

SPECIALTY UPDATE

What's New in Limb Lengthening and Deformity Correction

Sanjeev Sabharwal, MD, and S. Robert Rozbruch, MD

This update summarizes select articles pertaining to limb lengthening and deformity correction that were published between July 1, 2010 and June 30, 2011.

Limb-Length Discrepancy and Lower Limb Alignment

The minimum threshold for treating limb-length discrepancy is debatable. In the study by O'Brien et al., an imposed discrepancy of >10 mm was perceived by twenty-nine (97%) of thirty normal subjects¹. In the study by Golightly et al., an inequality of ≥ 20 mm was associated with progressive radiographic osteoarthritis of the knee².

There are subtle differences in lower limb alignment based on sex³ and ethnicity⁴. Measuring the anatomic axis of the femur and tibia in patients with osteoarthritis with use of limited radiographs of the knee may be less reliable than a full-length weight-bearing radiograph of the lower extremity⁵. A comprehensive monograph on the treatment of limb-length discrepancies was recently published⁶.

Pediatric Disorders

Guided Growth and Related Disorders

There are various methods for assessing growth remaining in children. The multiplier method, which is based on the child's chronological age, provides a reasonable estimate of limb length at skeletal maturity among preadolescent children, whereas other prediction methods utilizing skeletal age are more accurate during adolescence⁷. Growth modulation with use of staples, tension band plates, or transphyseal screws remains an attractive option for angular deformity correction in the skeletally immature patient^{8,9}. Jung et al. used a mathe-

matical model to evaluate the effect of hemiepiphyseal stapling around the knee on the length of the involved extremity and found that a smaller width of the involved physis, a longer distance between the involved physis and the ankle, and a larger angular deformity tended to increase the effective limb length¹⁰. Shin et al., in a retrospective study evaluating the efficacy of staples as compared with percutaneous transphyseal screws around the knee, found that both techniques were equally effective for correcting angular deformity and that both techniques had a similar incidence of physeal rebound phenomenon following implant removal (21% overall; twelve of fifty-six)¹¹. In a survey of members of the Pediatric Orthopaedic Society of North America (POSNA), sixty-five cases of mechanical failure of titanium nonlocking extraperiosteal plates were reported; failure was often due to a fracture of the cannulated screw as it entered the lateral cortex of the proximal tibial metaphysis¹². Use of alternatives such as dual plates, stainless steel material, or solid screws was suggested for the at-risk obese patient with Blount disease. Rupperecht et al. reported that temporary medial screw epiphysiodesis of the distal part of the tibia was effective for correcting valgus deformity of the ankle in children with hereditary multiple exostosis¹³.

Magnetic resonance imaging (MRI) findings correlated well with histological examination for measuring the extent of physeal bars in an animal model¹⁴. Novel approaches such as endoscopically aided removal of a distal femoral physeal bar combined with guided growth treatment have been described¹⁵.

Lower Limb Lengthening

Intraoperative arthrography can enhance visualization of the articular surfaces during realignment osteotomy in children with genu varum secondary to achondroplasia¹⁶. While the

Specialty Update has been developed in collaboration with the Board of Specialty Societies (BOS) of the American Academy of Orthopaedic Surgeons.

Disclosure: None of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of any aspect of this work. One or more of the authors, or his or her institution, has had a financial relationship, in the thirty-six months prior to submission of this work, with an entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. No author has had any other relationships, or has engaged in any other activities, that could be perceived to influence or have the potential to influence what is written in this work. The complete **Disclosures of Potential Conflicts of Interest** submitted by authors are always provided with the online version of the article.

WHAT'S NEW IN LIMB LENGTHENING AND DEFORMITY CORRECTION

Taylor Spatial Frame (Smith & Nephew, Memphis, Tennessee) has several advanced features compared with the standard Ilizarov fixator, there may be a slightly slower rate of bone maturation when the newer device is used in children¹⁷. The use of small-diameter flexible intramedullary nails in combination with the Ilizarov fixator has been associated with a substantial decrease in the duration of external fixation^{18,19}.

Neuromuscular Disorders

Children with various neuromuscular diseases often have gait abnormalities and lower limb deformities that can interfere with function. On the basis of sagittal T1-weighted MRI scans, Riad et al. reported that limb shortening in patients with spastic hemiplegia originated primarily distal to the knee²⁰. Yang et al. reported that, despite some recurrence, functional gains following extension femoral osteotomy and/or gradual distraction with circular external fixation were noted in arthrogryptic children with flexion contractures of the knee²¹. In addition to distal femoral extension osteotomy and soft-tissue releases, anterior distal femoral epiphysiodesis²² and the Ilizarov technique with gradual soft-tissue correction²³ are other potential options for addressing flexion deformities of the knee in children with spina bifida and other conditions²⁴. Gradual correction with external fixation can also be used to correct excessive tibial torsional and foot deformities in such children²³.

Blount Disease

Montgomery et al. reported a strong association between vitamin-D deficiency and Blount disease among obese youth, especially boys²⁵. In the study by Amer and Khanfour, a high rate of recurrent deformity following gradual deformity correction was noted in children with Blount disease who were more than four years old at the time of presentation²⁶.

Congenital Lower Limb Deficiencies

Congenital fibular deficiencies have been associated with a wide array of anomalies of the involved extremity besides limb shortening^{27,28}. Although a satisfactory clinical outcome can be expected following the use of the Ilizarov technique for limb reconstruction in selected cases of severe fibular hemimelia, complications are common²⁹. Birch et al., in a report based on a single institution's experience in the treatment of 104 patients (126 affected extremities) who had fibular hemimelia, reported that patients with three or fewer foot rays were more often managed with amputation rather than limb lengthening²⁷. Ulger and Sener reported that rehabilitation training following prosthetic fitting improved function and gait in children with lower limb amputations³⁰. Johari et al. reported that children with congenital posteromedial bowing of the tibia who are managed with single-stage lengthening closer to skeletal maturity rather than at a younger age may have fewer complications³¹.

Foot and Ankle Disorders

The treatment of pediatric foot and ankle deformities continues to evolve. The use of circular external fixation with gradual correction combined with limited soft-tissue releases has been reported to be effective for correcting relapsed and neglected clubfeet in older children^{32,33}. The Taylor Spatial Frame is an emerging tool for the treatment of a variety of multiplanar foot and ankle deformities in children³⁴⁻³⁶. Premature closure of the distal tibial or fibular growth plate may require realignment strategies during growth or at skeletal maturity to reestablish the anatomic relationship of the two bones at the ankle^{35,37}. A distal tibial rotational osteotomy for the treatment of symptomatic persistent idiopathic tibial torsion in early adolescence has been reported to improve frontal plane kinematics³⁸.

Congenital Pseudarthrosis of the Tibia

Despite advances in osteobiologics, congenital pseudarthrosis of the tibia remains a challenging condition to treat. Following extraperiosteal resection of the diseased tibial segment, novel reconstructive approaches such as the use of ipsilateral vascularized fibula³⁹, contralateral vascularized fibula in infancy⁴⁰, split tibia vascularized fibula⁴¹, periosteal fibular flap⁴², contralateral onlay tibial cortical grafting⁴³, temporary cement spacer followed by massive autogenous bone-grafting⁴⁴, and local application of bone morphogenetic proteins⁴⁵ with systemic administration of bisphosphonates⁴⁶ have been reported. While these supplemental procedures may enhance union, typical long-term problems such as refracture, limb shortening, and valgus deformity at the ankle remain unresolved.

Osteogenesis Imperfecta and Related Conditions

Telescopic intramedullary rods are often used for the treatment of osteopenic conditions associated with recurrent fractures and deformities of long bones^{47,48}. Cho et al., in a study of children with osteogenesis imperfecta with an intramedullary telescopic rod who were receiving bisphosphonates, noted a persistent fracture risk, especially at less-remodeled fracture or osteotomy sites and at the rod tip⁴⁷. Given the limited torsional stability with these telescopic implants, supplemental external fixation has been advocated for patients who have osteopenic conditions associated with poor healing potential⁴⁸. In older adolescents and adults with lower limb deformities secondary to metabolic bone disease, a fixator-assisted osteotomy stabilized with locked intramedullary nailing is effective for maintaining deformity correction and preventing refractures⁴⁹.

Trauma

Pediatric Trauma

Recent literature has focused on preventing and correcting deformity following fractures in children. The use of screw fixation alone for the treatment of displaced femoral neck

WHAT'S NEW IN LIMB LENGTHENING AND DEFORMITY CORRECTION

fractures may not provide adequate stability and was associated with posttraumatic coxa vara in twelve (55%) of twenty-two children in one study⁵⁰. Malunion, especially procurvatum, is a concern after the use of flexible titanium nails for the treatment of pediatric femoral shaft fractures. Divergence of the two nails in the sagittal plane may prevent such deformity⁵¹. In the report by Ballal et al., fixator-assisted plating combined with realignment osteotomy was used for the treatment of a segmental femoral fracture in a child who had a baseline valgus knee deformity⁵². In the study by Blondel et al., circular external fixation was used for the treatment of tibial fractures in children and demonstrated the potential ability to correct residual deformities in an outpatient setting⁵³. Realignment osteotomies of malunited radial neck fractures with intramedullary fixation may improve function⁵⁴.

