The Treatment of Femoral Head Deformity and Coxa Magna by the Ganz Femoral Head Reduction Osteotomy

Dror Paley, MD, FRCSC

The treatment of Perthes disease often results in a nonspherical femoral head (coxa plana) that is enlarged (coxa magna) compared with the normal side, with a short femoral neck (coxa breva) and a relatively high greater trochanter (coxa vara). The femoral head shape can vary from spherical to ellipsoid, to cylindrical, to saddle shaped. The acetabulum may also change in shape in conforming to the enlarged, flattened femoral head or becoming more dysplastic in reaction to the subluxed femoral head. The femoral head cartilage may be well preserved or degenerated. Degeneration of the femoral head cartilage is usually greatest in relation to the rim of the acetabulum. The rim of the acetabulum acts as a high concentration stress line that leads to indentation of the softened femoral head, contributing to the collapse of the femoral head. The cartilage along this indented part of the femoral head may become permanently concave as part of a saddle shaped femoral head. The best-preserved cartilage of the femoral head is often the lateral third, because this part of the head is permanently outside of the joint and experiences little wear and tear and no weight-bearing forces. Similarly, the medial cartilage of the femoral head is often well preserved because of the containment by the round acetabulum. The better molded the two are to each other (congruity), the less wear and degeneration in the medial third of the femoral head.

The treatment of Perthes disease can be divided into 4 time frames: precollapse; collapsed but not ossified; collapsed and ossified; remodeled and degenerative. Treatment during precollapse includes modalities to prevent collapse and speed reossification (bisphosphonates, core decompression, and containment methods). Treatment after collapse but before reossification aims at reduction of the subluxation, restoration of range of motion, and molding of the femoral head to the acetabulum (containment methods using casting and/or osteotomy and soft tissue releases, and hip joint distraction). Treatment after the femoral head is collapsed and ossified is aimed at reducing femoroacetabular impingement and at eliminating secondary deformities such as fixed flexion and adduction of the hip joint (valgus osteotomy and femoral head reshaping). Finally, once the femoral head and the acetabulum have remodeled fully, incongruity and femoroacetabular impingement leads to degenerative changes of the cartilage of the femoral head and acetabulum. Treatment during this phase ranges from femoral head reshaping, hip arthrodesis, pelvis support osteotomy, and prosthetic joint replacement.

The prognosis in Perthes disease is very strongly correlated with the final shape of the femoral head. The Stulberg classification of the femoral head is the most prognostic indicator of...
longevity of the femoral head. Although painful degenerative changes of the femoral head leading to the need for joint replacement are the final outcome of most Stulberg 4 and 5 hips, femoroacetabular impingement is a probably much earlier and more common problem with Perthes hips including Stulberg 2, 3, 4, and 5. Reshaping of the femoral head with chiroectomy has met with variable success.9–14 Long-term follow-up of chiroectomy done prior to the recent surgical dislocation approach shows good short-term improvement but no alteration in the degenerative natural history of the disease.15 The recent introduction of new methods to evaluate, understand, and treat the impingement of the misshapen femoral head has led to a renaissance of interest in the treatment of late Perthes disease. The older procedure of chiroectomy of the femoral head has been replaced by arthroscopic or open osteochondroplasty of the femoral head.14,16,17,24 The feared complication of avascular necrosis (AVN) of the femoral head has been reduced by the “safe surgical dislocation method” introduced by Reinhold Ganz.25 This approach has permitted more aggressive and extensive safe resection of the enlarged, impinging portions of the femoral head, with restoration of spherical congruity and movement of the hip joint. In 2001 Ganz and colleagues16,17 developed a new solution to the misshapen femoral head of Perthes disease. Ganz recognized that the central third of the enlarged femoral head was the most damaged while the lateral third had the best preservation of cartilage, as already explained. He therefore resected the central third of the femoral head while preserving and mobilizing the vascular pedicle to the lateral third. The resection of the central third was also done in a way to preserve the vascular pedicle to the medial third of the femoral head. After resecting the lateral third he advanced it to the medial third. Essentially, he removed the central part of an ellipsoid and brought the two spherical hemispheric ends together to reform a sphere. He called this femoral head reduction osteotomy (FHRO).16,17 This intra-articular osteotomy of the femoral head was stabilized with internal fixation screws.

The author has been performing the intra-articular FHRO since February 2006. The purpose of this article is to report the results of the author’s first 20 patients to undergo this procedure.

