

Composite Bone and Soft Tissue Loss Treated With Distraction Histiogenesis

CPT Michael J. Beltran, MD,¹ CPT Leah M. Ochoa, MD,² MAJ Richard M. Graves, MD,² MAJ(P) Joseph R. Hsu, MD,³ and the Skeletal Trauma Research Consortium

The purpose of this article is to describe the use of shortening and angulation to manage composite bone and soft tissue loss associated with combat-related type IIIB open tibia fractures. Four patients underwent placement of a software-driven circular fixator with acute shortening and angulation to manage composite bone and soft tissue loss. Frames were applied using the Rings First Method, and an induced deformity was created with the soft tissue defect within the concavity. Distraction histiogenesis was utilized to restore limb length and regenerate soft tissues. Three patients had healed fractures and mature regenerate allowing frame removal, while one remained in his frame for further consolidation. Mechanical alignment and limb length were restored in all patients. No major frame adjustments were required and all distracted soft tissues healed without complication. The article concludes that composite bone and soft tissue loss is effectively managed with distraction histiogenesis and the use of a software-driven circular fixator. (Journal of Surgical Orthopaedic Advances 19(1):23–28, 2010)

Key words: distraction histiogenesis, Ilizarov, shortening and angulation, Taylor spatial frame

Devastating extremity trauma remains a hallmark of the current military conflicts in Afghanistan and Iraq. Extremity injuries represent a large proportion of combat-related injuries and recently have been shown to utilize more resources and lead to greater rates of disability (1, 2). Tibia fractures represent a common injury seen in combat, often the result of blast injuries leading to multiple projectile penetrating trauma, and less commonly they are secondary to high-velocity gunshot wounds or blunt mechanisms; the high-energy nature of these injuries

means that many of these fractures are open and may be associated with loss of either bone or soft tissue (1).

The presence of segmental bone loss represents a major hurdle in the management of acute tibia fractures, with high complication rates and the frequent need for multiple surgical interventions (3–8). The goals of limb salvage surgery in this setting are to restore length and alignment, regenerate bone loss, obtain fracture union, and provide a stable, functional extremity. There are multiple modalities available from which to achieve these goals, including primary shortening, cancellous autografting, vascularized free fibula transfer, and distraction osteogenesis. Distraction osteogenesis may be performed using the monofocal bone transport technique originally described and taught by G.A. Ilizarov, or with more advanced techniques, including shortening with or without angulation, bifocal or trifocal transport, transport over an intramedullary nail, or hemifibular transport (9–12).

Associated soft tissue defects may be managed with either a rotational flap or free tissue transfer. In specific circumstances soft tissue transport in conjunction with bone transport may be pursued, or shortening with or without angulation with secondary tissue lengthening (distraction histiogenesis) may be necessary to close a defect (11, 13). The use of free flaps may be limited in the setting of a single vessel limb because of the risk of microvascular steal syndrome and resultant limb compromise (14, 15). The decision to use a particular technique is complex and dependent on multiple factors, including fracture location and size of the bone defect, presence and location of associated soft tissue defects, and other extremity injuries. Furthermore, surgeon availability

From ¹United States Army Medical Corps, Department of Orthopaedics and Rehabilitation, Brooke Army Medical Center, Fort Sam Houston, TX; ²United States Army Medical Corps, Orthopaedic Surgery Service, Department of Surgery, William Beaumont Army Medical Center, El Paso, TX; ³United States Army Medical Corps, United States Army Institute of Surgical Research, Fort Sam Houston, TX. Address correspondence to: CPT Michael J. Beltran, MD, United States Army Medical Corps, Department of Orthopaedics and Rehabilitation, Brooke Army Medical Center, 3851 Roger Brooke Drive, Fort Sam Houston, TX 78234; e-mail: Michael.beltran@amedd.army.mil.

Investigation performed at Brooke Army Medical Center, Fort Sam Houston, Texas, and William Beaumont Army Medical Center, Fort Bliss, Texas.

The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Army, Department of the Air Force, Department of the Navy, Department of Defense, or the United States Government. The authors of this research have no financial interests to disclose and have no proprietary interest in any device or equipment mentioned in the article.

Received for publication September 10, 2009; accepted for publication October 5, 2009.

For information on prices and availability of reprints call 410-494-4994 X226.