Familiarity with the subtleties of the radiographic assessment of the distal part of the humerus is helpful when treating elbow trauma in children. The lateral capitellohumeral and Baumann angles remain essentially unchanged during early childhood⁵⁵. A variety of osteotomies are available for addressing posttraumatic cubitus varus. Medialization of the distal fragment, with or without a step-cut osteotomy, avoids the lateral prominence of the distal part of the humerus^{56,57}. While internal rotation correction is not warranted because of the limited remodeling potential, correction of the hyperextension humeral deformity has been recommended for patients more than ten years old⁵⁸.

Adult Trauma**Lower Extremity Trauma**

Injudicious reaming of the tibial shaft can lead to extreme local hyperthermia, with a rare but catastrophic complication of segmental bone and soft-tissue necrosis. Seven such limbs were salvaged with bone transport with use of circular external fixation⁵⁹. Patients with complex femoral fractures associated with polytrauma are at risk for pulmonary complications. External fixation for immediate and definitive fixation has been successfully used for damage-control orthopaedics and for the prevention of the secondary hit phenomenon⁶⁰⁻⁶². The role of external fixation in the treatment of pilon fractures continues to be studied. In one study, two-stage open reduction and internal fixation was compared with limited internal fixation combined with external fixation for the treatment of closed tibial plafond fractures⁶³. The functional outcomes were similar, although radiation exposure and the prevalence of superficial soft-tissue infection were higher with external fixation. In the study by Kapoor et al., indirect reduction with use of an ankle-spanning Ilizarov fixator for the treatment of high-energy pilon fractures, with removal of the calcaneal ring approximately four weeks postoperatively to allow ankle motion, resulted in satisfactory healing in the majority of patients⁶⁴. Patzkowski et al. reported that the use of a newly designed ankle-foot orthosis combined with intensive physical therapy can further enhance

function patients requiring limb salvage following a combat-related wound⁶⁵.

In the biomechanical study by Mercer et al., the stiffest construct for spanning external fixation for the stabilization of traumatic knee dislocations was achieved when half-pins were placed anterolaterally on the femur and two connecting rods were used⁶⁶. In the study by Levy et al., a staged protocol involving the initial use of a spanning external fixator followed by vascular repair and ligament reconstruction demonstrated satisfactory clinical and functional outcomes in patients sustaining traumatic knee dislocation with an associated vascular injury⁶⁷.

Upper Extremity Trauma

A prospective randomized multicenter study on the treatment of unstable distal radial fractures suggested that dynamic external fixation resulted in better restoration of radial length and wrist mobility as compared with static external fixation⁶⁸. In the study by Wilcke et al., wrist function recovered more rapidly after volar locked plating than after external fixation, but functional outcomes were similar at one year postoperatively⁶⁹. Burg et al. reported that minimally invasive treatment of osteoporotic distal humeral fractures with closed reduction and ring fixation is a viable alternative to internal fixation or elbow arthroplasty in the older patient⁷⁰. Blonna et al. reported that, in comparison with traditional external fixation, a hybrid technique that combined osteosutures and external fixation was associated with better clinical outcomes when used for the treatment of proximal humeral fractures in the elderly⁷¹.

Bone and Soft-Tissue Defects

Chaddha et al. reported that, despite multiple complications, use of the Ilizarov technique of bone transport for the treatment of massive bone defects (average, 8.9 cm) was associated with an ultimate union rate of 92% (twenty-three of twenty-five)⁷². In the study by Parmaksizoglu et al., early limb lengthening via callus distraction after acute shortening for the treatment of traumatic below-the-knee amputations and severe open tibial fractures was associated with similar outcomes compared with a delayed strategy⁷³. Investigators comparing bone transport and compression-distraction treatment with use of monolateral fixation favored compression-distraction because of a lower rate of complications⁷⁴. However, the extent of bone loss should be considered when choosing between the two options.

Soft-tissue and bone-healing problems may arise during bone transport, especially at the docking site. A technique involving a reverse sural flap was described for the treatment of soft-tissue problems in the distal third of the leg with an overlying circular fixator⁷⁵. This sural artery-based fasciocutaneous flap was transposed anteromedially with the patient in the prone position. The Ilizarov fixator also has been used to gradually close traumatic soft-tissue defects⁷⁶. Hatzokos

WHAT'S NEW IN LIMB LENGTHENING AND DEFORMITY CORRECTION

et al. reported that healing time at the docking site following the application of demineralized bone matrix and autologous bone marrow was equivalent to that after autologous cancellous bone grafting and was superior to that after closed compression alone⁷⁷. The use of arthroscopic debridement of the docking site to enhance osseous healing was reported by Robinson et al.⁷⁸.

Malunion/Nonunion

Buijze et al. reported on a single surgeon's experience with twenty-nine of 152 eligible patients who underwent reconstruction with debridement of infected and necrotic tissues, external fixation, and soft-tissue coverage followed by autologous bone-grafting for the treatment of complex malunion or nonunion of the tibia or femur⁷⁹. After a median duration of follow-up of twenty years, all available patients were able to bear full weight with persistent osseous healing, despite functional limitations. A clamshell osteotomy with intramedullary stabilization for the correction of complex diaphyseal malunions of the femur or tibia was recently described as an alternative to more conventional techniques⁸⁰.

Upper Extremity Reconstruction

The mechanical axes of the wrist are oriented obliquely to the anatomic axes, with the primary direction being one of radial extension and ulnar flexion⁸¹. Distal radial osteotomies for the treatment of malunited fractures⁸² and Madelung deformity⁸³ with acute biplanar correction can restore anatomic alignment. External fixation with gradual lengthening and deformity correction continues to be utilized for the treatment of a variety of congenital and acquired conditions related to the humerus⁸⁴, forearm⁸⁵, and hand^{86,87}.

The functional range of elbow motion necessary for the performance of contemporary tasks such as using a cellular phone or a computer may be greater than previously reported⁸⁸. Surgical release of posttraumatic elbow contracture with⁸⁹ or without^{90,91} a hinged external fixator has been reported to be effective for improving elbow mobility. However, gains in health status and disability scores following open elbow contracture release may not correlate with improvement in function⁹⁰.

Lower Extremity Reconstruction

Ilizarov Hip Reconstruction

Pelvic support osteotomy combined with femoral lengthening and realignment (the Ilizarov hip reconstruction) is a comprehensive solution for the treatment of hip instability associated with limb shortening secondary to various etiologies. In the study by Gursu et al., a lower complication rate and a higher satisfaction rate were noted for patients who underwent such reconstruction for the treatment of the sequelae of hip infection as compared with those who underwent the procedure for the treatment of long-standing hip dislocation⁹².

Total Hip Arthroplasty

The assessment of limb length is pertinent both before and after total hip arthroplasty. Meermans et al. reported that, for the assessment of preoperative limb-length discrepancy in patients with osteoarthritis of the hip, the interteardrop line was a reliable pelvic reference and the center of the femoral head was a dependable femoral marker on an anteroposterior pelvic radiograph⁹³. Benedetti et al. reported that, for the evaluation of the effects of limb lengthening after a total hip arthroplasty, a limb-length discrepancy of <20 mm did not substantially affect hip kinetics⁹⁴.

Total Knee Arthroplasty

There are concerns regarding the outcome of total knee arthroplasty in patients who have undergone a previous high tibial osteotomy. Two recent intermediate-term studies suggested that a previous high tibial osteotomy did not influence the function or survival of a total knee replacement^{95,96}. Patients with skeletal dysplasia typically have anatomic variances and osseous deformities. While special considerations regarding implant selection and ligament balancing must be made during total knee arthroplasty, short-term results have revealed consistent improvements in terms of pain and function in such individuals⁹⁷. Patients with persistent hindfoot valgus deformity who undergo total knee arthroplasty are predisposed to postoperative lateral deviation of the mechanical axis that can negatively impact the longevity of the implant⁹⁸.

Periprosthetic fractures following total knee arthroplasty can be a challenging problem, especially in elderly patients with multiple medical comorbidities and osteopenia. An Ilizarov external fixator is a potential option for the treatment of such fractures around implants, allowing for the restoration of alignment, stable fixation with rapid mobilization, and osseous healing⁹⁹.