PATIENTS AND METHODS

Between February 2006 and February 2010, 21 patients with misshapen femoral heads underwent intra-articular FHRO to reshape the femoral head. One of these patients suffered a femoral neck fracture in surgery, resulting in conversion to a total hip replacement. This patient was eliminated from the study, leaving 20 patients between 1 and 5 years since the osteotomy (mean 2.7 years). The etiology of the femoral head pathology was Perthes in 15, adolescent AVN in 3, and dysplasia in 2 (Table 1). This study comprises a retrospective follow-up of the radiographs and clinical notes of this group of patients. Fourteen patients were treated for the right hip and 6 for the left hip. There were 8 males and 12 females. The average age at the time of the osteotomy was 14 years (range 10–23 years). Five patients were skeletally mature at the time of the osteotomy. In the rest the femoral head physis was still open on the treatment side in only one.

All patients complained of preoperative pain, which was attributed to femoroacetabular impingement, abductor muscle fatigue, or hip joint degeneration. All of the patients had evidence of limp, frequently including a lurch component, antalgic component, and a leg length discrepancy component. All patients had a positive acute or delayed Trendelenburg sign. Range of motion of the hip was reduced in all patients but was considered very stiff in 8 preoperatively. The rest had good preservation of flexion and extension range of the hip joint, with varying degrees of loss of passive abduction and rotation motion of the hip joint.

Four cases were bilateral but only had the osteotomy performed on one side at the time of this study. The other side is being considered for the same treatment but has not yet undergone surgery. Radiographic examination included measurement of the maximum anteroposterior (AP) diameter of the femoral head before and after the head reduction in all patients, and comparison with the normal other side in the 16 unilateral cases. In 4 of the cases the femoral head shape was also altered on the frog lateral or cross-table lateral radiograph of the hip.

Treatment alternatives were discussed with all patients as part of the informed consent process, including valgus intertrochanteric osteotomy, surgical dislocation with chiroectomy, hip fusion, pelvic support osteotomy, and hip replacement.

