Specialty Update

What’s New in Limb-Lengthening and Deformity Correction

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This update summarizes select articles pertaining to limb-lengthening and deformity correction that were published from January 1, 2013, to December 31, 2013.

Pediatric Lower-Extremity Disorders

Limb Alignment and Guided Growth

The optimal timing for performing growth modulation and the choice of implants continues to be investigated. Lee et al. compared five different methods used to calculate the exact timing of epiphysiodesis and found that, following percutaneous epiphysiodesis in forty-four children, all techniques gave an overcorrected value of limb-length discrepancy compared with what was noted at skeletal maturity. In another retrospective series of thirty-nine children with limb-length discrepancy, no difference in efficacy was noted among the use of staples, tension-band plates, and transphyseal screws. In a randomized clinical trial of twenty-six children with idiopathic genu valgum, stapling and tension-band hemiepiphysiodesis were equally effective in realigning the limb. In the early postoperative period following percutaneous permanent epiphysiodesis, volume computed tomography (CT) scanning with radiostereometric analysis may be used to confirm the anticipated physeal ablation. Using this imaging technology and clinical evaluation, authors have questioned the efficacy of tension-band plates in the proximal part of the tibia as an effective means of correcting limb-length discrepancy.

Several authors have reported on the efficacy of using less expensive implants (3.5-mm reconstruction plates and one-third tubular plates with noncannulated screws) as a viable alternative to currently available tension-band constructs for achieving temporary hemiepiphysiodesis around the knee. Guided growth is also effective in managing lower-extremity angular deformities in children with certain skeletal dysplasias and in pediatric amputees. However, caution should be exercised when using tension-band plates in children with small epiphyses or osteopenic bone, as the screw may get drawn into the physis and cause an iatrogenic growth arrest. In addition to being used for correction of angular deformities in the frontal plane, guided growth can be used for correcting sagittal plane, and perhaps rotational, deformities. On the basis of their work in a rabbit model, Arami et al. demonstrated the potential feasibility of altering axial rotational growth by using obliquely placed plates across the distal femoral physis.

Obesity-Related Issues

In general, genu valgum, primarily related to distal femoral deformity, is the predominant lower-limb malalignment in obese adolescents. Compared with their peers, children with Blount disease have advanced skeletal maturity. The use of a circular external fixator with a proximal tibial osteotomy remains an effective method to achieve limb realignment in morbidly obese adolescents. In another study, patients tended to gain weight during extended periods of external fixation.

Congenital Limb Deficiencies

At a mean follow-up of 21.5 years, patients who had undergone a Van Nes rotationplasty for the correction of congenital femoral deficiency functioned at a high level despite gait deviations. Koczewski et al. reported on nine patients with lower-limb hypoplasia involving deficiencies of the intermediate foot rays. Predicted limb-length discrepancy at skeletal maturity and the number of foot rays involved may influence...
the method of limb reconstruction in children with congenital fibular deficiency.51

**Congenital Pseudarthrosis of the Tibia**
The management of congenital pseudarthrosis of the tibia remains challenging.4,6 Prospective clinical trials may help to discern the role of various surgical and pharmacologic approaches for congenital pseudarthrosis of the tibia.52 The use of circular fixation and intramedullary nailing remain the primary treatment modalities for this disease.53,54 Spontaneous healing of the persistent nonunion without compression was noted during proximal tibial lengthening over the retained intramedullary nail in two children with congenital pseudarthrosis of the tibia.55 The two-stage induced membrane technique appears to be promising.56

**Hip Disorders**
A mean shortening of 19 mm (range, 10 to 38 mm) at skeletal maturity was noted in ninety-three (55%) of 168 patients with Legg-Calvé Perthes disease, advanced lateral pillar stage being the strongest predictor for future limb-length discrepancy.57 Varus osteotomy was not associated with residual shortening of the affected extremity. The evolution and technical considerations of the modified pelvic support osteotomy in pediatric patients was recently described by Choi et al.58