High Tibial Osteotomy

Despite advances in total knee arthroplasty, the use of high tibial osteotomy to address medial compartment osteoarthritis in active adults continues to generate interest. The biomechanical benefit of realignment via high tibial osteotomy for the treatment of medial compartment osteoarthritis was evaluated with use of a computational knee model in a study of thirty patients¹⁰⁰. The external knee adduction moment during stance phase, medial compartment load, and medial-to-lateral compartment load ratio were substantially improved postoperatively. Sterett et al. reported that, with a survival rate of 91% at seven years, microfracture combined with high tibial osteotomy could delay knee replacement in active patients with varus gonarthrosis¹⁰¹. Hui et al., in a study of 455 consecutive patients who underwent lateral closing-wedge high tibial osteotomy for the treatment of medial compartment osteoarthritis, reported that the probability of survival at five, ten, and fifteen years was 95%, 79%, and 56%, respectively¹⁰². An age of

WHAT'S NEW IN LIMB LENGTHENING AND DEFORMITY CORRECTION

less than fifty years, normal body mass index (BMI), and anterior cruciate ligament (ACL) deficiency were independent factors associated with improved long-term survival following high tibial osteotomy.

Various techniques are available for the performance of high tibial osteotomy. An opening-wedge technique with rigid fixation is gaining popularity^{103,104}. El Assal et al. reported an average time to union of 12.4 weeks following Page: 13 opening-wedge corrections of up to 14 mm that were performed with internal fixation and without bone graft¹⁰⁵. Good short-term results have also been reported following opening-wedge high tibial osteotomy with locked plates¹⁰⁶. In the study by Song et al., complications following opening-wedge high tibial osteotomy were similar to those following the closing-wedge technique, although obesity remained an independent predictive risk factor for postoperative complications¹⁰⁷.

The ideal candidate and timing for high tibial osteotomy remain controversial. In the study by Niemeyer et al., the severity of medial cartilage damage and partial-thickness defects of the lateral compartment as noted on preoperative arthroscopy did not appear to influence clinical outcome three years following high tibial osteotomy¹⁰⁸. Masrouha et al., in a study of active young adults (less than twenty-five years old) who had constitutional tibia vara, reported that opening-wedge correction resulted in satisfactory outcomes two years postoperatively¹⁰⁹. Kim et al. performed a clinical study to examine the role of high tibial osteotomy in patients with varus alignment without medial compartment knee arthrosis who were undergoing ACL reconstruction¹¹⁰. As the stability and functional scores after ACL reconstruction were not adversely affected by primary varus alignment, a concomitant high tibial osteotomy may not be necessary in the absence of medial compartment arthritis or varus thrust. In the cadaver study by Kendoff et al., incremental increases in valgus correction affected the length and strain on the posterolateral bundle of the ACL¹¹¹. Thus, the authors recommended that, if necessary, the high tibial osteotomy should be performed prior to ACL reconstruction.

Foot and Ankle

Deformity Analysis and Correction

Weight-bearing radiographs along with clinical evaluation are imperative when treating foot and ankle deformities. Naviculocuboid overlap, anteroposterior talonavicular coverage, and anteroposterior talus-first metatarsal angles measured on weight-bearing radiographs are reliable and valid indicators for assessing frontal plane hindfoot deformities¹¹². The hindfoot alignment view is often used for assessing the relationship of the long axis of the hindfoot and tibia. In the study by Frigg et al., the varus-valgus alignment noted on this radiograph in patients with an ankle or tibiotalar calcaneal fusion was correlated with pedographic load distribution¹¹³. A tibio-calcaneal angle of 5° to 10° valgus was associated with a physiologic gait pattern.

Circular external fixation allows gradual correction of complex foot and ankle deformities with minimally invasive methods. Deformities related to a variety of etiologies such as post-burn contractures¹¹⁴, chronic unreduced fracture-dislocation of the ankle¹¹⁵, neurologic disorders¹¹⁶, and others¹¹⁷ can be effectively treated with this strategy. However, one needs to be prepared for potential problems, including pin-track infections, hypoesthesia¹¹⁷, and recurrence of deformities¹¹⁶.

Charcot Arthropathy

This potentially limb-threatening condition is often seen in patients with diabetes and can be associated with peripheral sensory neuropathy, osteopenia, joint instability, and skin ulceration. A circular external fixator can be effectively used for deformity correction and arthrodesis in such patients^{118,119}.

Lengthening for Brachymetatarsia

Acute or gradual metatarsal lengthening can be performed to restore length and alignment in patients with brachymetatarsia. Various pitfalls associated with metatarsal lengthening along with preventive and management strategies have been outlined¹²⁰. In the study by Giannini et al., one-stage metatarsal lengthening with allograft interposition and intramedullary Kirschner wire fixation was used for twenty-nine patients (fifty metatarsals) with congenital brachymetatarsia and was associated with a mean gain of 13 mm and low morbidity¹²¹. Lee et al. noted similar outcomes following distraction osteogenesis for the treatment of first and fourth brachymetatarsia¹²². Despite eventual healing in all forty-eight patients (seventy-four metatarsals), stiffness of the metatarsophalangeal joint and malalignment of the lengthened metatarsal was noted in a few cases in each group.

Oncologic Reconstruction

Children with larger bone cysts may be predisposed to limb shortening as adults, possibly related to the effect on the adjacent growth plate¹²³. There are several options for addressing large bone defects following resection of malignant tumors¹²⁴⁻¹²⁶. Various biologic and prosthetic options such as allograft, extracorporeally radiated autograft, vascularized allograft with plate fixation, and custom diaphyseal implants have been utilized for joint-preserving reconstruction following diaphyseal resection of bone tumors¹²⁵. In the study by Hariri et al., one-stage reconstruction with vascularized fibular grafts was associated with superior functional results in comparison with the results of a two-stage approach following resection of metadiaphyseal tumors of the lower extremity¹²⁴. Distraction osteogenesis with hemicallotaxis¹²⁷ and medial transport of the ipsilateral fibula¹²⁸ are other innovative techniques for addressing tibial bone defects following tumor resection. Distal femoral growth arrest following a cemented proximal femoral endoprosthesis replacement in a child with Ewing sarcoma also has been reported¹²⁹.

WHAT'S NEW IN LIMB LENGTHENING AND DEFORMITY CORRECTION

Postoperative Complications and Their Treatment

In order to avoid injury to vital structures and to allow early detection of neurovascular compromise in patients undergoing external fixation, vigilance during the intraoperative and postoperative periods is warranted. Placement of a "retro-fibular wire" via a safe corridor in the distal part of the tibia can provide greater crossing angles and increased stability for fine-wire circular external fixation¹³⁰. Radial nerve injury following external fixation of the humerus¹³¹ and the use of ultrasound for localizing the site of nerve injury during humeral lengthening¹³² have been reported.

While the use of hydroxyapatite-coated half-pins has substantially decreased pin-track infections, pin-related problems associated with external fixation continue to be a source of concern. Further improvement in the design of osseous anchors, such as the use of iodine-supported titanium half-pins¹³³ and different pin-care regimens, continues to be investigated¹³⁴.

Soft-tissue problems are often encountered in patients being managed with distraction osteogenesis. While investigators continue to search for ways to prevent muscle fibrosis¹³⁵, innovative surgical techniques to address knee contractures with use of a combination of soft-tissue releases and hinged external fixation are being utilized¹³⁶. Ankle valgus deformity secondary to proximal migration of the fibula following tibial lengthening has been associated with poor regenerate formation and distal fibular nonunion¹³⁷.

Poor bone formation during limb lengthening and deformity correction can negatively impact clinical outcome. Besides autologous bone-grafting and innovative instrumentation, several biologic, chemical, and mechanical solutions are being investigated to enhance bone formation and to shorten the consolidation phase of distraction osteogenesis¹³⁸. Some of these potential ancillary methods include the use of autologous bone-marrow grafting combined with demineralized bone matrix⁷⁷, mesenchymal stem cells^{139,140}, bone morphogenetic proteins¹⁴¹, bisphosphonates¹⁴², thrombin peptide¹⁴³, erythropoietin¹⁴⁴, and low-intensity pulsed ultrasound stimulation¹⁴⁵.

New Tools and Techniques

Picture Archiving Systems/Preoperative Planning Software

With the transition in technology toward digital radiography and picture archiving and communication systems (PACS), surgical planning software programs are also gaining popularity. Digital measurements of lower limb length and alignment based on full-length radiographs of the lower extremity via PACS are similar to those obtained with use of conventional hard-copy radiographs¹⁴⁶. While the level of accuracy and reliability for making measurements from digital radiographs is quite high, there is still some variability¹⁴⁷.

Computer-aided preoperative planning for lower limb deformity correction based on computed tomographic (CT)

scan-derived data appears promising¹⁴⁸. Other software programs have been utilized for osteotomies of the proximal part of the femur and the pelvis¹⁴⁹, the distal part of the humerus¹⁵⁰, the olecranon¹⁵¹, and the distal part of the radius¹⁵².