SURGICAL METHOD

The technique used is modified from that recently published by Ganz and colleagues (Fig. 1).16,17 The patient is positioned in the lateral decubitus position with the affected side up. After prepping and draping the patient with the leg free, a bump is placed to abduct the leg. A midlateral incision from just distal to the iliac crest to a handbreadth...
### Table 1
**Cases of patients with misshapen femoral heads who underwent intra-articular femoral head reduction osteotomy (February 2006 to February 2010)**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (y)</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>Bilateral</th>
<th>% Pre</th>
<th>% Other Pre</th>
<th>% Other Post</th>
<th>Year/Month</th>
<th>AVN</th>
<th>ROM Pre</th>
<th>ROM Post</th>
<th>Pain Post</th>
<th>Result</th>
<th>Pelvis Osteotomy</th>
<th>Follow-Up (y)</th>
<th>EF</th>
<th>Biplanar</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>F</td>
<td>Dysplasia</td>
<td>Yes</td>
<td>72</td>
<td>—</td>
<td>—</td>
<td>2006/4</td>
<td>—</td>
<td>More</td>
<td>Better</td>
<td>E</td>
<td>Yes</td>
<td>5</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>M</td>
<td>AVN</td>
<td>—</td>
<td>87</td>
<td>115</td>
<td>92</td>
<td>2006/7</td>
<td>—</td>
<td>More</td>
<td>Better</td>
<td>E</td>
<td>—</td>
<td>5</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>F</td>
<td>Perthes</td>
<td>Yes</td>
<td>81</td>
<td>—</td>
<td>—</td>
<td>2006/9</td>
<td>—</td>
<td>More</td>
<td>Better</td>
<td>E</td>
<td>—</td>
<td>4.5</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>M</td>
<td>Perthes</td>
<td>—</td>
<td>71</td>
<td>140</td>
<td>100</td>
<td>2008/4</td>
<td>—</td>
<td>More</td>
<td>Better</td>
<td>E</td>
<td>—</td>
<td>3</td>
<td>Yes</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>F</td>
<td>Perthes</td>
<td>—</td>
<td>84</td>
<td>125</td>
<td>95</td>
<td>2008/4</td>
<td>—</td>
<td>More</td>
<td>Better</td>
<td>E</td>
<td>—</td>
<td>4</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>11</td>
<td>M</td>
<td>Perthes</td>
<td>—</td>
<td>70</td>
<td>150</td>
<td>100</td>
<td>2007/4</td>
<td>—</td>
<td>More</td>
<td>Better</td>
<td>G</td>
<td>—</td>
<td>3.6</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>7</td>
<td>15</td>
<td>F</td>
<td>Perthes</td>
<td>—</td>
<td>88</td>
<td>118</td>
<td>92</td>
<td>2007/10</td>
<td>—</td>
<td>Stiff</td>
<td>Stiff</td>
<td>Better</td>
<td>P</td>
<td>3.4</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>M</td>
<td>Perthes</td>
<td>—</td>
<td>57</td>
<td>160</td>
<td>84</td>
<td>2008/3</td>
<td>—</td>
<td>More</td>
<td>Better</td>
<td>G</td>
<td>—</td>
<td>3</td>
<td>Yes</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>9</td>
<td>21</td>
<td>M</td>
<td>Perthes</td>
<td>—</td>
<td>67</td>
<td>150</td>
<td>100</td>
<td>2008/4</td>
<td>—</td>
<td>Stiff</td>
<td>More</td>
<td>Better</td>
<td>G</td>
<td>2.5</td>
<td>Yes</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>10</td>
<td>23</td>
<td>F</td>
<td>AVN</td>
<td>—</td>
<td>83</td>
<td>118</td>
<td>91</td>
<td>2008/5</td>
<td>—</td>
<td>More</td>
<td>Better</td>
<td>E</td>
<td>—</td>
<td>3.1</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>11</td>
<td>13</td>
<td>F</td>
<td>Perthes</td>
<td>—</td>
<td>80</td>
<td>119</td>
<td>100</td>
<td>2008/2</td>
<td>—</td>
<td>More</td>
<td>Better</td>
<td>E</td>
<td>—</td>
<td>3</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>12</td>
<td>11</td>
<td>M</td>
<td>Perthes</td>
<td>Yes</td>
<td>77</td>
<td>—</td>
<td>—</td>
<td>2009/6</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>13</td>
<td>11</td>
<td>M</td>
<td>Perthes</td>
<td>Yes</td>
<td>62</td>
<td>—</td>
<td>—</td>
<td>2009/6</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>14</td>
<td>11</td>
<td>F</td>
<td>Perthes</td>
<td>—</td>
<td>70</td>
<td>141</td>
<td>100</td>
<td>2009/9</td>
<td>—</td>
<td>Stiff</td>
<td>Yes</td>
<td>Better</td>
<td>P</td>
<td>1.5</td>
<td>Yes</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>15</td>
<td>13</td>
<td>M</td>
<td>Perthes</td>
<td>—</td>
<td>72</td>
<td>120</td>
<td>100</td>
<td>2010/4</td>
<td>—</td>
<td>Stiff</td>
<td>More</td>
<td>Better</td>
<td>G</td>
<td>1</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>16</td>
<td>17</td>
<td>M</td>
<td>Dysplasia</td>
<td>—</td>
<td>67</td>
<td>127</td>
<td>100</td>
<td>2010/11</td>
<td>—</td>
<td>Stiff</td>
<td>More</td>
<td>Better</td>
<td>G</td>
<td>1</td>
<td>Yes</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>17</td>
<td>13</td>
<td>M</td>
<td>Perthes</td>
<td>—</td>
<td>81</td>
<td>150</td>
<td>91</td>
<td>2008/9</td>
<td>—</td>
<td>Stiff</td>
<td>More</td>
<td>Better</td>
<td>G</td>
<td>2.5</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>18</td>
<td>13</td>
<td>M</td>
<td>Perthes</td>
<td>—</td>
<td>76</td>
<td>129</td>
<td>93</td>
<td>2008/9</td>
<td>—</td>
<td>Stiff</td>
<td>More</td>
<td>Better</td>
<td>G</td>
<td>2.5</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>19</td>
<td>18</td>
<td>F</td>
<td>AVN</td>
<td>—</td>
<td>76</td>
<td>132</td>
<td>100</td>
<td>2009/10</td>
<td>—</td>
<td>Stiff</td>
<td>More</td>
<td>Better</td>
<td>G</td>
<td>1.5</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>20</td>
<td>12</td>
<td>M</td>
<td>Perthes</td>
<td>—</td>
<td>82</td>
<td>140</td>
<td>100</td>
<td>2009/10</td>
<td>—</td>
<td>Stiff</td>
<td>More</td>
<td>Better</td>
<td>G</td>
<td>1.5</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>Mean</td>
<td>14</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>75</td>
<td>133</td>
<td>96</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2.7</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
</tbody>
</table>

**Abbreviations:** AVN, avascular necrosis; E, excellent; EF, external fixator; G, good; P, poor; Post, postoperative; Pre, preoperative; ROM, range of motion.
distal to the greater trochanter is made to and through the fascia lata. The fascia lata is separated from the gluteus maximus muscle anteriorly until the intermuscular septum with the tensor fascia lata is reached. The gluteus maximus muscle is then mobilized from the septum and retracted posteriorly. The hip is then internally rotated. The piriformis tendon and muscle are identified at the posterior border of the gluteus medius and minimus muscles. A retractor is inserted between the hip capsule and the gluteus minimus. The vastus lateralis is elevated off of the proximal femur and retracted with a Homan retractor. The femur is internally rotated to expose the posterior part of the greater trochanter, so that a saw can be properly rotated to perform the trochanteric osteotomy while also clearing the posterior skin and soft tissues. The line connecting the elevated

