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Review Article

New Developments in Limb Lengthening and Deformity Correction

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Limb Assessment

Beatty et al. compared methods for bone age determination in six locations and concluded that a combined and modified approach using different tools could simplify skeletal maturity assessment. Sinkler et al. developed a method for assessing skeletal maturity from lateral radiographs of the elbow, confirming that four parameters on lateral elbow radiographs were as efficient as a combination of parameters from anteroposterior and lateral views. Furdock et al. compared the modified Fels knee skeletal maturity system with chronological age, finding better predictive accuracy.[1-3]

Min et al. created an algorithm to reconstruct 3D images of the tibia and fibula from 2D images, which was used in a mobile app. Ahrend et al. found that external rotation increased the perception of varus deformities while reducing valgus deformities, while internal rotation increased valgus and decreased varus deformities. These changes increased with sagittal plane angulation of the knee. Habada et al. confirmed a positive correlation between leg-length discrepancy and Cobb angle in scoliosis patients.[4]

Limb Deficiencies and Bone Defects

Solomin et al. proposed an alphanumeric Universal Long Bone Defect Classification (ULBDC) system for diagnosing and treating bone defects based on defect size and location. Gamieldien et al. managed large segmental defects of the femur and tibia using 3D-printed titanium truss cages, intramedullary nails, and autogenous bone graft. A retrospective review of the outcome in 9 patients showed all patients achieved functional union in 3 months. Rohilla et al. concluded that bone transport for infected tibial nonunions with defects of <6 cm produced more reliable functional outcomes compared to similar cases treated with the Masquelet technique. Ren et al. concluded that treating infected bone defects of the lower limb using the Masquelet technique was associated with lower hospitalization costs, a shorter time to union, and full weight-bearing. Khaled et al. reported a 94% success rate and a 90% satisfaction rate regarding the functional outcome.[5,6]

Further studies focused on tibial bone defects, with Hiyama et al. combining radiographic apparent bone gap and nonunion risk determination scores to identify patients at high risk for developing a tibial delayed union.[7-10] Yushan et al. described a surgical technique for bone transport using tetrafocal and pentafocal osteotomies of the tibia using the Ilizarov technique. Huang et al. modified their technique of acute shortening

and double-level lengthening to reduce bone-lengthening time, time in the frame, external fixation index, and postoperative complications for patients with large tibial defects.[11-14]

Hoellwarth et al. found no significant differences in mobility, quality-of-life measures, or complication rates between patients who underwent amputation without irradiation and those who underwent limb radiation therapy [15- 17].

Congenital Pseudarthrosis of the Tibia

Wu et al. developed a technique using a telescopic growing rod, locking compression plate, and a combination of cross-union of the tibia and fibula, autologous iliac crest bone graft, and bone morphogenetic protein-2 (BMP-2) to treat refractory congenital pseudarthrosis of the tibia. They reported a 100% union rate and no refracture in their 18 patients treated with this procedure. Cai et al. excised the abnormal tissue and filled the defect with autologous iliac crest bone and allogenic graft. The final step was the rotation of a gastrocnemius flap to ensure adequate blood supply. Union occurred in 10 months in 8 of 9 patients. Nahm et al. suggested that osteotomies may be performed for lengthening and deformity correction in patients with congenital pseudarthrosis of the tibia. Hu et al. assessed the efficacy of three different implants in managing postoperative valgus deformity in patients with congenital pseudarthrosis of the tibia. [18-22]

Achondroplasia

A retrospective review of 28 patients with achondroplasia who underwent bilateral humeral lengthening using a linear external fixator found that 89% of the group achieved the target of 8 cm of lengthening, resulting in significant improvements in functional outcome scores and independence. However, a 50% incidence of major complications such as unplanned reoperations, radial nerve palsy, and residual limb-length discrepancy was reported. Balci et al. found that simultaneous bilateral femoral and tibial lengthening resulted in greater disturbance of physeal growth.[23-25] Boero et al. analyzed functional and quality-of-life scores during Ilizarov external fixator lengthening of the tibia, finding that despite a significant difference in migration magnitude, functional and quality-of-life scores were not related to fixation of the proximal tibiofibular joint.[26-30]

