Temporary epiphyseodesis for limb-length discrepancy
8- to 15-year follow-up of 34 children

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Submitted 2014-01-23. Accepted 2014-06-22

Permanent epiphyseodesis was introduced by Phemister in 1933 (Phemister 1933) and temporary epiphyseodesis was introduced by Blount in 1949 (Blount and Clark 1949). The effectiveness of both methods for correction of angular deformities has been confirmed by several authors (Howorth 1971, Pistevos and Duckworth 1977, Stevens et al. 1999). However, a variety of complications have been reported, ranging from buried, misplaced, or fractured staples, and premature physeal closure or deviation of the mechanical axis (Frantz 1971).

There have only been a few reports on correction of LLD by temporary epiphyseodesis (Sengupta et al. 1993, Raab et al. 2001, Gorman et al. 2009). No reports have concentrated on the incidence and extent of secondary angular deformities at the time of skeletal maturity after temporary epiphyseodesis in patients with LLD. Thus, the primary goals of this study were to evaluate (1) the final difference in limb length, and (2) the final mechanical axis at the time of skeletal maturity in patients who had undergone a temporary epiphyseodesis for the treatment of LLD.

Patients and methods

Patients

Inclusion criteria were (1) a temporary epiphyseodesis performed for LLD of up to 5 cm (predicted LLD at time of skeletal maturity), (2) consistent preoperative, postoperative, and follow-up radiographs, and (3) skeletal maturity at the time of final follow-up examination. In the 6 children with an estimated LLD of less than 2 cm, the treatment decision was carefully discussed with the child and his/her parents.

61 patients with LLD were treated by temporary epiphyseodesis. 34 (21 of them boys) fulfilled the inclusion criteria and underwent follow-up examination. Temporary epiphyseodesis was performed with Blount staples in 30 children and with...
8-plates in 4 children. Mean age at the time of epiphyseodesis was 12.8 (10–16) years. 16 children had idiopathic LLD, followed by a secondary LLD in 8 cases (Table 1).

**Epiphyseodesis and hardware removal**

To predict the LLD at skeletal maturity and to define the optimal time for surgery, we used the Anderson and Green growth-remaining charts and the Paley multiplier method (Anderson et al. 1963, Paley et al. 2000). The epiphyseodesis was performed at the distal femoral physes, the proximal tibial physes, or both, depending on the location of the main inequality. We inserted 2 Blount staples or one 8-plate on the medial and lateral side of the physis. The fibular physis was not treated. The main goal was a balanced limb length at the time of skeletal maturity, with both knees at the same level. No overcorrection according to the estimated LLD at maturity was intended. The implants should completely bridge the physis. The prongs/screws should be placed parallel to the physis and at an equal distance from the anterior and posterior margins of the bone. To ensure proper positioning of hardware, we performed intraoperative fluoroscopy and postoperative radiography in 2 planes. Implants were removed at maturity or when the limb length was balanced.

**Radiographic analysis**

Digital radiography at the time of treatment was not available at our institution. 3 radiographs centred over the hip, knee, and ankle joint with an underlying measuring tape were obtained. This technique was common for LLD analysis at our institution until 2008. At the time of follow-up, digital radiography with long, standing anteroposterior radiographs of the lower extremity was available. To ensure that the radiographs are standardized, the patient stands with the back exactly parallel to the back-pillar of the radiographic equipment, patellae forward, with weight balanced on both feet and straight legs.