1548-825X/10/1901-0023\$22.00/0

Copyright © 2010 by the Southern Orthopaedic Association

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 01 MAR 2010		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Composite bone and soft tissue loss treated with distraction histiogenesis				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Beltran M. J., Ochoa L. M., Graves R. M., Hsu J. R.,				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) United States Army Institute of Surgical Research, JBSA Fort Sam Houston, TX				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON
a REPORT unclassified	b ABSTRACT unclassified	c THIS PAGE unclassified			

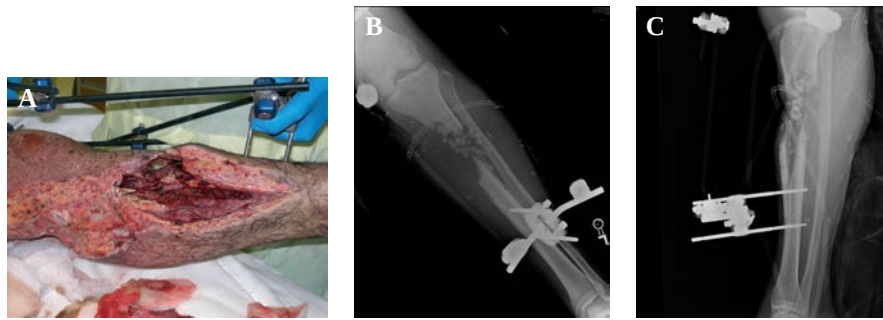


FIGURE 1 A 22-year-old soldier with severe bone and soft tissue loss from multiple projectile penetrating trauma from an improvised explosive device. The bone loss measured 7 cm. Severe injury to the medial head of the gastrocnemius was present, precluding safe use of a rotational flap to obtain soft tissue coverage.

plays a major role in determining the optimal treatment modality, with free tissue transfer dependent on the presence of a qualified flap surgeon.

We present a series of four US military service members with combat-related type IIIB open tibia fractures treated at two military medical centers by the senior author (JRH) with composite bone and soft tissue loss reconstructed utilizing distraction histiogenesis with principles of acute shortening and angulation. All patients consented to the use of their medical records in conducting this research.

Objective

The objective of this study was to demonstrate that composite bone and soft tissue loss associated with combat-related type IIIB open tibia fractures can be effectively managed with Ilizarov techniques of shortening and angulation, and that the use of software-driven circular external fixation (Taylor Spatial Frame, TSF, Smith and Nephew, Memphis, TN) can simplify the process, avoiding the need for major frame adjustments and making correction of residual deformity easier.

Methods

Between May 2005 and March 2009, the senior author (JRH) treated four patients with distraction histiogenesis and principles of acute shortening and angulation to manage large composite bone and soft tissue defects. All four patients were active duty service members (three US Army and one US Marine). Each patient was a poor candidate for flap coverage because of various reasons. One poly-traumatized patient with burns was adamantly opposed to the use of a free flap from an uninjured part of his body. Another had a single patent posterior tibial artery, precluding free tissue transfer. The other two patients were smokers with severe local muscle injury, which eliminated safe use of either a soleus or gastrocnemius flap for rotational coverage (Fig. 1). All

patients were male with an average age of 24 years (range, 22–26). Three involved segmental loss of the tibial diaphysis and one loss of the proximal tibia. All fractures were Gustilo and Anderson type IIIB injuries. Two of the four patients were tobacco users as mentioned previously.

Prior to definitive shortening and angulation, aggressive and thorough debridement was performed until only healthy, viable tissue remained within the wound bed. A Taylor Spatial Frame was then mounted using the Rings First Method. In this technique the rings are mounted orthogonal to the proximal and distal bone fragments first prior to shortening or angulation being performed. Using this method, no individualized preoperative planning or intraoperative frame construction is necessary. Once the rings and struts were mounted using wires and half-pins, an “induced deformity” was created by shortening and angulating the limb, with the soft tissue defect focused within the concavity of the deformity (Fig. 2). The limbs were shortened and angulated as much as necessary to obtain bone and soft tissue coverage; in one patient this distance was 8 cm.