**Surgical Techniques and Outcomes**
In a retrospective review of 125 children undergoing supra-malleolar derotational osteotomies, a complication rate of 12.8% was noted with conventional plate fixation compared with 2.4% with cross-pinning.59 The use of locking plates for stabilizing long-bone osteotomies following acute correction and gradual correction is gaining popularity. While femoral lengthening over an intramedullary nail decreases the external fixation time, Gordon et al. noted a 38% complication rate (including failure to lengthen, fractures, implant failures, subluxation of the hip and knee joints, and deep infections) in a series of thirty-seven children.60 Launay et al. reported twenty fractures (18%) following lower-limb lengthening of a total of 111 limb segments in fifty-eight children. Risk factors included congenital etiology and less than seven days of latency period following the osteotomy.61 Martin et al. described a novel technique of performing quadricepsplasty for managing extension contracture of the knee following femoral lengthening.62

**Osteomyelitis**
Despite residual limb shortening, sequestrectomy followed by nonvascularized fibular grafting can effectively address gap nonunion of long bones secondary to osteomyelitis in children.63 With some additional risks, the Ilizarov technique can allow comprehensive management of pseudarthrosis following hematogenous osteomyelitis of the tibia.64

**Pediatric Trauma**
Zenios reported that, despite the prolonged use of an external fixator, twelve skeletally immature patients with an unstable tibial fracture (eight closed, four open) had satisfactory healing and alignment with use of the Taylor Spatial Frame (Smith & Nephew, Memphis, Tennessee), with one patient developing a compartment syndrome postoperatively.65 On the basis of a mean follow-up of twenty-one (range, sixteen to twenty-eight) years for individuals with a pediatric femoral fracture, Palmu et al. reported a positive correlation between residual angular deformity and premature arthritis of the knee joint.66 In a retrospective review of pediatric femoral shaft fractures treated with flexible intramedullary nailing, Park et al. reported that a low nail-canal diameter ratio may be associated with femoral overgrowth.67 The development of premature growth arrest following intra-articular physeal fractures of the medial malleolus correlated with the magnitude of initial displacement and a delay in surgical intervention.68

**Posttraumatic Bone Defects in Adults**
The clinical outcomes, including the cost associated with complex posttraumatic limb reconstruction, have been reported.69-72 Lowenberg et al. reviewed thirty-four patients who had a mean tibial bone defect size of 8.7 cm and soft-tissue defects and who were referred for a second opinion prior to amputation. These lower limbs were successfully salvaged with flap reconstruction and bone transport. The mean duration of bone transport was 10.8 months, and one flap failed. Despite a 29% reoperation rate, all gaps had healed, without recurrent infection, at a mean follow-up time of eleven years and the majority had satisfactory functional outcomes. The average lifetime cost per patient per year was appreciably less than the published cost for amputation. Two other studies reported satisfactory subjective outcome scores for this type of reconstruction for tibial bone defects.73,74 Two groups have reported on the use of the Taylor Spatial Frame to simultaneously address the problems of bone and soft-tissue loss in high-energy open tibial fractures. The basic technique involves the intentional creation of a shortening and angulation deformity at the fracture site, which allows the soft-tissue envelope to be closed primarily and avoid the need for a local or free tissue transfer. After healing of the soft tissue, but prior to bone-healing, the deformity is gradually corrected and then lengthening or bone transport is employed to treat the remaining bone defect.75 The Direct Scheduler module of the Taylor Spatial Frame software is designed to facilitate this type of treatment without the need for frame mounting parameters.76 Mora et al. reported on 120 infected tibial nonunions with combined bone and soft-tissue loss, which were treated without plastic surgical tissue transfer and with use of the soft-tissue recruitment associated with bone transport (6 to 18 cm) alone (epidermato-fascial osteoplasty). Karargyris et al. in their series of seven patients, reported acceptable outcomes with use of a similar technique combining bone transport,
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Papineau grafting, and negative-pressure wound care without formal plastic surgical coverage. These demanding techniques can provide a solution in otherwise unsalvageable situations.

The problem of achieving a successful knee arthrodesis with a large bone defect following debridement of an infected periarticular fracture was addressed in four patients.

The technique involved debridement and soft-tissue coverage followed by bone transport (6 to 10 cm) with a circular fixator. The authors recommend a “peg in socket” docking technique to increase mechanical stability.

The prolonged external fixation time associated with the consolidation phase of either lengthening or bone transport can be decreased substantially with use of a technique that incorporates a locking plate and unilateral monorail transport. This allows the external frame to be removed at the time of either docking or completion of lengthening. The regenerate bone is protected by the locked implant. With use of this technique in a series of ten segmental posttraumatic tibial defects (3.8 to 9.3 cm), Oh et al. were able to substantially reduce the external fixation index (average 13.4 days/cm) with excellent healing of the docking site and consolidation of the lengthening regenerate.