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**Table 1. Patient data**

| Patient | Age at OP (years) | Sex | Etiology     | OP    | Implant | IR (months) | Closed phys at IR | Age at IR (years) | FU (months) | Complication | Additional surgery |
|---------|-------------------|-----|--------------|-------|---------|-------------|-------------------|-------------------|-------------|--------------|---------------------|
| 1       | 13                | M   | idiopathic   | fem.: left | staples | 17 | yes | 14 | 117 |               |               |
| 2       | 11                | F   | idiopathic   | fem.: right | staples | 8  | yes | 12 | 78  |               |               |
| 3       | 13                | M   | KTS          | tib.: right | staples | 36 | yes | 15 | 65  | AD          | IR fconcave side |
| 4       | 13                | F   | hypoplasia of fibula | tib.: left | staples | 30 | yes | 15 | 105 |               |               |
| 5       | 12                | F   | idiopathic   | both: left | staples | 13 | yes | 13 | 72  |               |               |
| 6       | 13                | M   | idiopathic   | both: right | staples | 7  | no  | 13 | 51  |               |               |
| 7       | 11                | M   | post-traumatic | fem.: right | staples | 33 | yes | 13 | 123 | > LLD at FU | add. fem. epiphys. |
| 8       | 13                | M   | post-traumatic | fem.: left | staples | 20 | yes | 15 | 150 |               |               |
| 9       | 15                | M   | post-traumatic | fem.: right | staples | 19 | yes | 17 | 95  |               |               |
| 10      | 12                | F   | idiopathic   | tib.: left | plates  | 39 | yes | 15 | 87  |               |               |
| 11      | 14                | M   | idiopathic   | fem.: right | staples | 69 | yes | 19 | 69  |               |               |
| 12      | 13                | M   | idiopathic   | tib.: right | staples | 24 | no  | 15 | 104 |               |               |
| 13      | 14                | M   | post-infectious | fem.: right | staples | 42 | yes | 17 | 58  |               |               |
| 14      | 13                | M   | idiopathic   | tib.: left | staples | 39 | yes | 16 | 97  | AD          | IR concave side |
| 15      | 13                | M   | idiopathic   | fem.: right | staples | 66 | yes | 18 | 66  |               |               |
| 16      | 10                | F   | post-traumatic | fem.: right | staples | 13 | no  | 11 | 159 |               |               |
| 17      | 13                | M   | hypoplasia of fibula | tib.: right | staples | 30 | yes | 16 | 61  |               |               |
| 18      | 13                | M   | neurologic   | fem.: left | staples | 24 | yes | 15 | 97  | IL and AD  | IR concave side |
| 19      | 14                | M   | stenosis a.iliaca ext. | fem.: right | staples | 13 | yes | 15 | 87  | IL          | implant change |
| 20      | 12                | F   | neurologic   | both: left | staples | 13 | no  | 13 | 100 |               |               |
| 21      | 14                | M   | idiopathic   | both: left | staples | 21 | yes | 16 | 64  |               |               |
| 22      | 11                | F   | idiopathic   | both: right | staples | no IR | no IR | no IR | 72  |               |               |
| 23      | 12                | F   | aseptic osteonecrosis | fem.: left | staples | 26 | yes | 14 | 145 |               |               |
| 24      | 12                | M   | idiopathic   | tib.: right | plates  | 20 | no  | 14 | 87  | IL          | implant change |
| 25      | 14                | F   | KTS          | both: left | staples | 35 | yes | 16 | 100 | > LLD at FU | osteotomy       |
| 26      | 12                | M   | idiopathic   | both: right | staples | 28 | yes | 14 | 65  | IL          | implant change |
| 27      | 13                | M   | post-traumatic | fem.: right | staples | 37 | yes | 16 | 96  |               |               |
| 28      | 12                | F   | idiopathic   | fem.: left | staples | 55 | yes | 16 | 55  |               |               |
| 29      | 16                | M   | idiopathic   | both: right | staples | 25 | yes | 18 | 115 |               |               |
| 30      | 12                | M   | dysplasia of hip | both: left | plates  | 21 | no  | 14 | 83  |               |               |
| 31      | 14                | F   | idiopathic   | both: right | staples | 38 | yes | 17 | 183 |               |               |
| 32      | 11                | F   | aseptic osteonecrosis | fem.: right | staples | 59 | yes | 15 | 117 |               |               |
| 33      | 13                | M   | idiopathic   | both: left | staples | 40 | no  | 16 | 66  |               |               |
| 34      | 12                | F   | neurologic   | both: right | staples | 52 | yes | 17 | 52  |               |               |
| mean    | 12.8              | 21   | M            | 30 staples | 30     | 26 yes | 15.2 | 92  | n = 8 | n = 8 |               |
| SD      | 1.2               | 13    | F            | 4 plates   | 16     | 7 no  | 1.8  | 32  |               |               |

OP: operation; IR: implant removal; FU: follow-up; M: male; F: female; KTS: Klippel-Trenaunay syndrome; AD: angular deformity; IL: implant loosening; LLD: leg-length discrepancy; Add.: additional; fem.: femoral.
All radiographs were evaluated for limb length in a standardized manner. The long, standing radiographs at the time of follow-up were analyzed for the mechanical axis according to Stevens et al. (2004) (Figure 1), for the mechanical axis deviation (MAD) referred to the center of the knee joint, the lateral distal femoral angle (LDFA), and the medial proximal tibial angle (MPTA). The uninstrumented leg acted as the reference.