Intraoperative Doppler testing was utilized to assess for changes in vascular status before and after shortening and angulating the limbs. In two patients the skin edges came into approximation and primary closure was possible. The third patient, once shortened and angulated, had redundant local muscle available for coverage and only split-thickness skin grafting was necessary. The final patient, whose anteromedial soft tissue defect would have required a large latissimus dorsi free tissue transfer for coverage (>17 cm in length), refused a free flap procedure and chose instead to undergo local rotational coverage. By shortening and angulating the limb, the resultant smaller wound was easily managed with a soleus flap and skin grafting. After a variable latency period of 2 to 4 weeks to allow soft tissue healing, routine anteroposterior and lateral radiographs were templated in order to perform a gradual correction of the induced deformity. We utilized the Taylor Spatial Frame software, version 3.0.1 (Smith and Nephew, Memphis, TN) and performed

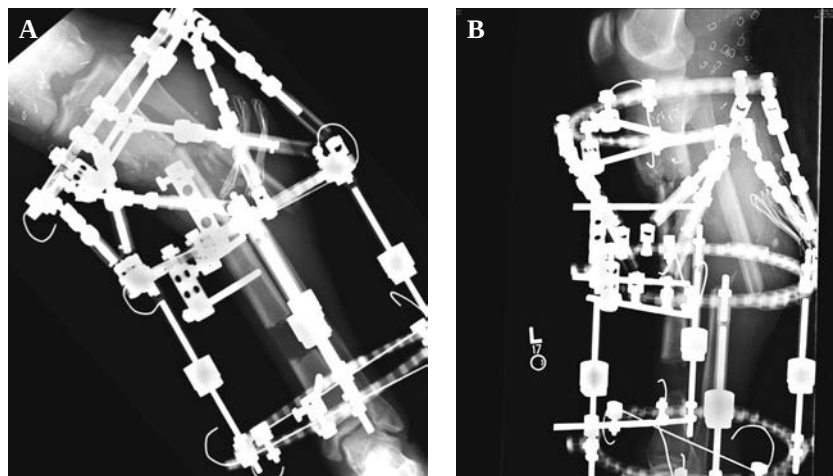


FIGURE 2 Anteroposterior and lateral radiographs after placement of Taylor Spatial Frame with acute shortening and angulation to obtain soft tissue coverage. A distal corticotomy with proximal bone transport was performed to restore limb length.

a total residual program. The skin edges of the wound were defined as the “structure at risk,” and distraction was done at the rate of 1 mm per day until length and alignment were restored. Total residual programs were run at regular office visits until length and alignment were restored compared to the contralateral uninjured limb on standing bilateral hip-to-ankle radiographs.

In three patients corticotomy with distraction osteogenesis was required to restore limb length. In two limbs the corticotomy was distal and in one limb it was proximal. Bone grafting of the docking site or fracture was performed on a case-by-case basis at the discretion of the senior author. All three patients who underwent bone transport utilized low-intensity pulsed ultrasound to encourage regenerate maturation (Exogen, Smith and Nephew, Memphis, TN). None of the patients used nonsteroidal anti-inflammatory drugs as part of their postoperative pain pathway.

Results

At an average follow-up of 16.9 months (range, 4–33), 4/4 (100%) patients had a healed soft tissue envelope (Figs. 3 and 4). No cases of ulceration, breakdown, or wound separation occurred in this series of patients with correction of the induced deformity and resultant lengthening of the soft tissue. The three patients who had their frames removed had healed docking sites, and the fourth whose frame remained in place had a healing fracture without evidence of delayed union. In 2/4 (50%) of the patients, staged bone grafting of the docking site was performed directly through the distracted soft tissue bed without resultant complications. The average bone loss in this series measured 7 cm (range, 5–8 cm). In the four patients, there were no major frame adjustments necessary

during their treatment course. Only routine strut changes were necessary, and these were performed during scheduled office visits.

The average frame time for the patients who completed therapy was 12.1 months (range, 8.8–17.0). The three patients who required bone transport had an average distraction gap of 7.67 cm (range, 7–8 cm). The estimated frame index for these three patients was 1.74 (range, 1.01–2.13). The average radiographic consolidation index, as defined by Paley and Maar (8), was 1.72 (range, 1.09–2.13). The patient whose frame time extended to 17 months was a tobacco user with persistent delay in regenerate consolidation.

Complications were defined as minor or major. Major complications required a return to the operating room. One patient had no complications, while the other three patients had a total of seven complications (five minor and two major). Four of the five minor complications were

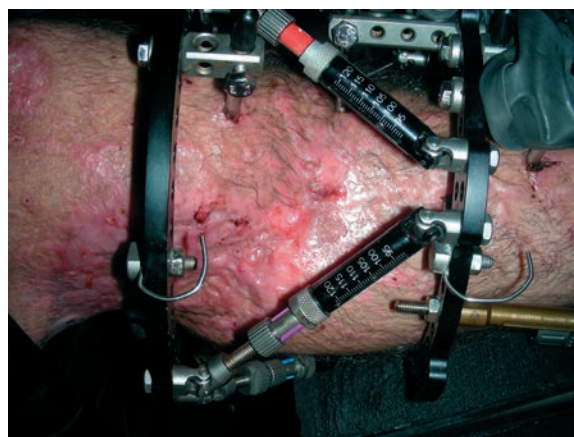


FIGURE 3 Healed soft tissue envelope at 3 months postoperatively.