Upper-Extremity Reconstruction

Several studies have highlighted the utility of advanced techniques of external fixation for a variety of challenging upper-extremity pathologic conditions. Bumbasirevic et al. reported on their retrospective series of fifteen patients (average age, twenty-four years) with scaphoid nonunions, which were treated with the Ilizarov technique without bone graft. The treatment consisted of three stages: distraction, compression, and immobilization. Healing was achieved in all patients with an improvement in Mayo wrist score from 21 to 86.

Osteotomy at the level of congenital radioulnar synostosis with gradual correction by means of circular external fixation was used to improve forearm position in four adolescents with severe pronation deformities (mean pronation angle, 100°). Two patients sustained temporary radial neurapraxia following attempts at partial acute correction intraoperatively. Hosny and Kandel reported on five patients (mean age, twenty-one years) with posttraumatic radial clubhand (mean shortening of radius, 4.2 cm) treated with distraction lengthening of the radius with use of a circular fixator. At an average follow-up of twenty-five months, all patients healed without supplemental bone-grafting and had improved hand function.

A hybrid monolateral fixator restored length and alignment in a series of forty humeri (twenty-three patients). The mean age at surgery was fourteen years (range, ten to twenty-two years). The average duration of external fixation was 8.3 months with a mean lengthening of 8.8 cm and a healing index of twenty-eight days/cm. There were three refractures and two cases of varus angulation. Five elbows developed a flexion contracture.

Sewell et al. reported on distraction osteogenesis for the treatment of congenital clavicular hypoplasia in five patients (seven clavicles), with a mean age of fifteen years. The average length gained was 31 mm (24.7% of original bone length), and the mean time in the monolateral fixator was 174 days with an external fixation index of fifty-six days/cm. Two patients required internal fixation following fixator removal. The Oxford shoulder scores improved from 28.5 to 41.

Lower-Limb Reconstruction in Adults

A closing-wedge high tibial osteotomy results in negligible changes in limb length, whereas an opening-wedge high tibial osteotomy can increase limb length, especially in patients who require a large angular correction. A “safe zone” has been identified through which a medial opening-wedge high tibial osteotomy should be directed to minimize the possibility of fracturing the lateral cortex. Medial opening-wedge high tibial osteotomy may increase patellofemoral contact pressure. Compared with manual techniques, computer-assisted navigation was reported to be more accurate and reproducible when high tibial osteotomy surgery is being performed. Small degrees of valgus malalignment may be treated successfully with a lateral opening-wedge high tibial osteotomy.

A systematic review and meta-analysis suggests that total knee arthroplasty following high tibial osteotomy provides an outcome similar to that associated with total knee arthroplasty done in patients without a prior osteotomy. The clinical outcomes (limb alignment, complications, or patient-reported results) were similar in patients undergoing total knee arthroplasty following an opening-wedge or closing-wedge high tibial osteotomy. A proximal tibial osteotomy distal to the tibial tubercle does not affect the posterior tibial slope or patellar height. The use of patient-specific guides for total knee arthroplasty resulted in success in obtaining neutral mechanical axes in the majority of patients. Kinematically aligned total knee arthroplasty restores function without catastrophic failure, regardless of alignment. Compared with conventional techniques, robotic-assisted total knee arthroplasty improves flexion-extension gap balance and alignment.

The LLRS AIM index (a mnemonic indicating seven pretreatment domains: Location and number of deformities, Leg-length inequality at maturity, Risk factors, Soft-tissue coverage, Angular deformity, Infection/bone quality, and Motion/stability of the joints above and below) of the Limb Lengthening and Reconstruction Society is a reliable classification system for lower-extremity deformities. The domains are rated on a 0 to 4 scale of increasing intensity, and the scores are combined into a single index of complexity ranging from normal to high. Identifying and treating lower-limb malrotation is effective in addressing patellofemoral pain and instability in adolescents and young adults. The fusion and complication rates associated with use of a multiplanar, multi-axis external fixator for knee fusions are comparable with those of other methodologies.
Foot and Ankle
External fixation has continued to be useful in arthrodesis, deformity correction, and arthroplasty of various segments of the foot and ankle. Subtalar distraction osteogenesis with external fixation allows restoration of calcaneal height that is often lost when performing subtraction subtalar arthrodesis for posttraumatic arthritis following intra-articular calcaneal fractures. The Ilizarov fixator can facilitate healing in patients undergoing a Pirogoff amputation with ankle disarticulation and tibiocalcaneal fusion. Ankle arthrodesis in patients with infection, deformity, compromised soft tissues, and bone loss can be successfully achieved with a circular external fixator. Cavovarus deformities may have concomitant problems such as torsional malalignment and leg-length discrepancies that can be addressed successfully with external fixation. The Ortho-SUV Frame (OSF; Ortho-SUV Ltd, St. Petersburg, Russia) is a versatile tool in correcting forefoot and hindfoot deformities.