Computer Navigation

Computer navigation is a potential means for improving surgical safety and accuracy. Manzotti et al. reported that while computer-assisted surgery was more effective for minimizing limb-length discrepancy during total hip arthroplasty, the surgical time was prolonged compared with the control group¹⁵³. In the study by Iorio et al., accurate correction of mechanical axis alignment and minimal unintentional change in the posterior slope following opening-wedge high tibial osteotomy was noted in association with computer navigation¹⁵⁴. Finally, the case report by Kang et al. illustrated the use of computer navigation during the surgical resection of a physal bar in a child with premature growth arrest of the distal part of the tibia¹⁵⁵. It remains to be determined if the increased cost and longer operative times are justified by the advantages of this new technology in orthopaedics.

Intramedullary Lengthening Devices

Interest in and experience with the use of internal lengthening nails have grown in the last decade. Although external fixation is avoided, other challenges associated with such devices have become apparent. Three studies examined difficulties associated with the only current Food and Drug Administration (FDA)-approved internal lengthening device. Burghardt et al. evaluated the mechanical failures of the Intramedullary Skeletal Kinetic Distractor (ISKD) (Orthofix, Verona, Italy) in a study of 180 patients (242 limb segments)¹⁵⁶. In all, fifteen ISKD devices failed in twelve patients; the failures included ten device fractures. Following unplanned interventions, the lengthening goal was finally achieved in all twelve patients. In another study, substantial difficulties were noted in forty-five (65%) of sixty-nine patients undergoing lengthening with use of the ISKD device¹⁵⁷. However, successful femoral lengthening was achieved in fifty-two (90%) of fifty-eight patients whereas tibial lengthening was achieved in only five (45%) of eleven patients. In a third study, insufficient bone regenerate developed in eight (23%) of thirty-five patients undergoing femoral lengthening with use of the ISKD device¹⁵⁸. Important risk factors for poor bone formation were a lengthening rate of >1.5 mm/day, an age of thirty years or more, smoking, and lengthening of >4 cm. Distraction problems associated with the ISKD device were related mostly to internal malfunction of the lengthening mechanism.

Intramedullary lengthening with use of a different device (FITBONE; WITTENSTEIN intens GmbH, Igersheim, Germany) was retrospectively analyzed by Krieg et al. in a study of thirty-two patients¹⁵⁹. Lengthening was successful in thirty (94%) of the thirty-two patients, with faster healing in the femur than in the tibia. Implant-related problems were noted in five instances. As the intramedullary lengthening devices become

WHAT'S NEW IN LIMB LENGTHENING AND DEFORMITY CORRECTION

more reliable in terms of their mechanical integrity and control of the distraction rate, their popularity may increase.

Hybrid Techniques

Hybrid techniques combine external and internal fixation, primarily to minimize time in external fixation. Fixator-assisted nailing is an effective method for addressing lower limb deformities secondary to metabolic bone disease⁴⁹. The accuracy of deformity correction and clinical outcome following distal femoral osteotomy with use of external fixation was comparable with fixator-assisted plating, although the operative time was longer with supplemental internal fixation¹⁶⁰.

In the study by Sun et al., lengthening over a nail was compared with classic lengthening of the tibia with use of external fixation alone¹⁶¹. Although faster healing with less axial deviation and callus subsidence was seen with lengthening over a nail, a higher prevalence of equinus contracture was noted. In the study by Chen et al., tibial lengthening over a small-diameter humeral nail was successfully performed in a group of patients with poliomyelitis¹⁶². When an intramedullary nail is already in place, lengthening over the nail can be performed without removal of the nail¹⁶³. In children, lengthening over small-diameter flexible nails can decrease the duration of external fixation¹⁸.

Upcoming Events

Specialty Day of the Limb Lengthening and Reconstruction Society (LLRS) will be held at the Annual Meeting of the American Academy of Orthopaedic Surgeons (AAOS) on February 11, 2012, in San Francisco, California. The Annual Scientific Meeting of the LLRS will be held on July 27 and 28, 2012, in Cincinnati, Ohio. A workshop on "Essentials in Deformity Correction" is planned for July 28, 2012, in Cincinnati, Ohio. Details are available at the LLRS web site: www.llrs.org.

Sanjeev Sabharwal, MD
Department of Orthopaedics and Pediatrics,
UMDNJ-New Jersey Medical School,
90 Bergen Street, Suite 1200, Newark, NJ 07103.
E-mail address: sabharsa@umdnj.edu

S. Robert Rozbruch, MD
Hospital for Special Surgery,
Weill Cornell Medical College,
535 East 70th Street, New York, NY 10021.
E-mail address: rozbruchsr@hss

References

- O'Brien S, Kernohan G, Fitzpatrick C, Hill J, Beverland D. Perception of imposed leg length inequality in normal subjects. *Hip Int.* 2010;20:505-11.
- Golightly YM, Allen KD, Helmick CG, Schwartz TA, Renner JB, Jordan JM. Hazard of incident and progressive knee and hip radiographic osteoarthritis and chronic joint symptoms in individuals with and without limb length inequality. *J Rheumatol.* 2010;37:2133-40.
- Brophy RH, Backus S, Kraszewski AP, Steele BC, Ma Y, Osei D, Williams RJ. Differences between sexes in lower extremity alignment and muscle activation during soccer kick. *J Bone Joint Surg Am.* 2010;92:2050-8.
- Tang Q, Zhou Y, Yang D, Xu H, Liu Q. The offset of the tibial shaft from the tibial plateau in Chinese people. *J Bone Joint Surg Am.* 2010;92:1981-7.
- Sheehy L, Felson D, Zhang Y, Niu J, Lam YM, Segal N, Lynch J, Cooke TD. Does measurement of the anatomic axis consistently predict hip-knee-ankle angle (HKA) for knee alignment studies in osteoarthritis? Analysis of long limb radiographs from the multicenter osteoarthritis (MOST) study. *Osteoarthritis Cartilage.* 2011;19:58-64.
- Hamdy RC, McCarthy JJ. Management of limb-length discrepancies. American Academy of Orthopaedic Surgeons. 2011; Monograph series (45).
- Sanders JO, Howell J, Qiu X. Comparison of the Paley method using chronological age with use of skeletal maturity for predicting mature limb length in children. *J Bone Joint Surg Am.* 2011;93:1051-6.
- Saran N, Rathjen KE. Guided growth for the correction of pediatric lower limb angular deformity. *J Am Acad Orthop Surg.* 2010;18:528-36.
- Eastwood DM, Sanghrajka AP. Guided growth: recent advances in a deep-rooted concept. *J Bone Joint Surg Br.* 2011;93:12-8.
- Jung HJ, Cho TJ, Choi IH, Chung CY, Yoo WJ, Park MS, Bae JY. Change in effective leg length after angular deformity correction by hemiepiphyseal stapling. *Clin Orthop Surg.* 2010;2:85-9.
- Shin SJ, Cho TJ, Park MS, Bae JY, Yoo WJ, Chung CY, Choi IH. Angular deformity correction by asymmetrical physeal suppression in growing children: stapling versus percutaneous transphyseal screw. *J Pediatr Orthop.* 2010;30:588-93.
- Burghardt RD, Specht SC, Herzenberg JE. Mechanical failures of eight-plate guided growth system for temporary hemiepiphyseal. *J Pediatr Orthop.* 2010;30:594-7.
- Rupprecht M, Spiro AS, Rueger JM, Stücker R. Temporary screw epiphyseodesis of the distal tibia: a therapeutic option for ankle valgus in patients with hereditary multiple exostosis. *J Pediatr Orthop.* 2011;31:89-94.
- Koff MF, Chong le R, Virtue P, Ying L, Gholve PA, Rodeo SA, Widmann RF, Potter HG. Correlation of magnetic resonance imaging and histologic examination of physeal bars in a rabbit model. *J Pediatr Orthop.* 2010;30:928-35.
- Loraas EK, Schmale GA. Endoscopically aided physeal bar takedown and guided growth for the treatment of angular limb deformity. *J Pediatr Orthop B.* 2011 Apr 27. [Epub ahead of print].
- Fraser SC, Neubauer PR, Ain MC. The role of arthrography in selecting an osteotomy for the correction of genu varum in pediatric patients with achondroplasia. *J Pediatr Orthop B.* 2011;20:14-6.
- Iobst C. Limb lengthening combined with deformity correction in children with the Taylor Spatial Frame. *J Pediatr Orthop B.* 2010;19:529-34.
- Popkov D, Popkov A, Haumont T, Journeau P, Lascombes P. Flexible intramedullary nail use in limb lengthening. *J Pediatr Orthop.* 2010;30:910-8.
- Popkov D, Journeau P, Popkov A, Haumont T, Lascombes P. Ollier's disease limb lengthening: should intramedullary nailing be combined with circular external fixation? *Orthop Traumatol Surg Res.* 2010;96:348-53.
- Riad J, Finnbogason T, Broström E. Leg length discrepancy in spastic hemiplegic cerebral palsy: a magnetic resonance imaging study. *J Pediatr Orthop.* 2010;30:846-50.
- Yang SS, Dahan-Oliel N, Montpetit K, Hamdy RC. Ambulation gains after knee surgery in children with arthrogryposis. *J Pediatr Orthop.* 2010;30:863-9.
- Spiro AS, Babin K, Lipovac S, Rupprecht M, Meenen NM, Rueger JM, Stuecker R. Anterior femoral epiphyseodesis for the treatment of fixed knee flexion deformity in spina bifida patients. *J Pediatr Orthop.* 2010;30:858-62.
- Kelley SP, Bache CE, Graham HK, Donnan LT. Limb reconstruction using circular frames in children and adolescents with spina bifida. *J Bone Joint Surg Br.* 2010;92:1017-22.
- Gaurav K, Vilas J. A new approach to the management of fixed flexion deformity of the knee using Ilizarov's principle of distraction histogenesis: a preliminary communication. *Int J Low Extrem Wounds.* 2010;9:70-3.
- Montgomery CO, Young KL, Austen M, Jo CH, Blasler RD, Ilyas M. Increased risk of Blount disease in obese children and adolescents with vitamin D deficiency. *J Pediatr Orthop.* 2010;30:879-82.
- Amer AR, Khanfour AA. Evaluation of treatment of late-onset tibia vara using gradual angulation translation high tibial osteotomy. *Acta Orthop Belg.* 2010;76:360-6.