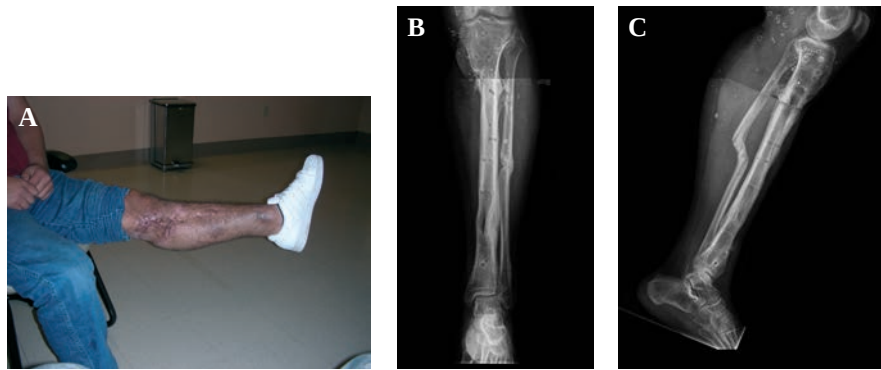


FIGURE 4 Mature soft tissue envelope at 1-year follow-up, with restoration of limb length and mechanical axis.

pin-tract infections and one was a painful pin requiring removal. The first major complication included premature fibular consolidation leading to syndesmosis subluxation during tibia distraction. This required repeat fibular osteotomy and syndesmosis fixation. The second major complication was a scarred tibialis anterior tendon within the lengthened soft tissue requiring local release. Each of the major complications was successfully managed with a single additional operative procedure.

Final limb length and alignment were determined using serial bilateral standing hip-to-ankle radiographs. All four patients had the mechanical axis and limb length restored as determined on these radiographs. The three service members whose frames have been removed have returned to athletic activities, including some running. The fourth soldier, despite being in his frame, walks without the use of assistive devices, and can easily stand on his one injured leg. One patient has returned to active duty.

Discussion

Reconstruction of bone and soft tissue defects associated with high-energy open tibia fractures remains a challenging task under the best of circumstances. Flap complications and/or failure rates have exceeded 20% in some studies (16–18). Although rotational and free tissue transfer techniques account for the majority of the soft tissue reconstructions performed for high-energy traumatic wounds (19–23), there is growing attention being paid to the use of the Ilizarov method of external fixation, with use of temporary shortening with or without angulation to reconstruct soft tissue. This soft tissue can subsequently be lengthened under the tension-stress effect with expected lengthening of skin, muscles, nerves, and even blood vessels (24–29). Additionally, secondary bone grafting procedures at the fracture or docking site can safely be performed through this relengthened soft tissue (30). Multiple authors have demonstrated good results with shortening and angulation, with the principle goal

of avoiding the need for rotational or free tissue transfer (13, 31).

Although three or four centimeters have arbitrarily been assigned as the maximal amount of acute shortening that may be safely employed (12), we have found that greater amounts of acute shortening can be safe. We routinely use intraoperative Doppler signaling to assess distal arterial flow before, during, and after acute shortening or angulation. Any change in the normal triphasic signal indicates possible vascular kinking, and shortening is relaxed until flow is restored and a normal Doppler signal is obtained. We successfully shortened all patients in our series acutely, even with defects of 8 cm, and had no change in Doppler signal concerning for vascular compromise. The importance of being able to shorten large defects acutely to obtain primary soft tissue closure is critical when one considers that most wound infections are nosocomial in nature and delays in closure are associated with increased rates of wound infection (32–37).

In contrast to previously described techniques of concomitant bone and soft tissue defect management with the Ilizarov apparatus, the Taylor Spatial Frame is unique in that it requires minimal preoperative frame planning or major postoperative frame adjustments. Despite the creation of complex and often dramatic appearing induced deformities, gradual correction is possible and further simplified with the use of the Total Residual Program software. Through the “virtual hinge” created by the Spatial Frame software, continuous fine tuning of the reduction can occur without frame revisions. The software allows this fine tuning at any step in the process. Furthermore, the Web-based Spatial Frame software simplifies the surgeon’s ability to consistently provide 1 mm of soft tissue lengthening daily at the critical skin edge by defining it as the “structure at risk.”