**Fig. 1.** Femoral head reduction osteotomy (FHRO) technique. (A) Coxa magna with saddle-shaped femoral head. The lateral retinacular and the medial branch of the medial femoral circumflex artery are shown. (B) Surgical dislocation is performed after a trochanteric flip osteotomy. (C) The medial part of the stable trochanter is resected to decompress and mobilize the piriformis fossa and the retinacular pedicular flap. (D) The lateral femoral head osteotomy is performed, preserving its vascular pedicle. (E) The medial femoral head osteotomy is performed and the segment of the femoral head resected. (F) The lateral segment is advanced and fixed to the greater trochanter.
Ganz Femoral Head Reduction Osteotomy

vastus and glutei is visualized and the greater trochanter is osteotomized with a saw along this line, staying lateral to the piriformis tendon. The partial-thickness segment of greater trochanter remains attached to the gluteus minimus, gluteus medius, and vastus lateralis muscles. The piriformis tendon is often split by the osteotomy, with part of it remaining attached to the more medial stable trochanter and part to the mobile trochanteric segment. The piriformis fibers are released off of the mobile trochanter. The mobile trochanter is flipped anteriorly with its three trigastric muscles (gluteus medius, gluteus minimus, and vastus lateralis). The gluteus minimus muscle should be reflected off of the capsule and supra-acetabular ileum. One Homan retractor should be hammered into this bone proximal to the acetabulum and one should be inserted over the anterior inferior spine. The reflected tendon of the rectus femoris can be either left alone or released and reflected anteriorly as needed. The hip can now be externally rotated to tension and expose the capsule. The capsulotomy is made in a Z-shaped manner. The transverse limb is made at 1 or 11 o’clock on the right and left hips, respectively, from lateral to medial, without cutting the labrum. The longitudinal arms of the Z should be anterior lateral along the lateral aspect of the neck going distally and posterior along the acetabular rim medially. The femur can be externally rotated while dropping the leg and knee over the anterior side of the table into a sterile pocket. In doing so, the femoral head will start to dislocate. The ligamentum teres may restrict the dislocation and should be cut with long curved type of scissors to release the femoral head from the acetabulum. The femoral head is now fully dislocated and can be inspected circumferentially. The areas of degeneration of cartilage can be identified. The acetabulum can also be inspected and probed to look for cartilage and labral tears. Labral tears should be repaired with sutures. Cartilage flaps should be debrided. Microfracture can be done to any denuded cartilage areas. In children this is not commonly the situation. The ligamentum teres should be resected from the femoral head and from the depth of the acetabulum. The femoral head shape can now be measured with a femoral head spherical template (Wright Medical, Memphis, TN). The most important measurement is the spherical size of the medial femoral head. The ostotomies can be parallel or convergent, depending on the geometry of the femoral head. When the femoral head is enlarged in both the AP and medial-lateral directions, it should be resected in a wedge shape with the base of the wedge anterolateral and the apex of the wedge posterior-medial. In the rare cases when the femoral head is enlarged in a proximal to distal direction together with AP direction, the wedge should be based superanteroinferiorly. Before making the osteotomy, the line of the osteotomy should be measured along the circumference of the femoral head. The length of this line should be the same for both osteotomies, thus ensuring that the lateral mobile segment of the femoral head will match the medial stable part of the femoral head. The osteotomy should also be parallel to the femoral neck. The lateral cut which is made first includes the superior part of the femoral neck to avoid damaging the retinacular vessels that provide circulation to this segment. Finally, the acetabulum should be templated using the ball-shaped templates from a total hip replacement instrumentation set. The femoral head spherical template is used in a medial-lateral direction to see where the femoral head leaves the round. This point is marked with a pen. The femoral head can now be reduced into the acetabulum. It should be observed for impingement with the acetabulum by taking it through different ranges of motion (flexion, flexion-internal rotation, abduction in flexion and extension). While the femoral head is reduced again, the stable trochanter should be resected to decompress and expose the vessels to the femoral head. The line of resection should follow the physis of the greater trochanter in children. The osteotomy should cut from lateral to medial and distal to proximal, and from anterior to posterior. The osteotomy should not penetrate the piriform fossa posteromedially. It should crack the medial cortex and then using a knife, and a pituitary clamp for traction, the bone fragment should be peeled away from the medial soft tissues. Anteriorly, less bone is removed while posteriorly, resection of bone is more distal, paralleling the increasing depth of the piriform fossa posteriorly. The medial soft tissues should not be disturbed. The hip can be redischloated after the resection of the stable trochanter. The next step is to decide on the osteotomy lines. Two osteotomies are made, one medial and one lateral, resecting a segment of femoral head between them. The two cuts can be parallel or convergent, depending on the geometry of the femoral head. When the femoral head is enlarged in both the AP and medial-lateral directions, it should be resected in a wedge shape with the base of the wedge anterolateral and the apex of the wedge posterior-medial. In the rare cases when the femoral head is enlarged in a proximal to distal direction together with AP direction, the wedge should be based superanteroinferiorly. Before making the osteotomy, the line of the osteotomy should be measured along the circumference of the femoral head. The length of this line should be the same for both osteotomies, thus ensuring that the lateral mobile segment of the femoral head will match the medial stable part of the femoral head. The osteotomy should also be parallel to the femoral neck. The lateral cut which is made first includes the superior part of the femoral neck to avoid damaging the retinacular vessels that provide circulation to this segment. The medial part of the femoral head derives its blood supply from the postero-medial branch of the medial circumflex femoral artery,