WHAT'S NEW IN LIMB LENGTHENING AND DEFORMITY CORRECTION

27. Birch JG, Lincoln TL, Mack PW, Birch CM. Congenital fibular deficiency: a review of thirty years' experience at one institution and a proposed classification system based on clinical deformity. *J Bone Joint Surg Am.* 2011;93:1144-51.
28. Rodriguez-Ramirez A, Thacker MM, Becerra LC, Riddle EC, Mackenzie WG. Limb length discrepancy and congenital limb anomalies in fibular hemimelia. *J Pediatr Orthop B.* 2010;19:436-40.
29. Catagni MA, Radwan M, Loviseti L, Guerreschi F, Elmoghazy NA. Limb lengthening and deformity correction by the Ilizarov technique in type III fibular hemimelia: an alternative to amputation. *Clin Orthop Relat Res.* 2011;469:1175-80.
30. Ulgur O, Sener G. Functional outcome after prosthetic rehabilitation of children with acquired and congenital lower limb loss. *J Pediatr Orthop B.* 2011;20:178-83.
31. Johari AN, Dhawale AA, Salaskar A, Aroojis AJ. Congenital postero-medial bowing of the tibia and fibula: is early surgery worthwhile? *J Pediatr Orthop B.* 2010;19:479-86.
32. Tripathy SK, Saini R, Sudes P, Dhillon MS, Gill SS, Sen RK, Agarwal A, Dhatt S, Mootha AK. Application of the Ponseti principle for deformity correction in neglected and relapsed clubfoot using the Ilizarov fixator. *J Pediatr Orthop B.* 2011;20:26-32.
33. Ahmed AA. The use of the Ilizarov method in management of relapsed club foot. *Orthopedics.* 2010;33:881.
34. Eidelman M, Katzman A. Treatment of arthrogryptic foot deformities with the Taylor Spatial Frame. *J Pediatr Orthop.* 2011;31:429-34.
35. Monsell FP, Barnes JR, Kirubanandan R, McBride AM. Distal tibial physeal arrest after meningococcal septicaemia: management and outcome in seven ankles. *J Bone Joint Surg Br.* 2011;93:839-43.
36. Eidelman M, Katzman A, Zaidman M, Keren Y. Deformity correction using supramalleolar gigli saw osteotomy and Taylor spatial frame: how to perform this osteotomy safely? *J Pediatr Orthop B.* 2011;20:318-22.
37. Kang SH, Rhee SK, Song SW, Chung JW, Kim YC, Suh KH. Ankle deformity secondary to acquired fibular segmental defect in children. *Clin Orthop Surg.* 2010;2:179-85.
38. MacWilliams BA, McMullin ML, Baird GO, Stevens PM. Distal tibial rotation osteotomies normalize frontal plane knee moments. *J Bone Joint Surg Am.* 2010;92:2835-42.
39. Tan JS, Roach JW, Wang AA. Transfer of ipsilateral fibula on vascular pedicle for treatment of congenital pseudarthrosis of the tibia. *J Pediatr Orthop.* 2011;31:72-8.
40. Erni D, De Kerviler S, Hertel R, Slongo T. Vascularised fibula grafts for early tibia reconstruction in infants with congenital pseudarthrosis. *J Plast Reconstr Aesthet Surg.* 2010;63:1699-704.
41. Takazawa A, Matsuda S, Fujioka F, Uchiyama S, Kato H. Split tibia vascularized fibular graft for congenital pseudarthrosis of the tibia: a preliminary report of 2 cases. *J Pediatr Orthop.* 2011;31:e20-4.
42. Trigui M, de Billy B, Metaizeau JP, Clavert JM. Treatment of congenital pseudarthrosis of the fibula by periosteal flap. *J Pediatr Orthop B.* 2010;19:473-8.
43. Shah H, Doddabasappa SN, Joseph B. Congenital pseudarthrosis of the tibia treated with intramedullary rodding and cortical bone grafting: a follow-up study at skeletal maturity. *J Pediatr Orthop.* 2011;31:79-88.
44. Gouron R, Deroussen F, Juvet M, Ursu C, Plancq MC, Collet LM. Early resection of congenital pseudarthrosis of the tibia and successful reconstruction using the Masquelet technique. *J Bone Joint Surg Br.* 2011;93:552-4.
45. Spiro AS, Babin K, Lipovac S, Stenger P, Mladenov K, Rupprecht M, Rueger JM, Stuecker R. Combined treatment of congenital pseudarthrosis of the tibia, including recombinant human bone morphogenetic protein-2: a case series. *J Bone Joint Surg Br.* 2011;93:695-9.
46. Birke O, Schindeler A, Ramachandran M, Cowell CT, Munns CF, Bellemore M, Little DG. Preliminary experience with the combined use of recombinant bone morphogenetic protein and bisphosphonates in the treatment of congenital pseudarthrosis of the tibia. *J Childr Orthop.* 2010;4:507-17.
47. Cho TJ, Kim JB, Lee JW, Lee K, Park MS, Yoo WJ, Chung CY, Choi IH. Fracture in long bones stabilised by telescopic intramedullary rods in patients with osteogenesis imperfecta. *J Bone Joint Surg Br.* 2011;93:634-8.
48. Birke O, Davies N, Latimer M, Little DG, Bellemore M. Experience with the Fassier-Duval telescopic rod: first 24 consecutive cases with a minimum of 1-year follow-up. *J Pediatr Orthop.* 2011;31:458-64.
49. Kocaoğlu M, Bilen FE, Sen C, Eralp L, Balci HI. Combined technique for the correction of lower-limb deformities resulting from metabolic bone disease. *J Bone Joint Surg Br.* 2011;93:52-6.
50. Eberl R, Singer G, Ferlic P, Weinberg AM, Hoellwarth ME. Post-traumatic coxa vara in children following screw fixation of the femoral neck. *Acta Orthop.* 2010;81:442-5.
51. Sagan ML, Datta JC, Olney BW, Lansford TJ, McIff TE. Residual deformity after treatment of pediatric femur fractures with flexible titanium nails. *J Pediatr Orthop.* 2010;30:638-43.
52. Ballal MS, Verma R, Nayagam S. Segmental fracture of the femur with concomitant genu valgum: a one-stage solution. *J Pediatr Orthop B.* 2010;19:431-5.
53. Blondel B, Launay F, Glard Y, Jacopin S, Jouve JL, Bollini G. Hexapodal external fixation in the management of children tibial fractures. *J Pediatr Orthop B.* 2010;19:487-91.
54. Ceroni D, Campos J, Dahl-Farhoumand A, Holveck J, Kaelin A. Neck osteotomy for malunion of neglected radial neck fractures in children: a report of 2 cases. *J Pediatr Orthop.* 2010;30:649-54.
55. Shank CF, Wiater BP, Pace JL, Jinguji TM, Schmale GA, Bittner RC, Bompadre V, Stults JK, Kregel WF 3rd. The lateral capitellohumeral angle in normal children: mean, variation, and reliability in comparison to Baumann's angle. *J Pediatr Orthop.* 2011;31:266-71.
56. Moon MS, Kim SS, Kim ST, Lee SR, Lee BJ, Jin JM, Moon JL. Lateral closing wedge osteotomy with or without medialisation of the distal fragment for cubitus varus. *J Orthop Surg (Hong Kong).* 2010;18:220-3.
57. Davids JR, Lamoreaux DC, Brooker RC, Tanner SL, Westberry DE. Translation step-cut osteotomy for the treatment of posttraumatic cubitus varus. *J Pediatr Orthop.* 2011;31:353-65.
58. Takagi T, Takayama S, Nakamura T, Horiuchi Y, Toyama Y, Ikegami H. Supracondylar osteotomy of the humerus to correct cubitus varus: do both internal rotation and extension deformities need to be corrected? *J Bone Joint Surg Am.* 2010;92:1619-26.
59. Loviseti G, Sala F, Thabet AM, Catagni MA, Singh S. Osteocutaneous thermal necrosis of the leg salvaged by TSF/Ilizarov reconstruction. Report of 7 patients. *Int Orthop.* 2011;35:121-6.
60. Sala F, Capitani D, Castelli F, La Maida GA, Loviseti G, Singh S. Alternative fixation method for open femoral fractures from a damage control orthopaedics perspective. *Injury.* 2010;41:161-8.
61. Sala F, Albisetti W, Capitani D. Versatility of Taylor Spatial Frame in Gustilo-Anderson III C femoral fractures: report of three cases. *Musculoskelet Surg.* 2010;94:103-8.
62. Sala F, Talamonti T, Agus MA, Capitani D. Sequential reconstruction of complex femoral fractures with circular hybrid Sheffield frame in polytrauma patients. *Musculoskelet Surg.* 2010;94:127-36.
63. Wang C, Li Y, Huang L, Wang M. Comparison of two-staged ORIF and limited internal fixation with external fixator for closed tibial plafond fractures. *Arch Orthop Trauma Surg.* 2010;130:1289-97.
64. Kapoor SK, Kataria H, Patra SR, Boruah T. Capsuloligamentotaxis and definitive fixation by an ankle-spanning Ilizarov fixator in high-energy pilon fractures. *J Bone Joint Surg Br.* 2010;92:1100-6.
65. Patzkowski JC, Blanck RV, Owens JG, Wilken JM, Blair JA, Hsu JR. Can an ankle-foot orthosis change hearts and minds? *J Surg Orthop Adv.* 2011;20:8-18.
66. Mercer D, Firoozbakhsh K, Prevost M, Mulkey P, DeCoster TA, Schenck R. Stiffness of knee-spanning external fixation systems for traumatic knee dislocations: a biomechanical study. *J Orthop Trauma.* 2010;24:693-6.
67. Levy BA, Krych AJ, Shah JP, Morgan JA, Stuart MJ. Staged protocol for initial management of the dislocated knee. *Knee Surg Sports Traumatol Arthrosc.* 2010;18:1630-7.
68. Hove LM, Krukhaug Y, Revheim K, Helland P, Finsen V. Dynamic compared with static external fixation of unstable fractures of the distal part of the radius: a prospective, randomized multicenter study. *J Bone Joint Surg Am.* 2010;92:1687-96.
69. Wilcke MK, Abbaszadegan H, Adolphson PY. Wrist function recovers more rapidly after volar locked plating than after external fixation but the outcomes are similar after 1 year. *Acta Orthop.* 2011;82:76-81.
70. Burg A, Berenstein M, Engel J, Luria T, Salai M, Dudkiewicz I, Velkes S. Fractures of the distal humerus in elderly patients treated with a ring fixator. *Int Orthop.* 2011;35:101-6.
71. Blonna D, Castoldi F, Scelsi M, Rossi R, Falcone G, Assom M. The hybrid technique: potential reduction in complications related to pins mobilization in the treatment of proximal humeral fractures. *J Shoulder Elbow Surg.* 2010;19:1218-29.
72. Chaddha M, Gulati D, Singh AP, Singh AP, Maini L. Management of massive posttraumatic bone defects in the lower limb with the Ilizarov technique. *Acta Orthop Belg.* 2010;76:811-20.
73. Parmaksizoglu F, Koprulu AS, Unal MB, Cansu E. Early or delayed limb lengthening after acute shortening in the treatment of traumatic below-knee amputations and Gustilo and Anderson type IIIC open tibial fractures: the results of a case series. *J Bone Joint Surg Br.* 2010;92:1563-7.
74. Lavini F, Dall'Oca C, Bartolozzi P. Bone transport and compression-distraction in the treatment of bone loss of the lower limbs. *Injury.* 2010;41:1191-5.
75. Boopalan PR, Jepegnanam TS. Reverse sural flap cover within a ring fixator. *Acta Orthop Belg.* 2010;76:684-8.
76. Bibbo C, Karnik SS, Albright JT. Ilizarov wound closure method for traumatic soft tissue defects. *Foot Ankle Int.* 2010;31:628-33.
77. Hatzokos I, Stavridis SI, Iosifidou E, Karataglis D, Christodoulou A. Autologous bone marrow grafting combined with demineralized bone matrix improves