Lower-Extremity Deformity

Wongcharoenwatana et al. compared the accuracy of metaphyseal-diaphyseal angle and medial metaphyseal beak angle in distinguishing early Blount disease from physiologic bowing in a retrospective review of 158 limbs in 79 children. Belaıd et al. performed biomechanical tests using finite element analysis to determine the relationship between mala lignment of the lower limb and stress variation in the proximal femur. Their study confirmed that stress loading in the proximal femur was greatest with varus malalignment of the lower limb.[31-35]

Kariksiz and Karakoyun described their technique for acute correction of distal femoral deformities using a single Schanz screw each in the proximal and distal fragments. Iobst and Bafor described a modified reverse planning method for correcting distal femoral valgus deformity without the use of intraoperatively placed Schanz screws. [36]

Gigi et al. showed that the use of 3D-printed cutting guides and plates reduced intraoperative blood loss and surgery duration in patients who underwent osteotomy for complex, oblique plane, lower-limb deformity. Hamid et al. reported improved 3D gait analysis and Pediatric Outcomes Data Collection Instrument (PODCI) scores following surgical correction of femoral torsion in patients with internal and external femoral torsional deformities.[37- 40]

Sohn et al. found that preoperative knee joint line obliquity and joint line congruence angle are risk factors for an excessive medial proximal tibial angle in patients undergoing medial opening-wedge, high tibial osteotomy. A retrospective review of 858 consecutive osteotomies revealed a 3.7% complication rate, mostly minor wound infections, more common in gradual correction and posttraumatic cases. Osteoclasis also increased the risk of vascular injury compared to osteotomy with an oscillating saw.[41]

Foot and Ankle Deformity

Elbaum et al. studied 93 patients using a functional or French method based on the Saint Vincent de Paul protocol. The protocol involved daily foot manipulation by physical therapists and orthotics for splinting. A posteromedial release was needed in 15% of cases due to insufficient correction or deformity recurrence. The

protocol had a higher cost. In ambulatory patients with cerebral palsy and equinus contractures, gait analysis showed favorable short-term outcomes after Achilles tendon lengthening.[42-45]

Limb Lengthening

Geffner et al. found that an antegrade trochanteric-entry femoral lengthening nail is a safe and efficient treatment option for skeletally immature patients with limb-length discrepancy correction.[46] Chowdhury et al. found no significant differences in external fixation index between distal and proximal tibial osteotomies for tibia lengthening in children. A trochanteric entry point had a significantly increased tendency to reduce the neck-shaft angle compared to a piriformis entry point. [47] Frommer et al. found that antegrade femoral intramedullary lengthening using a magnetically driven nail remains an accurate and reliable procedure. [48] Radler et al. observed low complication rates following intramedullary lengthening of the femur and tibia in 34 adult patients with posttraumatic limb-length discrepancy. Two further studies compared complication rates and quality-of-life measures between groups of children treated with intramedullary lengthening nails and external fixator lengthening. A multicenter study reviewed 314 lower-limb segments treated with internal lengthening nails and found a 53% complication rate and a higher risk of complications in the tibia compared with the femur and for >30-year-old age groups.[49]

Maai et al. compared the mechanical properties of intramedullary lengthening nails, finding larger-diameter cobalt-chromium and steel implants have greater resistance to bending forces than titanium nails.[50] Chavan et al. concluded that limb segment lengthening in amputees is beneficial due to improved prosthetic fitting and use, despite potential complications like segment overlengthening[51].