**Results**

**Epiphyseodesis and hardware removal**

We used Blount staples in 30 children and 8-plates in 4 children. The implants were inserted only on the femoral side in 14 children, and on the tibial side in 8 children. In 12 children, combined femoral and tibial epiphyseodesis was performed (Table 1 and Figure 2). The position of the implant was rated as being adequate in 32 children. In 2 children, a staple was placed too far anteriorly and was therefore rated as having inadequate placement. In these cases, no complications occurred that necessitated revision surgery. All staples or plates captured the physis at the time of insertion. The 2 children with the misplaced staples had no secondary deformity during the treatment period.

In 33 cases, the implants were removed after mean 31 (7–69) months. Mean age at removal was 15.2 (11–19) years (14.5 (11–17) years for girls and 15.5 (13–19) years for boys). In 7 cases, the LLD was balanced before physeal closure. 1 patient did not want to have the staples removed after physeal closure.

**Follow-up**

All 34 patients were available for the follow-up investigation. Mean follow-up time was 7.7 (4.2–15) years. Mean age at this time was 20 (15–28) years.

**Leg-length discrepancy (LLD)**

The mean LLD preoperatively was 2.3 (0.9–4.5) cm and the...
predicted LLD at maturity was 2.6 (1.0–5.0) cm. At the time of implant removal, the LLD was reduced to 0.9 (–1.0 to 2.4) cm (p < 0.001). Subsequently, no alteration occurred until follow-up. Compared with the initial LLD, the temporary epiphysodesis resulted in a mean LLD correction of 1.6 (–0.2 to 3.8) cm (p < 0.001). 1 child had a final LLD of > 2 cm, 21 children had a final LLD of < 1 cm, and 10 had a final LLD of < 0.5 cm.

The mean difference in knee joint level of the operated limb and the uninstrumented limb at the time of follow-up was 0.3 (–3.4 to 2.7) cm (p = 0.2) (Table 2 and Figure 3).

### Mechanical axis

Before epiphysodesis, none of the children had an angular deformity on clinical examination. At the time of follow-up, the mechanical axis of the operated limb was within Steven’s zone 1 in 32 children (15 medial and 17 lateral), and in zone 2 in 2 children (1 medial and 1 lateral). The mechanical axis of the uninstrumented leg crossed within zone 1 in 33 patients (9 medial and 24 lateral), and in only 1 case within zone 2. No axis deviation into zone 3 occurred.

The mean MAD of the operated leg at follow-up was –0.06 (–2.87 to 1.91) cm, and that of the uninstrumented leg was –0.4 (–2.31 to 2.48) cm (minus designates valgus). We considered a MAD of ≥ 1 cm to be clinically important. Consequently, the axes of both legs differed by 0.34 (–2.77 to 2.78) cm (p = 0.1). The mean LDFA of the instrumented leg at the time of follow-up was 87.2° (81–94), and that of the contralateral leg was 86.5° (82–90). We calculated a mean difference in angle between the instrumented and uninstrumented leg at follow-up was 0.7 (–2.8 to 3.2) cm (p = 0.01).
leg and the uninstrumented leg of 0.7° (–8 to 9) according to the LDFA (p = 0.3) and of 0.2° (–7 to 8) according to the MPTA (p = 0.731) (Table 2 and Figure 4).

Complications
In 26 cases, the entire treatment was uneventful. No deep infections or neurovascular lesions were seen. None of the 34 children had a permanent decrease in knee motion or persistent knee pain. No genu recurvatum occurred. Complications occurred in 8 children (Table 1). 4 children had implant failure or loosening (Figure 5), which was managed by repeated epiphyseodesis in 3 cases. Due to insufficient correction, an additional femoral epiphyseodesis was performed in 1 child and a shortening osteotomy was performed in another child. In 1 case, a medial tibial exostosis occurred after staple removal (Figure 5). In 3 cases, a secondary angular deformity necessitated implant removal from the concave side. In these cases, a return to a normal mechanical axis was achieved (Figure 6).

Discussion
Besides nonoperative management for LLD of less than 2 cm, numerous surgical procedures exist: circumferential periosteal
release (Wilde and Baker 1987), arteriovenous fistula (Hieron 1961), lumbar sympathectomy (Barr et al. 1950), inclusion of foreign bodies at the metaphyseal level (Castle 1971), and pulsed electromagnetic fields on the shorter leg. However, the results of these methods are inconsistent (Raab et al. 2001). Osteotomies and callus distraction are preferred in cases with LLD of more than 5 cm. The inhibition of growth by temporary or permanent epiphyseodesis appears to be a more accepted surgical treatment for LLD ranging from 2 to 5 cm.