similar to a Pipkin II fracture.\textsuperscript{16,26,27} Prior to the osteotomy, a posterior retinacular flap should be created to mobilize the vascular pedicles of the segments away from the back of the femur and the osteotomy line. The osteotomy is made with an oscillating saw. The author’s preference is to use a saw with an oscillating tip because it cuts from its tip without the blade of the saw moving. The saw cut stops just short of the posterior cortex. A sharp, thin osteotome is used to crack the posterior cortex, thus avoiding injury to the vascular pedicles. After the first osteotomy, the lateral segment is free and can be mobilized on its vascular pedicle. The medial osteotomy is made in the same fashion. The segment of femoral head that is resected is removed, peeling off any remaining soft tissues posteriorly. Care should be taken not to narrow the femoral neck too much with the second cut. This goal can be achieved by taking a minimal amount of femoral neck with the first cut and by limiting the amount of neck resected with the second cut. After the osteotomies are completed, the lateral segment of femoral head should be advanced medially. The two should be fitted together as best as possible. If one is shorter anteroposteriorly from the other, the congruity of the osteotomy should be optimized posteriorly. The anterolateral part of the femoral head is normally outside of the acetabulum and only enters the joint with flexion and internal rotation or abduction. Furthermore, a negative cartilage defect is well tolerated whereas a positive step is harmful. Any gaps or defects can be filled with autogenous bone graft from the resected femoral head segment. The lateral segment can be stabilized with 4.5-mm cannulated headless screws. Three guide wires are inserted from the lateral to the medial fragment. Before drilling over these guide wires, the shape of the femoral head is measured again with the spherical templates. If it is not spherical, consider resecting more of the lateral segment. After measuring the length of the wire, the appropriate cannulated drill is used and the headless screw inserted. It is important to make sure that the screw does not protrude through the medial/inferior articular surface of the femoral head or from the lateral insertion site. Two screws are put through the femoral head articular surface laterally, and one screw is inserted across the femoral neck portion of the lateral segment. Because the femoral neck is narrowed and weakened by this resection, it is at risk of stress fracture. The author prefers to insert a prophylactic 4.5-mm solid screw up the femoral neck. A guide wire is drilled from the fovea to the lateral femur parallel to the femoral neck in the medial stable part of the femoral head and neck. The wire can be overdrilled with a cannulated 3.2-mm drill from the lateral side. A 4.5-mm screw of the correct length is then inserted up the femoral neck from the lateral side. The length of this screw should not exit through the medial femoral head but should extend the entire length of the femoral head and neck. It is important to insert this screw before reducing the femoral head into the acetabulum. In one case the author reduced the hip into joint. The femoral head got stuck on the anterior lip of the acetabulum and the large lever arm force of the reduction maneuver was able to fracture the narrowed femoral neck. Test the movement of the femoral head in the acetabulum. There should be no impingement. The femoral head should be completely stable to flexion and extension because the anteroposterior shape of the large medial part of the femoral head has not been changed. There may be medial-lateral instability and inferior-superior instability, depending on the shape of the acetabulum and on the capsular laxity created by the reduced femoral head size. There is always medial-lateral laxity if there is proximal-distal instability. However, if there is a normally shaped acetabulum there can be medial-lateral instability without proximal-distal instability. Medial-lateral instability alone is caused by capsular laxity due to the redundant capsule following reduction of the intracapsular femoral head volume. This instability can usually be successfully stabilized by tightening the capsule. The femur should be slightly abducted with a bump placed between the two thighs. The posterior capsule, which is attached laterally, should be advanced medially by using supra-acetabular suture anchors. The anterior capsule should be advanced laterally and posteriorly by suturing to the posterior capsule and suture anchors into the anterolateral femur. Once the capsule is closed, the stability of the hip can be tested under image intensifier visualization. The other type of instability is caused by dysplasia of the acetabulum due to remodeling of the acetabulum. In these cases, when the femoral head is reduced a large space can be seen laterally between the articular surface of the acetabulum and the femoral head. In these cases one should consider a reshaping of the acetabulum. Because the entire lateral rim of the acetabulum is exposed and the inside of the acetabulum is visible, an incomplete osteotomy can be performed to hinge down the lateral wall of the acetabulum to better contain the femoral head and to be more congruous to the femoral head shape.\textsuperscript{28} This method is equivalent to an adult version of the Dega osteotomy.\textsuperscript{29} The osteotomy gap should be filled with a bone graft.\textsuperscript{16} The
resected part of the femoral head can be used for this, and if additional bone is required an allograft is used. These grafts are usually stable without internal fixation. The acetabular osteotomy is combined with the capsular tightening capsulorrhaphy described earlier. After the capsular repair, the greater trochanter can be reattached and advanced. The greater trochanter is almost always high in cases of Perthes. Furthermore, with coxa breva its moment arm is short. It should be advanced both laterally and distally, producing what is referred to as a relative neck lengthening. The greater trochanter is fixed with 3 identical-length 3.2-mm drill bits. Using the image intensifier, these are drilled from proximal lateral to distal medial. The length of these is measured using a free 3.2-mm drill bit and a ruler. Each drill bit is sequentially replaced with a 4.5-mm screw and a large fragment washer. These 3 screws and washers give excellent fixation of the greater trochanter. The rest of the closure includes the vastus lateralis, fascia lata over a drain, Scarpa’s fascia, and subcutaneous and skin layers. Intraoperative radiographs should be taken to make sure that the femoral head is well reduced in the acetabulum. If the femoral head is laterally subluxed, consideration should be given to application of a temporary articulated spanning external fixator to reduce and hold the femoral head in place for 6 weeks while the capsule heals.