WHAT'S NEW IN LIMB LENGTHENING AND DEFORMITY CORRECTION

consolidation of docking site after distraction osteogenesis. *J Bone Joint Surg Am.* 2011;93:671-8.

- 78.** Robinson PM, Papanna M, Younis F, Khan SA. Arthroscopic debridement of docking site in Ilizarov bone transport. *Ann R Coll Surg Engl.* 2010;92:437-8.
- 79.** Buijze GA, Richardson S, Jupiter JB. Successful reconstruction for complex malunions and nonunions of the tibia and femur. *J Bone Joint Surg Am.* 2011;93:485-92.
- 80.** Russell GV, Graves ML, Archdeacon MT, Barei DP, Brien GA Jr, Porter SE. The clamshell osteotomy: a new technique to correct complex diaphyseal malunions: surgical technique. *J Bone Joint Surg Am.* 2010;92 Suppl 1 Pt 2:158-75.
- 81.** Crisco JJ, Heard WM, Rich RR, Paller DJ, Wolfe SW. The mechanical axes of the wrist are oriented obliquely to the anatomical axes. *J Bone Joint Surg Am.* 2011;93:169-77.
- 82.** Verhaegen F, Degreef I, de Smet L. Corrective osteotomy of the distal radius: dorsal or volar approach, closing or opening wedge. *Acta Orthop Belg.* 2010;76:604-7.
- 83.** Kampa R, Al-Beer A, Axelrod T. Madelung's deformity: radial opening wedge osteotomy and modified Darrach procedure using the ulnar head as trapezoidal bone graft. *J Hand Surg Eur Vol.* 2010;35:708-14.
- 84.** McLawhorn AS, Sherman SL, Blyakher A, Widmann RF. Humeral lengthening and deformity correction with the multiaxial correction system. *J Pediatr Orthop B.* 2011;20:111-6.
- 85.** Vogt B, Tretow HL, Daniilidis K, Wacker S, Buller TC, Henrichs MP, Roedel RW, Schiedel F. Reconstruction of forearm deformity by distraction osteogenesis in children with relative shortening of the ulna due to multiple cartilaginous exostosis. *J Pediatr Orthop.* 2011;31:393-401.
- 86.** Seitz WH Jr, Shimko P, Patterson RW. Long-term results of callus distraction-lengthening in the hand and upper extremity for traumatic and congenital skeletal deficiencies. *J Bone Joint Surg Am.* 2010;92 Suppl 2:47-58.
- 87.** Kawakatsu M, Ishikawa K, Terai T, Saito S. Distraction arthrolysis using an external fixator and flexor tenolysis for proximal interphalangeal joint extension contracture after severe crush injury. *J Hand Surg Am.* 2010;35:1457-62.
- 88.** Sardelli M, Tashjian RZ, MacWilliams BA. Functional elbow range of motion for contemporary tasks. *J Bone Joint Surg Am.* 2011;93:471-7.
- 89.** Liu S, Fan CY, Ruan HJ, Li FF, Tian J. Combination of arthrolysis by lateral and medial approaches and hinged external fixation in the treatment of stiff elbow. *J Trauma.* 2011;70:373-6.
- 90.** Lindenhovius AL, Doornberg JN, Ring D, Jupiter JB. Health status after open elbow contracture release. *J Bone Joint Surg Am.* 2010;92:2187-95.
- 91.** Park MJ, Chang MJ, Lee YB, Kang HJ. Surgical release for posttraumatic loss of elbow flexion. *J Bone Joint Surg Am.* 2010;92:2692-9.
- 92.** Gursu S, Demir B, Yildirim T, Oke R, Bursali A, Sahin V. The influence of aetiology of hip instability on the results of pelvic support osteotomy. *Hip Int.* 2010;20:518-23.
- 93.** Meermans G, Malik A, Witt J, Haddad F. Preoperative radiographic assessment of limb-length discrepancy in total hip arthroplasty. *Clin Orthop Relat Res.* 2011;469:1677-82.
- 94.** Benedetti MG, Catani F, Benedetti E, Berti L, Di Gioia A, Giannini S. To what extent does leg length discrepancy impair motor activity in patients after total hip arthroplasty? *Int Orthop.* 2010;34:1115-21.
- 95.** Efe T, Heise TJ, Boese C, Timmesfeld N, Fuchs-Winkelmann S, Schmitt J, Theisen C, Schofer MD. TKA following high tibial osteotomy versus primary TKA—a matched pair analysis. *BMC Musculoskelet Disord.* 2010;11:207.
- 96.** Meding JB, Wing JT, Ritter MA. Does high tibial osteotomy affect the success or survival of a total knee replacement? *Clin Orthop Relat Res.* 2011;469:1991-4.
- 97.** Kim RH, Scuderi GR, Dennis DA, Nakano SW. Technical challenges of total knee arthroplasty in skeletal dysplasia. *Clin Orthop Relat Res.* 2011;469:69-75.
- 98.** Mullaji A, Shetty GM. Persistent hindfoot valgus causes lateral deviation of weightbearing axis after total knee arthroplasty. *Clin Orthop Relat Res.* 2011;469:1154-60.
- 99.** Beris AE, Lykissas MG, Sioros V, Mavrodontidis AN, Korompilias AV. Femoral periprosthetic fracture in osteoporotic bone after a total knee replacement: treatment with Ilizarov external fixation. *J Arthroplasty.* 2010;25:1168.e9-12.
- 100.** Bhatnagar T, Jenkyn TR. Internal kinetic changes in the knee due to high tibial osteotomy are well-correlated with change in external adduction moment: an osteoarthritic knee model. *J Biomech.* 2010;43:2261-6.
- 101.** Sterett WJ, Steadman JR, Huang MJ, Matheny LM, Briggs KK. Chondral resurfacing and high tibial osteotomy in the varus knee: survivorship analysis. *Am J Sports Med.* 2010;38:1420-4.
- 102.** Hui C, Salmon LJ, Kok A, Williams HA, Hockers N, van der Tempel WM, Chana R, Pinczewski LA. Long-term survival of high tibial osteotomy for medial compartment osteoarthritis of the knee. *Am J Sports Med.* 2011;39:64-70.
- 103.** Hankemeier S, Mommsen P, Krettek C, Jagodzinski M, Brand J, Meyer C, Meller R. Accuracy of high tibial osteotomy: comparison between open- and closed-wedge technique. *Knee Surg Sports Traumatol Arthrosc.* 2010;18:1328-33.