Joint-preserving realignment surgery may be applicable for patients with asymmetric valgus ankle osteoarthritis. A supramalleolar and lateralizing calcaneal osteotomy provide similar redistribution of elevated ankle joint contact forces for fixed cavovarus foot deformities. Temporary intraoperative ankle distraction can improve surgical exposure of lateral osteochondral lesions of the talus. Patients with osteochondral defects of the talus with concomitant osteoarthritis may be amenable to twelve weeks of ankle distraction and allograft resurfacing. Arthrodiastasis with microfracture shows promising results for osteochondral lesions of the tarsal navicular in young athletes. Use of a customized foot plate in patients undergoing lower-extremity limb salvage allowed patients to engage in advanced weight-bearing activities.

Benign and Malignant Tumors
Intraduillary fixation without use of supplemental bisphosphonates was effective in treating acute and impending long-bone fractures in children with fibrous dysplasia. Li et al. reported satisfactory healing and alignment in twenty-one patients with fibrous dysplasia following a valgus proximal femoral osteotomy with dynamic hip-screw fixation. Despite its association with a prolonged duration of external fixation, distraction osteogenesis remains a viable biologic solution for addressing long-bone defects following oncologic resection. However, the use of perioperative cytotoxic agents may delay bone-healing. Epiphysis-preserving resection of malignant tumors of the proximal part of the tibia along with reconstruction that makes use of fibular autografts and circular external fixation can preserve the native knee joint in children but may require a protracted postoperative course. Alternatively, expandable prostheses can be utilized, although an implant-related complication rate of 51% was reported in thirty-two children with sarcoma of the femur.

A computer-assisted navigation system can facilitate guided multiplanar osteotomies during resection of a well-circumscribed chondrosarcoma about the knee. Tibial corticostral strut autograft interposition arthrodesis following resection of distal radial tumors resulted in acceptable function with low donor-site morbidity in seventeen patients.

Postoperative Complications and Their Management

Pin-Track Infection
In an effort to improve the pin-bone interface during external fixation, Toksvig-Larsen et al. studied the use of bisphosphonate-coated stainless steel pins as compared with hydroxyapatite-coated pins and uncoated pins in adult patients undergoing proximal tibial correction with hemicallotasis for the treatment of medial compartment arthritis. They noted that, in the metaphysis, the bisphosphonate-coated pins yielded a removal torque that was similar to that associated with the hydroxyapatite-coated pins. In an animal model, Koseki et al. determined that the photocatalytic bactericidal effect of titanium-dioxide-coated pins (as compared with that of uncoated pins) was more effective in decreasing infection. Other potential strategies for decreasing pin-track infection include the use of titanium-copper alloys and the application of a coating of nanosilver, nitric oxide, chitosan, chlorhexidine, iodine, hydroxyapatite, and certain antibiotics. When selected members of the Limb Lengthening and Reconstruction Society were surveyed, most respondents (81%) preferred the use of hydroxyapatite-coated half pins.

Lethaby et al. performed a meta-analysis with eleven trials (including 572 patients) to evaluate the efficacy of various pin-site care regimens. A variety of topical solutions (saline solution, alcohol, povidone iodine, hydrogen peroxide), application frequencies (daily, weekly), and techniques (sterile, nonsterile) were compared. The authors noted that due to the heterogeneity, confounding variables, and poor quality of evidence, they were unable to identify a pin-care strategy that clearly minimized infection. In another study, the effect of retention or removal of the crust of dried exudate that forms at the pin-skin interface of transfixation wires was investigated. Retention of the dried crust reduced the infection rate (36% compared with 61%), but rendered subsequently infected pin sites more refractory to treatment.