Postoperatively, the patient can be placed in continuous passive motion. The author prefers to use this modality at home for 6 weeks. This method should be combined with physical therapy to maintain the active and passive range of flexion and extension of the hip joint. Because continuous passive motion does not fully extend the hip, the therapist should make sure to stretch the hip to full extension. The hip may be passively abducted for the first 6 weeks. Active abduction should be avoided until the greater trochanter is healed (usually at 6 weeks). Passive and active adduction and external rotation range of motion should be avoided because they stress the capsular repair and the trochanteric fixation. These motions can be resumed after 6 weeks. Weight bearing is restricted to touch-down weight bearing for 3 months. After 6 weeks the extremes of motion should be stretched passively. To ensure that this is correctly done, the physical therapist should be educated about the use of the contralateral hip to lock the pelvis. For example, to maximize abduction stretch the contralateral hip should first be maximally abducted to lock the pelvis from moving as one stretches the affected hip into abduction. Full extension of the hip requires first flexing both hips, then leaving the contralateral hip in maximum flexion (Thomas test) while pushing the affected hip into extension. Full flexion requires prior hyperextension of the contralateral hip before stretching the affected hip into flexion; this locks the pelvis into full extension so that all flexion motion seen is real. Finally, internal and external rotation can best be done by rotation of the contralateral hip into internal and external rotation, respectively.

RESULTS

The femoral head maximum diameter was an average of 133% larger than the opposite normal side on the AP view (range 115%–160%). Compared with itself, the femoral head after reduction was an average of 96% the diameter of the opposite normal side (range 91%–100%). Compared with the preoperative diameter, the femoral head was reduced by an average of 25% (range 13%–43%) (Figs. 2 and 3; see Table 1).

In all 20 patients the femoral head and greater trochanteric osteotomy was healed. The greater trochanter osteotomy was usually healed by 6 weeks and the FHRO was healed by 12 weeks. Five patients also underwent a pelvic osteotomy, all of which also healed uneventfully. Three of the pelvic osteotomies (Wagner 1 types) were performed at the time of the index procedure as already described, while 2 had the Ganz periacetabular osteotomy performed 6 months after the index osteotomy (Figs. 2 and 3; see Table 1).