- 104.** Poignard A, Flouzat Lachaniette CH, Amzallag J, Hernigou P. Revisiting high tibial osteotomy: fifty years of experience with the opening-wedge technique. *J Bone Joint Surg Am.* 2010;92 Suppl 2:187-95.
- 105.** El-Assal MA, Khalifa YE, Abdel-Hamid MM, Said HG, Bakr HM. Opening-wedge high tibial osteotomy without bone graft. *Knee Surg Sports Traumatol Arthrosc.* 2010;18:961-6.
- 106.** Kolb W, Guhlmann H, Windisch C, Koller H, Grütner P, Kolb K. Opening-wedge high tibial osteotomy with a locked low-profile plate: surgical technique. *J Bone Joint Surg Am.* 2010;92 Suppl 1 Pt 2:197-207.
- 107.** Song EK, Seon JK, Park SJ, Jeong MS. The complications of high tibial osteotomy: closing- versus opening-wedge methods. *J Bone Joint Surg Br.* 2010;92:1245-52.
- 108.** Niemeyer P, Schmal H, Hauschild O, von Heyden J, Südkamp NP, Köstler W. Open-wedge osteotomy using an internal plate fixator in patients with medial-compartment gonarthrosis and varus malalignment: 3-year results with regard to preoperative arthroscopic and radiographic findings. *Arthroscopy.* 2010;26:1607-16.
- 109.** Masrouha KZ, Sraji S, Lakkis S, Sagheh S. High tibial osteotomy in young adults with constitutional tibia vara. *Knee Surg Sports Traumatol Arthrosc.* 2011;19:89-93.
- 110.** Kim SJ, Moon HK, Chun YM, Chang WH, Kim SG. Is correctional osteotomy crucial in primary varus knees undergoing anterior cruciate ligament reconstruction? *Clin Orthop Relat Res.* 2011;469:1421-6.
- 111.** Kendoff D, Koulalis D, Citak M, Voos J, Pearle AD. Open wedge valgus tibial osteotomies: affecting the distinct ACL bundles. *Knee Surg Sports Traumatol Arthrosc.* 2010;18:1501-7.
- 112.** Lee KM, Chung CY, Park MS, Lee SH, Cho JH, Choi IH. Reliability and validity of radiographic measurements in hindfoot varus and valgus. *J Bone Joint Surg Am.* 2010;92:2319-27.
- 113.** Frigg A, Nigg B, Davis E, Pederson B, Valderrabano V. Does alignment in the hindfoot radiograph influence dynamic foot-floor pressures in ankle and tibiotalar calcaneal fusion? *Clin Orthop Relat Res.* 2010;468:3362-70.
- 114.** Sagheh S, El Bitar Y, Berjawi G, Harfouche B, Atiyeh B. Distraction histogenesis in ankle burn deformities. *J Burn Care Res.* 2011;32:160-5.
- 115.** Tellisi N, Deland JT, Rozbruch SR. Gradual reduction of chronic fracture dislocation of the ankle using Ilizarov/Taylor Spatial Frame. *HSSJ.* 2011;7:85-8.
- 116.** Lee DY, Choi IH, Yoo WJ, Lee SJ, Cho TJ. Application of the Ilizarov technique to the correction of neurologic equinovarus foot deformity. *Clin Orthop Relat Res.* 2011;469:860-7.
- 117.** Floerkeemeier T, Stukenborg-Colsman C, Windhagen H, Waizy H. Correction of severe foot deformities using the Taylor spatial frame. *Foot Ankle Int.* 2011;32:176-82.
- 118.** Yousry AH, Abdalrhady AM. Management of diabetic neuropathic ankle arthropathy by arthrodesis using an Ilizarov frame. *Acta Orthop Belg.* 2010;76:821-6.
- 119.** Lamm BM, Gottlieb HD, Paley D. A two-stage percutaneous approach to Charcot diabetic foot reconstruction. *J Foot Ankle Surg.* 2010;49:517-22.
- 120.** Lamm BM, Gourdi-Shaw MC. Problems, obstacles, and complications of metatarsal lengthening for the treatment of brachymetatarsia. *Clin Podiatr Med Surg.* 2010;27:561-82.
- 121.** Giannini S, Faldini C, Pagkrati S, Miscione MT, Luciani D. One-stage metatarsal lengthening by allograft interposition: a novel approach for congenital brachymetatarsia. *Clin Orthop Relat Res.* 2010;468:1933-42.
- 122.** Lee KB, Park HW, Chung JY, Moon ES, Jung ST, Seon JK. Comparison of the outcomes of distraction osteogenesis for first and fourth brachymetatarsia. *J Bone Joint Surg Am.* 2010;92:2709-18.
- 123.** Glowacki M, Ignys-O'Byrne A, Ignys I, Wroblewska K. Limb shortening in the course of solitary bone cyst treatment—a comparative study. *Skelet Radiol.* 2011;40:173-9.
- 124.** Hariri A, Mascard E, Atlan F, Germain MA, Heming N, Dubouset JF, Wicart P. Free vascularized fibular graft for reconstruction of defects of the lower limb after resection of tumour. *J Bone Joint Surg Br.* 2010;92:1574-9.
- 125.** Agarwal M, Puri A, Gulia A, Reddy K. Joint-sparing or physal-sparing diaphyseal resections: the challenge of holding small fragments. *Clin Orthop Relat Res.* 2010;468:2924-32.
- 126.** Webber NP, Seidel M. Combining advanced technologies: the compress-repiphysis prosthesis for pediatric limb salvage. *Orthopedics.* 2010;33:823.
- 127.** Kosuge DD, Pugh H, Ramachandran M, Barry M, Timms A. Marginal excision and Ilizarov hemicallosis for osteofibrous dysplasia of the tibia: a case report. *J Pediatr Orthop B.* 2011;20:89-93.
- 128.** Saridis AG, Megas PD, Georgiou CS, Diamantakis GM, Tyllianakis ME. Dual-fibular reconstruction of a massive tibial defect after Ewing's sarcoma resection in a pediatric patient with a vascular variation. *J Pediatr Orthop.* 2011;31:297-302.
- 129.** Gaston CL, Tillman RM, Grimer RJ. Distal femoral physal growth arrest secondary to a cemented proximal femoral endoprosthesis replacement. *J Bone Joint Surg Br.* 2011;93:708-10.