Miscellaneous
The possibility of beginning early functional weight-bearing physical therapy during posttraumatic limb-salvage treatment with use of an ankle-spanning circular external fixator with a custom foot plate was reported by Blair et al.

Prophylactic intramedullary fixation with use of one or two titanium elastic nails following femoral lengthening with external fixation minimizes secondary interventions should the lengthening regenerate fracture.

New Tools and Techniques
Enhancing Bone-Healing
Our understanding of bone-healing continues to advance. In a study of the Masquelet technique, the osteogenesis-improving
capabilities of the induced membrane decreased over time and the authors suggested that the optimal time for the second stage may be within one month following implantation of the membrane-inducing foreign material. The use of teriparatide in the treatment of nonunions shows early promise and needs further investigation in human subjects. In an animal study, the combination of bone morphogenetic protein (BMP) and bisphosphonate as an adjunct to autograft was superior to autograft with BMP or autograft alone. A quantitative assessment of the yield of osteoblastic progenitor cells in bone-marrow aspirate from the iliac crest, tibia, and calcaneus revealed that the iliac crest had a higher concentration than the other two sites. In another study, the concentration and yield of osteoprogenitor cells was greater in aspirates obtained from the posterior iliac crest as compared with the concentration obtained from the anterior iliac crest. Optimal management of the docking site at the conclusion of bone transport continues to be controversial. Sala et al. noted that a minimally invasive endoscopic procedure at the docking site was a safe and viable technique, with union rates similar to conventional open techniques, in nine patients undergoing bone transport.

**Surgical Implants and Perioperative Techniques**

External fixators used for deformity correction continue to evolve. When compared with the Ilizarov fixator, the Smart Correction device (Response Ortho, Edgewater, New Jersey) was more accurate in correcting deformities, especially multi-planar deformities. Twenty-nine humeral shaft fractures treated surgically with external fixator-assisted reduction and minimally invasive plate osteosynthesis resulted in excellent reductions and high union rates, although there were two cases of transient radial nerve palsy.

There are several imaging options for assessing patients with limb-length discrepancy and angular deformities. A standing-upright assessment of individuals with limb-length discrepancy with use of EOS (EOS Imaging, Paris, France) low-dose radiography was more accurate than CT scanograms and conventional radiographs, with the added benefit of significantly lower radiation exposure. Compared with the intraoperative navigation system, the Dugdale method for preoperative planning for opening-wedge high tibial osteotomy can theoretically undercorrect the angular correction. Imaging software using picture archiving and communication system (PACS)-enhanced software methods reliably enable direct measurement of osteotomy gaps in high tibial osteotomy surgery. A novel locked-plate fixation device allows full weight-bearing following opening-wedge osteotomy for varus gonarthrosis. Malrotation errors during insertion of femoral intramedullary nails can be minimized with intraoperative measurement of femoral antetorsion with use of the anterior cortical angle method available with smartphones.

Novel computer-assisted preoperative guides and surgical instrumentation seem promising. A custom simulation-based surgical template facilitated the intraoperative execution of a three-dimensional corrective osteotomy for thirty patients with posttraumatic cubitus varus deformities. Individualized guides were more precise, faster, and easier to use compared with navigated distal radial osteotomies in a laboratory experiment. Virtual three-dimensional planning and patient-specific osteotomy guides for deformities about the knee were useful in single, double, and triple-plane osteotomies. A computer-aided design and custom-made guide in conjunction with a custom-made intramedullary nail may be useful in corrective osteotomy for complex femoral deformities. In an animal study, the use of a piezoelectric bone-cutting instrument enhanced bone-healing compared with conventional saws. A case of 14 cm of lower-limb shortening as a late sequela of childhood meningococcemia was corrected with use of a fully implantable nail. With the increasing availability of various fully implantable intramedullary lengthening nails, a more in-depth analysis will be required to assess their efficacy, safety, and cost compared with more conventional surgical devices and techniques.

**Upcoming Events**

Specialty Day of the LLRS (Limb Lengthening and Reconstruction Society) will be held at the Annual Meeting of the American Association of Orthopaedic Surgeons (AAOS) on March 28, 2015, in Las Vegas, Nevada. The combined meeting of the LLRS and the International LLRS is planned for November 4 through 7, 2015, in Miami, Florida. Details are available at the LLRS web site: www.llrs.org.

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**References**

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