with cannulated self-reinforced poly-l-levolactic acid screws in the near future.

**REFERENCES (EDITORIAL DISCUSSION)**