In 5 patients an articulated external fixator was applied across the hip joint to help maintain the reduction of the femoral head in the acetabulum. Only 2 of these had the application performed at the index procedure. The other 3 had the external fixator applied 2 weeks after surgery when the first postoperative radiograph showed lateral subluxation. All the fixators were removed after 6 weeks, and recurrent subluxation did not occur. There was one AVN with fragmentation that occurred 18 months after the head reduction osteotomy. None of the other cases showed evidence of AVN. All but 2 patients in this study had follow-up longer than 18 months. This AVN patient was the only one in this series with an open femoral head physis at the time of the osteotomy, and the only one to have undergone a previous varus osteotomy, which altered and complicated the resection osteotomy. One year after the head reduction osteotomy, a valgus intertrochanteric osteotomy was performed. Finally, this case also...
had the largest resection of the femoral head of any case (38%) and had the most preoperative subluxation and acetabular dysplasia of any case in the study. A periacetabular (Dega-like) osteotomy was performed at the time of the head reduction surgery and an external fixator was used postoperatively. The AVN case was also 1 of the 4 bilateral cases.

All patients who had good range of flexion-extension motion of the hip preoperatively had excellent full range of motion after healing. Eight patients with very stiff hip flexion-extension range of motion showed initial improvement, but 5 of these developed marked restricted range of motion by 1 year of follow-up. All 8 of these had advanced degeneration of the hip cartilage at the time of surgical dislocation. Five of the 8 are now painless.

Only 3 patients experienced pain during follow-up. Two have been treated by a hip replacement, while a repeat hip dislocation is planned on the other.

Patients with normal range of motion, no pain, and no limp were classified as excellent. Those with improved range of motion from preoperatively but less than 80% of normal, no pain, and mild limp were classified as good. Patients with very stiff hips, moderate limp, but no pain were classified as fair. Patients with significant pain, stiffness, and limp were considered poor. There were 7 excellent, 7 good, 3 fair, and 3 poor final results.

**DISCUSSION**

The misshapen femoral head has been an unsolved problem in orthopedics leading to pain, limp,
limitation of motion, impingement, acetabular dysplasia, and arthritis. In some cases valgus and valgus-extension osteotomy can alleviate many of the symptoms and can lead to hip preservation for 10 or more years.\(^8\) Cheilectomy has been performed with variable results and without altering the natural history.\(^9-14\) Most cases end up with some form of hip arthroplasty at a young age. Recent advances in the understanding, recognition, and treatment of femoroacetabular impingement have opened new opportunities, including safer more extensive cheilectomy techniques.\(^13,16,17,26\) Most recently the Ganz safe surgical dislocation technique combined with a FHRO based on the femoral head vascular anatomy has for the first time offered the opportunity to restore sphericity to a nonspherical femoral head.\(^16,17\)

The Stulberg and Mose classifications\(^21,23\) classify and correlate femoral head sphericity to prognosis. Theoretically, if femoral head sphericity can be restored then the femoral head should last much longer. Because the longest follow-up in this study is 5 years, it is too early to comment on whether this procedure will alter the natural history. What can be said in this short-term follow-up is that by 18 months after surgery most patients have fully recovered their muscle strength and have no limp or pain, and avascular necrosis if present is already evident. Most patients have returned to unrestricted activities including sports and physical education. If a patient has good flexion-extension range of motion preoperatively, they maintain this and improve in all ranges of motion. If a patient has a lot of joint degeneration...
and restriction of flexion-extension range preoperatively, they often end up with permanent limitation of hip range of motion. Few patients ended up with residual pain. The 3 patients with poor results in this study all had residual pain. One developed avascular necrosis and the other 2 had preoperative stiffness and degenerative changes. The one case of avascular necrosis may be been predisposed because of 3 factors: open physis, large resection, and previous varus osteotomy.

Based on this study, the best indications for FHRO are misshapen femoral head, with good flexion and extension motion and limited cartilage degeneration on the acetabular side, and degeneration on the femoral side corresponding to the segment to be resected. Previous intertrochanteric osteotomy affects the ability to reduce the femoral head in the correct direction. The best shape to reduce is either an elliptical-shaped or a saddle-shaped femoral head.

Although the risk of avascular necrosis is significant, this study demonstrates that if the osteotomy is performed correctly this procedure can be accomplished with a very low rate of AVN. Most of these patients faced the prospect of an early hip replacement as one of the only alternative treatments. Therefore, the risk of AVN in a symptomatic patient may be acceptable because it does not burn any bridges with respect to performing a hip replacement.

Ganz’s first report on the FHRO was in 2009. At that time he briefly reported the technique and the results of the first 11 patients: 9 for Perthes, 1 for AVN, and 1 for a high dislocation. The patients ranged in age from 9 to 15 years. In 3 hips postoperative instability was treated by a femoral varus osteotomy in 2 and a pariacetabular osteotomy (PAO) in 1 to stabilize the hip. Subsequently the next 3 cases were treated with PAO at the time of the FHRO.