Complications when using ringed fixators are common, and our series of patients is no different. Two of the four patients (50%) in our series had major complications requiring an additional operation, which is similar to other reports using Ilizarov techniques (3, 8, 10). Many of

the complications that we report in our series (5/7) are considered problems or obstacles by some authors rather than true complications (38). The frame times experienced in our series of patients and the time to consolidation are consistent with previous reports of larger series of patients from multiple authors (3, 7, 8, 10).

Conclusion

Acute shortening and angulation with use of software-driven circular external fixation is an effective treatment modality when managing composite bone and soft tissue loss. It allows for simple frame application, correction of residual deformity, and avoidance of major frame adjustments. Regeneration of lost bone and soft tissue can obviate the need for massive bone grafting and free tissue transfer.

References

- Owens, B. D., Kragh, J. F., Wenke, J. C., et al. Combat wounds in operation Iraqi Freedom and operation Enduring Freedom. *J. Trauma* 64:295–299, 2008.
- Masini, B. D., Waterman, S. M., Wenke, J. C., et al. Resource utilization and disability outcome assessment of combat casualties from Operation Iraqi Freedom and Operating Enduring Freedom. *J. Orthop. Trauma* 23:261–266, 2009.
- Prokuski, L., Marsh, J. L. Segmental bone deficiency after acute trauma: the role of bone transport. *Orthop. Clin. North Am.* 25:753–763, 1994.
- Watson, J. T., Anders, M., Moed, B. R. Management strategies for bone loss in tibial shaft fractures. *Clin. Orthop. Relat. Res.* 315:138–152, 1995.
- Cierny, G., Zorn, K. L. Segmental tibial defects, comparing conventional and Ilizarov methodologies. *Clin. Orthop. Relat. Res.* 301:118–133, 1994.
- Cattaneo, R., Catagni, M., Johnson, E. E. The treatment of infected nonunions and segmental defects of the tibia by the methods of Ilizarov. *Clin. Orthop. Relat. Res.* 280:143–152, 1992.
- Mahuluxmivala, J., Nadarajah, R., Allen, P. W., et al. Ilizarov external fixator: acute shortening and lengthening versus bone transport in the management of tibial non-unions. *Injury* 36:662–668, 2005.
- Paley, D., Maar, D. C. Ilizarov bone transport treatment for tibial defects. *J. Orthop. Trauma* 14:76–85, 2000.
- Raschke, M. J., Mann, J. W., Oedekoven, G., et al. Segmental transport after unreamed intramedullary nailing: preliminary report of a “monorail” system. *Clin. Orthop. Relat. Res.* 282:233–240, 1992.
- Sen, C., Kocaoglu, M., Eralp, L., et al. Bifocal compression-distraction in the acute treatment of grade III open tibia fractures with bone and soft-tissue loss: a report of 24 cases. *J. Orthop. Trauma* 18:150–157, 2004.
- Rozbruch, S. R., Weitzman, B. A., Watson, J. T., et al. Simultaneous treatment of tibial bone and soft-tissue defects with the Ilizarov Method. *J. Orthop. Trauma* 20:197–205, 2006.
- Watson, J. T. Distraction osteogenesis. *J. Am. Acad. Orthop. Surg.* 14:S168–S174, 2006.
- Nho, S. J., Helfet, D. L., Rozbruch, S. R. Temporary intentional leg shortening and deformation to facilitate wound closure using the Ilizarov/Taylor Spatial Frame. *J. Orthop. Trauma* 20:419–424, 2006.
- Tosenovsky, P., Zalesak, B., Janousek, L., et al. Microvascular steal syndrome in the pedal bypass and free muscle transfer? *Eur. J. Vasc. Endovasc. Surg.* 26:562–564, 2003.
- Sonntag, B. V., Murphy, R. X., Chernofsky, M. A., et al. Microvascular steal phenomenon in lower extremity reconstruction. *Ann. Plast. Surg.* 34:336–339, 1995.
- Gonzalez, M. H., Tarandy, D. I., Troy, D., et al. Free tissue coverage of chronic traumatic wounds of the lower leg. *Plast. Reconstr. Surg.* 109:592–600, 2002.