Ilharreborde et al. (2012) used transphyseal screws (PETS) for the treatment of LLD. The final loss of growth at maturity noted with PETS was only two-thirds of that predicted preoperatively; furthermore, use in the proximal tibia was associated with a substantial rate of complications, including valgus deformity (20%). These results argue for an eventual benefit of temporary epiphyseodesis using staples (Ilharreborde et al. 2012, Kemnitz et al. 2003), but Cabalzar (1978) concluded that epiphyseal stapling should not be used for correction of LLD, as safer techniques for lengthening of the affected leg are available with low complication rates and the advantage of correction of associated deformities (Cabalzar 1978). Gorman et al. (2009) noted inconsistent results in one quarter of their patients who still had a discrepancy in excess of 2 cm after epiphyseal stapling. In recent years, the 8-plate has been used to treat angular deformities and LLD. Lauge-Pedersen and Hägglund (2013) reported that the 8-plate did not reduce growth when applied both medially and laterally in a symmetrical way at the proximal tibial physis for LLD treatment in 2 patients. In the present study, the 4 patients who were treated with 8-plates showed LLD correction similar to that in the patients treated with Blount staples. However, an implant breakage occurred in one case. If the remaining growth potential and the expected LLD correction can be estimated exactly, a percutaneous permanent epiphyseodesis would be the method of choice for LLD treatment, because implant-related complications are avoided and implant removal is not required. Kemnitz et al. (2003) reviewed 57 patients who underwent percutaneous permanent epiphyseodesis for LLD correction. They reported good results in 39 patients with a final LLD of less than 1.5 cm, and identified the error in timing as the main problem associated with this technique.

At the time of follow-up, 33 out of 34 of our patients had a residual LLD of less than 2 cm, and 21 of 34 had less than 1 cm. Similar results have been reported by Watillon et al. (1986), Sengupta et al. (1993), and Raab et al. (2001). Sengupta and colleagues noted a residual LLD of < 1 cm in two-thirds to three-quarters of their patients. A mild overcorrection at the time of skeletal maturity (0.2–1.0 cm) occurred in 4 of our patients. One girl had a final LLD of 2.6 cm, caused by a delayed initial presentation (14 years of age) and LLD of 3.8 cm.

Apart from over- and under-correction of LLD, a possible complication of epiphyseodesis is secondary angular deformity. In a series of 54 patients with LLD and a minimum follow-up of 2 years, Gorman et al. (2009) reported a shift in the mechanical axis of > 1 cm toward varus in 27 patients after Blount stapling. To correct the varus deformity, a high tibial osteotomy became necessary in 6 cases. In contrast to that report, Sengupta and Gupta (1993) noted an angular deformity...
in only 8 (2%) of 503 cases after stapling for LLD correction, requiring a staple removal from the concave side in 3 patients and an osteotomy in 2. Raab et al. (2001) reported a mild deviation (4–9°) in the mechanical axis in 4 of 24 patients after stapling, but none of these patients needed an osteotomy. In the present study, no difference between the mechanical axes of both legs occurred at skeletal maturity. In 32 of 34 patients, the axes crossed within Steven’s zone 1, representing a physiological situation. An osteotomy did not become necessary to treat secondary angular deformities in any of our patients. In 3 patients, a staple removal from the concave side was successfully performed during the treatment period. We had no cases with superficial or deep wound infections and no neurovascular complications. Raab et al. (2001) found no cases of deep infection after Blount’s stapling for correction of length discrepancies and angular deformities of the leg in 48 patients. Gorman et al. (2009) reported 2 cases of a superficial suture abscess in a series of 54 patients after staple epiphysodesis for limb-length inequality.

The limitations of our study include the retrospective design and the absence of preoperative standing anteroposterior radiographs of the lower extremity, precluding an accurate comparison of the mechanical axis before and after treatment. In addition, we cannot comment on sagittal plane deformities because we did not have standardized lateral radiographs at follow-up. Apart from the evaluation of the mechanical axis in the frontal plane, the analysis of the sagittal plane is of major interest. The sagittal plane uncovers recurvatum or procurvatum deformities, for example, which influence the functional range of motion. The major strength of the present study was the complete long-term follow-up in a large group of mature patients.

MS: data collection and interpretation, writing; KR: data analysis; SB: statistical analysis and interpretation; RS: study design, correction; MR: study design, interpretation, writing, correction.

No competing interests declared.