Guided Growth

Franzone et al. studied the role of guided growth surgery in correcting angular deformities in 18 patients with osteogenesis imperfecta. Harmer et al. described a technique for anterior distal femoral hemiepiphysiodesis using percutaneous cannulated screws to correct knee flexion contractures in patients with cerebral palsy. They highlighted the speed and accuracy of screw placement facilitated by simultaneous bi-planar fluoroscopy. Wingstrand et al. used radiostereometric analysis to determine the time taken to achieve physeal growth arrest in children treated for limb-length discrepancy or extremely tall stature using percutaneous physiodesis. [52]

They concluded that physeal growth arrest occurs within 12 weeks after the surgical procedure, affected by the growth rate at the time of the surgical procedure and in the immediate postoperative period. Hassanein et al. performed biomechanical studies using Sawbones models to determine the ideal location for the placement of 8 plates over the distal femoral physis to correct knee flexion deformities. Abood et al. simulated growth by axial distraction of a cadaveric femoral physeal model and utilized CT and electronic goniometer measurements to determine the amount of rotation during distraction. Erdal et al. retrospectively evaluated the effect of tension band plating on coronal plane alignment in 26 children with non-pathologic limb-length discrepancy. Weinmayer et al. retrospectively assessed 140 knees in 88 patients for secondary angular deformity following percutaneous epiphysiodesis for limb-length discrepancy. Jain et al. retrospectively reviewed radiographic images of patients with evidence of screw migration after tension band plating to determine predisposing factors for migration. Gerges et al. reported a 36% rebound rate and a 16% incidence of tethering and undesired continuation of growth modulation in a cohort of patients who converted a guided-growth implant for angular deformity correction around the knee.[53]

Basic Science

Wong et al. found that human mesenchymal stem exosomes improved the repair of damaged growth plates in female Sprague-Dawley rats, but did not prevent the formation of a bone bridge. Kalay et al. found that treatment with BMP-2 increased load-to-failure and bending moment values during distraction osteogenesis in a lapine model, but found no significant differences in endochondral, periosteal, or intramembranous ossification or significant changes in vascular endothelial growth factor (VEGF) scores.[54]

Pin-Site Infection

Pin-site infections remain a significant issue in limb reconstruction surgery, and the Pin Site Consensus Group established a consensus on clinical questions regarding pin site complications using a modified Delphi approach. Nine questions related to factors affecting pin-site viability were defined, and systematic reviews were conducted to reach a consensus statement for each question. However, most reviews found few studies specific to the nine critical aspects identified by the process, suggesting that further studies are needed.[55]

Researchers have found an increased risk of pin-site infection in patients with diabetes, elevated hemoglobin A1C levels, and congestive heart failure. A meta-analysis found limited evidence for the influence of material and coating on the incidence of pin-site infections. Laubscher et al. identified a lack of comparative studies in the literature and concluded that further studies are necessary to determine the effect of frame and fixation factors on the incidence of pin-site infection. Ban et al. found inconclusive results in a review of studies focused on the relationship between wire application technique and pin-site infection. Ferguson et al. explored the impact of cleaning solutions and techniques on the incidence of pin-site infections but found no consensus on methodology, study population, intervention, and outcomes. Iliadis et al. concluded that there is a lack of consensus on the definition and grading of pin-site infections.

Tillmann et al. reported that primary closure of temporary external fixator pin sites did not result in higher infection rates compared to secondary wound healing, and pin sites healed significantly faster after primary closure.[56]

Practical Tips and Pearls

A limb-lengthening reconstruction checklist was developed to document findings and reduce errors during postoperative follow-up visits for patients undergoing limb lengthening and reconstruction surgery. It emphasizes the importance of attaching the extractor to the nail before removing interlocking screws or pegs, obtaining adequate visualization to rule out bone growth, clearing the tip of the nail with a large-diameter reamer, and using a bump underneath the knee for easier access to the nail. Mona´rrez et al. suggested dividing the Ponseti cast for clubfoot management on one side to reduce cast-saw injuries during cast removal. A prospective randomized study found that routine use of tourniquets during high tibial osteotomies did not reduce surgery duration, intraoperative complications, or postoperative blood loss. However, knee function recovered earlier and morphine requirements were reduced postoperatively when a tourniquet was not used.[57]

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