- Pollak, A. N., McCarthy, M. L., Burgess, A. R. Short-term wound complications after application of flaps for coverage of traumatic soft-tissue defects about the tibia. The Lower Extremity Assessment Project (LEAP) Study Group. *J. Bone Joint Surg.* 82-A:1681–1691, 2000.
- Redett, R. J., Robertson, B. C., Chang, B., et al. Limb salvage of lower-extremity wounds using free gracilis muscle reconstruction. *Plast. Reconstr. Surg.* 106:1507–1513, 2000.
- Duman, H., Sengezer, M., Celikoz, B., et al. Lower extremity salvage using a free flap associated with the Ilizarov method in patients with massive combat injuries. *Ann. Plast. Surg.* 46:108–112, 2001.
- Agarwal, S., Agarwal, R., Jain, U. K., et al. Management of soft-tissue problems in leg trauma in conjunction with application of the Ilizarov fixator assembly. *Plast. Reconstr. Surg.* 107:1732–1738, 2001.
- Feibel, R. J., Oliva, A., Buncke, G. M., et al. Soft-tissue reconstruction in orthopedic surgery. Secondary procedure. *Orthop. Clin. North Am.* 24:537–548, 1993.
- Levin, L. S. New developments in flap techniques. *J. Am. Acad. Orthop. Surg.* 14:S90–93, 2006.
- Nanchahal, J., Pearse, M. F. Management of soft-tissue problems in leg trauma in conjunction with application of the Ilizarov fixator assembly. *Plast. Reconstr. Surg.* 111:1359–1360, 2003.
- Ilizarov, G. A. The tension-stress effect on the genesis and growth of tissues. Part I: The influence of stability of fixation and soft-tissue preservation. *Clin. Orthop. Relat. Res.* 238:249–281, 1989.
- Ilizarov, G. A. The tension-stress effect on the genesis and growth of tissues. Part II: The influence of the rate and frequency of distraction. *Clin. Orthop. Relat. Res.* 239:263–285, 1989.
- Kocialkowski, A., Marsh, D. R., Shackley, D. C. Closure of the skin defect overlying infected non-union by skin traction. *Br. J. Plast. Surg.* 51:307–310, 1998.
- Lenoble, E., Lewertowski, J. M., Goutallier, D. Reconstruction of compound tibial and soft tissue loss using a traction histogenesis technique. *J. Trauma* 39:356–360, 1995.
- Lerner, A., Ullman, Y., Stein, H., et al. Using the Ilizarov external fixation device for skin expansion. *Ann. Plast. Surg.* 45:535–537, 2000.
- Low, C. K., Looi, K. P. Ilizarov’s technique used to expand skin from a groin flap. *J. Hand Surg.* 24B:361–362, 1999.
- Hsu, J. R., Ochoa, L. M., Graves, R. M. Taylor spatial frame for soft tissue defects: technique of angulation with shortening. Presented at the Limb Lengthening and Reconstruction Society Annual Meeting 2006, William Beaumont Army Medical Center, Texas Tech University Health Sciences Center, San Diego, CA.
- Hsu, J. R., Beltran, M. J. Shortening and angulation for soft-tissue reconstruction of extremity wounds in a combat support hospital. *Mil. Med.* 174:838–842, 2009.
- Templeman, D. C., Gulli, B., Tsukayama, D. T., et al. Update on the management of open fractures of the tibial shaft. *Clin. Orthop.* 350:18–25, 1998.
- Gustilo, R. B., Merkow, R. L., Templeman, D. The management of open fractures. *J. Bone Joint Surg.* 72-A:299–304, 1990.

34. Patzakis, M. J., Harvey, J. P., Jr., Ivler, D. The role of antibiotics in the management of open fractures. *J. Bone Joint Surg.* 56-A:532–541, 1974.
35. Benson, D. R., Riggins, R. S., Lawrence, R. M., et al. Treatment of open fractures: a prospective study. *J. Trauma* 23:25–30, 1983.
36. DeLong, W. G., Jr., Born, C. T., Wei, S. Y., et al. Aggressive treatment of 119 open fracture wounds. *J. Trauma* 46:1049–1054, 1999.
37. Gopal, S., Majunder, S., Batchelor, A. G., et al. Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia. *J. Bone Joint Surg.* 82-B:959–966, 2000.
38. Paley, D. Problems, obstacles, and complications of limb lengthening by the Ilizarov technique. *Clin. Orthop. Relat. Res.* 250:81–104, 1990.