In 2010 Ganz and colleagues reported on their first 14 FHROs since 2001. Eight hips also had a PAO at the same time as the index procedure while 3 had a PAO performed at a later date. In one case a varus intertrochanteric osteotomy was performed to treat subluxation, and in another a Colonna was performed at the same time. Therefore only 1 of their 14 cases did not have an additional procedure. None of the 14 cases developed avascular necrosis. No other details on this group were reported.

In a personal communication on one of their earliest and youngest patients, a recurrent femoral head deformity developed following a FHRO in a patient with an open proximal femoral physis. The two parts of the physis continued to grow in different directions, leading to a bifid femoral head. In the author’s series the only case of AVN was in a child with an open femoral physis. A persistent open physis may therefore be a relative contraindication to this procedure.

This series of 20 FHRO osteotomies is currently the largest single-surgeon series of this procedure to the author’s knowledge. It is also the first detailed study of FHRO. As in Ganz’s series, the early results are very promising. This case series served to describe and report the short-term results of the technique. As noted previously, there are some modifications to the original technique. The surgical technique described is a more objective one, with intraoperative measurements of diameter and curvature to reduce the femoral head to as near normal as possible. This reduction in size is greater than that proposed by Ganz. However, as can be seen from the ratio of the postreduction to the size of the opposite normal side, reduction was achieved to within less than 10% of normal in all cases and to 100% of the normal diameter in 9 of the 16 unilateral cases. Although Ganz mentions that the segment resected can be triangular or trapezoidal in shape, there is no description of how to alter the shape of the femoral head in multiple planes. In this study, such an alteration was done in 5 cases. Furthermore, the 2 dysplasia cases in this series had a vertical reduction in the shape and size of the femoral head. This study showed that the femoral head and neck can be reduced in all 3 dimensions, namely frontal, sagittal, and transverse planes. Headless screws were used here instead of 3.5-mm headed screws recommended by Ganz. Finally, the surgical and postoperative management is outlined in much greater detail.

Longer term follow-up is important to determine whether the early excellent results will hold up, and whether the natural history of the disease will be altered by this osteotomy procedure.

REFERENCES

Ganz Femoral Head Reduction Osteotomy


Dear Author,

Please check your proof carefully and mark all corrections at the appropriate place in the proof (e.g., by using on-screen annotation in the PDF file) or compile them in a separate list. To ensure fast publication of your paper please return your corrections within 48 hours.

For correction or revision of any artwork, please consult http://www.elsevier.com/artworkinstructions.

Any queries or remarks that have arisen during the processing of your manuscript are listed below and highlighted by flags in the proof.

<table>
<thead>
<tr>
<th>Location in article</th>
<th>Query / Remark: Click on the Q link to find the query’s location in text Please insert your reply or correction at the corresponding line in the proof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Please approve the short title to be used in the running head at the top of each right-hand page.</td>
</tr>
<tr>
<td>Q2</td>
<td>This is how your name will appear on the contributor’s list. Please add your academic title and any other necessary titles and professional affiliations, verify the information, and OK DROR PALEY, MD, FRCSC, Paley Advanced Limb Lengthening Institute, West Palm Beach, Florida</td>
</tr>
<tr>
<td>Q3</td>
<td>The following synopsis is the one that you supplied, but edited down to less than 100 words. Please confirm OK, or submit a replacement (also less than 100 words). Please note that the synopsis will appear in PubMed: The aspherical coxa magna femoral head can be made more spherical by intra-articular osteotomy. The Ganz technique of femoral head reduction osteotomy to reduce the size and restore the spherical shape of the femoral head has been performed in 20 patients over the past 5 years. A good or excellent functional and radiographic result was obtained in 14 of the 20. A fair result (decreased pain but no improvement in range of motion) occurred in 3, and a poor result (stiffness and pain) occurred in 3. The preliminary results of this technique are therefore very promising.</td>
</tr>
<tr>
<td>Q4</td>
<td>Please verify the affiliation address and provide the missing information (department name).</td>
</tr>
<tr>
<td>Q5</td>
<td>As per Clinics style, Citation is not allowed in section heading. Hence citation of Fig. 1 has been moved to the end of the first sentence of the paragraph “The technique used is modified…”. Please verify.</td>
</tr>
<tr>
<td>Q6</td>
<td>The journal title in Ref. 3 does not match that in PubMed. Please check that the reference details are correct.</td>
</tr>
<tr>
<td>Q7</td>
<td>Please provide page number in Ref. 14.</td>
</tr>
<tr>
<td>Q8</td>
<td>Please verify volume, issue and page number in Ref. 17.</td>
</tr>
<tr>
<td>Q9</td>
<td>Please verify or modify the suggested caption for Table 1.</td>
</tr>
</tbody>
</table>

Thank you for your assistance.