WHAT'S NEW IN LIMB LENGTHENING AND DEFORMITY CORRECTION

- 130.** Loughenbury PR, Harwood PJ, Tunstall R, Britten S. The 'Retro-Fibular Wire': an anatomical study describing a safe corridor for placement of fine wires in the distal tibia. *J Bone Joint Surg Br.* 2010;92:1041-4.
- 131.** Baumann G, Nagy L, Jost B. Radial nerve disruption following application of a hinged elbow external fixator: a report of three cases. *J Bone Joint Surg Br.* 2011;93:e51.
- 132.** Rozbruch SR, Fryman C, Bigman D, Adler R. Use of ultrasound in detection and treatment of nerve compromise in a case of humeral lengthening. *HSS Journal: the musculoskeletal journal of Hospital for Special Surgery.* 2011;7:80-4.
- 133.** Shirai T, Shimizu T, Ohtani K, Zen Y, Takaya M, Tsuchiya H. Antibacterial iodine-supported titanium implants. *Acta Biomater.* 2011;7:1928-33.
- 134.** Ogbemudia AO, Bafor A, Edomwonyi E, Enemudo R. Prevalence of pin tract infection: the role of combined silver sulphadiazine and chlorhexidine dressing. *Niger J Clin Pract.* 2010;13:268-71.
- 135.** Koplín SA, Su L, Salamat S, Torrealba J, McCarthy J, Mitchell J, Olabisi R, Noonan KJ. Distraction osteogenesis-induced muscle fibrosis may not be associated with TGF- β 1. *J Pediatr Orthop.* 2011;31:413-20.
- 136.** Lee DH, Kim TH, Jung SJ, Cha EJ, Bin SI. Modified Judet quadricepsplasty and Ilizarov frame application for stiff knee after femur fractures. *J Orthop Trauma.* 2010;24:709-15.
- 137.** Park HW, Kim HW, Kwak YH, Roh JY, Lee JJ, Lee KS. Ankle valgus deformity secondary to proximal migration of the fibula in tibial lengthening with use of the Ilizarov external fixator. *J Bone Joint Surg Am.* 2011;93:294-302.
- 138.** Sabharwal S. Enhancement of bone formation during distraction osteogenesis: pediatric applications. *J Am Acad Orthop Surg.* 2011;19:101-11.
- 139.** Oshima S, Ishikawa M, Mochizuki Y, Kobayashi T, Yasunaga Y, Ochi M. Enhancement of bone formation in an experimental bony defect using ferumoxide-labelled mesenchymal stromal cells and a magnetic targeting system. *J Bone Joint Surg Br.* 2010;92:1606-13.
- 140.** Cox G, McGonagle D, Boxall SA, Buckley CT, Jones E, Giannoudis PV. The use of the reamer-irrigator-aspirator to harvest mesenchymal stem cells. *J Bone Joint Surg Br.* 2011;93:517-24.
- 141.** Eguchi Y, Wakitani S, Naka Y, Nakamura H, Takaoka K. An injectable composite material containing bone morphogenetic protein-2 shortens the period of distraction osteogenesis in vivo. *J Orthop Res.* 2011;29:452-6.
- 142.** Heidari P, Abbaspour A, Baghdadi T, Espandar R, Farzan M, Amanpour S, Rasouli MR, Mohagheghi MA, Amir HR, Yasui N. Effect of risedronate on bone resorption during consolidation phase of distraction osteogenesis: a rabbit model. *J Orthop Surg (Hong Kong).* 2010;18:228-34.
- 143.** Cakarar S, Olgac V, Aksakalli N, Tang A, Keskin C. Acceleration of consolidation period by thrombin peptide 508 in tibial distraction osteogenesis in rats. *Br J Oral Maxillofac Surg.* 2010;48:633-6.
- 144.** Garcia P, Speidel V, Scheuer C, Laschke MW, Holstein JH, Histing T, Pohlemann T, Menger MD. Low dose erythropoietin stimulates bone healing in mice. *J Orthop Res.* 2011;29:165-72.
- 145.** Tobita K, Ohnishi I, Matsumoto T, Ohashi S, Bessho M, Kaneko M, Matsuyama J, Nakamura K. Effect of low-intensity pulsed ultrasound stimulation on callus remodelling in a gap-healing model: evaluation by bone morphometry using three-dimensional quantitative micro-CT. *J Bone Joint Surg Br.* 2011;93:525-30.
- 146.** Khakharia S, Bigman D, Fragomen AT, Pavlov H, Rozbruch SR. Comparison of PACS and hard-copy 51-inch radiographs for measuring leg length and deformity. *Clin Orthop Relat Res.* 2011;469:244-50.
- 147.** Fowler JR, Ilyas AM. The accuracy of digital radiography in orthopaedic applications. *Clin Orthop Relat Res.* 2011;469:1781-4.
- 148.** Subburaj K, Ravi B, Agarwal M. Computer-aided methods for assessing lower limb deformities in orthopaedic surgery planning. *Comput Med Imaging Graph.* 2010;34:277-88.
- 149.** Kim HT, Baek SD, Jang JH, Lee JS. Preoperative plan for corrective osteotomy of the hip: a method using picture-editing software. *J Pediatr Orthop.* 2011;31:95-101.
- 150.** Zhang YZ, Lu S, Chen B, Zhao JM, Liu R, Pei GX. Application of computer-aided design osteotomy template for treatment of cubitus varus deformity in teenagers: a pilot study. *J Shoulder Elbow Surg.* 2011;20:51-6.
- 151.** Garg R, Hammoud S, Lipman J, Wolfe SW. Preoperative computer-assisted design templating of complex articular olecranon osteotomy: case report. *J Hand Surg Am.* 2010;35:1990-4.e1.
- 152.** Miyake J, Murase T, Moritomo H, Sugamoto K, Yoshikawa H. Distal radius osteotomy with volar locking plates based on computer simulation. *Clin Orthop Relat Res.* 2011;469:1766-73.
- 153.** Manzotti A, Cerveri P, De Momi E, Pullen C, Confalonieri N. Does computer-assisted surgery benefit leg length restoration in total hip replacement? Navigation versus conventional freehand. *Int Orthop.* 2011;35:19-24.
- 154.** Iorio R, Vadalà A, Giannetti S, Pagnottelli M, Di Sette P, Conteduca F, Ferretti A. Computer-assisted high tibial osteotomy: preliminary results. *Orthopedics.* 2010;33(10 Suppl):82-6.
- 155.** Kang HG, Yoon SJ, Kim JR. Resection of a physeal bar under computer-assisted guidance. *J Bone Joint Surg Br.* 2010;92:1452-5.
- 156.** Burghardt RD, Herzenberg JE, Specht SC, Paley D. Mechanical failure of the Intramedullary Skeletal Kinetic Distractor in limb lengthening. *J Bone Joint Surg Br.* 2011;93:639-43.
- 157.** Schiedel FM, Pip S, Wacker S, Pöpping J, Tretow H, Leidinger B, Rödl R. Intramedullary limb lengthening with the Intramedullary Skeletal Kinetic Distractor in the lower limb. *J Bone Joint Surg Br.* 2011;93:788-92.
- 158.** Kenaway M, Krettek C, Liodakis E, Meller R, Hankemeier S. Insufficient bone regenerate after intramedullary femoral lengthening: risk factors and classification system. *Clin Orthop Relat Res.* 2011;469:264-73.
- 159.** Krieg AH, Lenze U, Speth BM, Hasler CC. Intramedullary leg lengthening with a motorized nail. *Acta Orthop.* 2011;82:344-50.
- 160.** Seah KT, Shafi R, Fragomen AT, Rozbruch SR. Distal femoral osteotomy: is internal fixation better than external? *Clin Orthop Relat Res.* 2011;469:2003-11.
- 161.** Sun XT, Easwar TR, Manesh S, Ryu JH, Song SH, Kim SJ, Song HR. Complications and outcome of tibial lengthening using the Ilizarov method with or without a supplementary intramedullary nail: a case-matched comparative study. *J Bone Joint Surg Br.* 2011;93:782-7.
- 162.** Chen D, Chen J, Liu F, Jiang Y. Tibial lengthening using a humeral intramedullary nail combined with a single-plane external fixator for leg discrepancy in sequelae of poliomyelitis. *J Pediatr Orthop B.* 2011;20:84-8.
- 163.** Kim HJ, Fragomen AT, Reinhardt K, Hutson JJ Jr, Rozbruch SR. Lengthening of the femur over an existing intramedullary nail. 2011 Jun 4 [Epub ahead of print].