treatment of bone infections. Expert Opin Drug Deliv. 2016;13:613–620. doi:10.1517/17425247.2016.1146673.
[76] Sayin B, Caliş S, Atilla B, Marangoz S, Hincal AA. Implantation of vancomycin microspheres in blend with human/rabbit bone grafts to infected bone defects. J Microencapsul. 2006;23:553–566. doi:10.1080/02652040600775632.
[77] Tamazawa G, Ito A, Miyai T, Matsuno T, Kitahara K, Sogo Y, et al. Gatifloxacine-loaded PLGA and ß-tricalcium phosphate composite for treating osteomyelitis. Dent Mater J. 2011;30:264–273.
[78] Uskoković V, Desai TA. Phase composition control of calcium phosphate nanoparticles for tunable drug delivery kinetics and treatment of osteomyelitis. II. Antibacterial and osteoblastic response. J Biomed Mater Res A. 2013;101:1427–1436. doi:10.1002/jbm.a.34437.
[79] Uskoković V, Hoover C, Vukomanović M, Uskoković DP, Desai TA. Osteogenic and antimicrobial nanoparticulate calcium phosphate and poly-(D,L-lactide-co-glycolide) powders for the treatment of osteomyelitis. Mater Sci Eng C Mater Biol Appl. 2013;33:3362–3373. doi:10.1016/j.msec.2013.04.023.
[80] Yenice I, Caliş S, Atilla B, Kaş HS, Ozalp M, Ekizoğlu M, et al. In vitro/in vivo evaluation of the efficiency of teicoplanin-loaded biodegradable microparticles formulated for implantation to infected bone defects. J Microencapsul. 2003;20:705–717. doi:10.1080/0265204031000154179.
[81] Zhu CT, Xu YQ, Shi J, Li J, Ding J. Liposome combined porous beta-TCP scaffold: preparation, characterization, and anti-biofilm activity. Drug Deliv. 2010;17:391–398. doi:10.3109/10717541003762870.
[82] Tetsworth K, Cierny G. Osteomyelitis debridement techniques. Clin Orthop Relat Res. 1999:87–96.
[83] Heitmann C, Patzakis MJ, Tetsworth KD, Levin LS. Musculoskeletal sepsis: principles of treatment. Instr Course Lect. 2003;52:733–743.
[84] Cierny G. Chronic osteomyelitis: results of treatment. Instr Course Lect. 1990;39:495–508.
[85] Cierny G. Infected tibial nonunions (1981-1995). The evolution of change. Clin Orthop Relat Res. 1999:97–105.

• • • • •

Authors: Janet Conway, Stephen Quinnan

QUESTION 8: What is the optimal management (Masquelet technique, bone transport) of postinfective bone defects in different long bones (tibia, femur, humerus, etc.)? How does this vary by type of defect (conical vs. cylindrical)?

RECOMMENDATION: The type of defect (cylindrical vs. conical) was not determined to be relevant to the treatment method. Instead, optimal management of partial vs. full segmental defects is relevant. Each long bone requires different preferred methods of stabilization.

LEVEL OF EVIDENCE: Moderate

DELEGATE VOTE: Agree: 95%, Disagree: 0%, Abstain: 5% (Unanimous, Strongest Consensus)

RATIONALE

The most complete systematic review was published in 2017 by Kadhim et al. [1] This review reported that in 96 femoral segmental bone defects, monolateral external fixation with bone transport was 99.7% effective for union and 94.7% successful for function compared with 88.9% and 57.6% for circular external fixation, respectively. Supplemental internal fixation in this study decreased the external fixation time. Yin et al. [2] reported their series of 38 femoral fractures with infected segmental bone defects (average size, 6.5 cm) that were treated with application of monolateral external fixation and bone transport. The mean external fixation index was 1.5 months/cm (range, 1.3–1.7 months/cm). Only five femurs required docking site bone grafting. Good/excellent results (evaluated using the Association for the Study and Application of the Methods of Ilizarov (ASAMI) Classification) for bone were 87.3% and good/excellent results for functional outcome were 79%. Multiple other studies have reported similar results with monolateral bone transport but with fewer numbers of patients [3–5]. Docking site bone grafting is not always necessary except in longer transports that result in fibrous tissue at the docking site with some atrophy of the transported bone end [4,5]. Monolateral bone transport is much less technically challenging than classic Ilizarov transport in the femur; therefore, this technique is more accessible to a larger number of surgeons.

Few studies document the success of vascularized fibular bone grafts (VFBGs) in post-infectious segmental bone defects [6–8]. Minami et al. [6] reported on 23 post-infectious femoral segmental bone defects treated with VFBG. Twenty of 23 patients achieved primary bone union; however, 2 patients had recurrent infections. Both of these patients underwent VFBG less than one month following resection for osteomyelitis; therefore, the authors' recommendation [6] was to delay the VFBG for longer than one month after the resection and until serologic infection markers returned to normal. Gao-Hong et al. [7] reported using VFBG for infected femoral segmental defects ranging from 6 to 18 cm with primary bone healing in 10 of 12 patients. Additional surgery improved the healing rate to 100% (12/12) with eradication of infection in all cases. According to Enneking scoring, excellent/good results were observed in 11 of 12 patients [7]. Han et al. [9] reported on VFBG for defects following infection with a primary union rate of only 48%. With additional procedures, this rate increased to 77% (46/60). The literature has small numbers of VFBG reconstruction for post-infectious defects of the femur with results that are not comparable to the success of bone transport. Song et al. [10] studied post-infectious femoral defects (> 8 cm) and compared 20 cases treated with internal bone transport to 17 cases treated with VFBG. The bone transport cases had 65% excellent/good result compared to 35% in the VFBG cases. The complication rate is high regarding donor site morbidity [11] and fibular stress fractures, which range between 15% and 32% [12,13]. The VFBG technique is technically demanding, requires microsurgical skills, and is not readily accessible to many orthopaedic surgeons.

No large series has been reported of the induced membrane technique for post-infectious defects of the femur. There are 3 series with 19, [14] 13, [15] and 13 cases [16]. Wu et al. [14] reported 19 cases with an average 5.5-cm defect (range, 2–10.9 cm). The first stage was external fixation and cement spacer placement. The second stage of treatment was combined internal fixation with autograft/auto-allograft mix into the induced membrane. All femurs united and were free of infection [14]. Yu et al. [15] reported 13 cases of septic femoral bone defects averaging 9.8 cm (range, 5–16 cm). The first stage fixation was an antibiotic-coated locked plate and the second stage fixation was an intramedullary nail. The reported union rate was 100%, and 92% of patients were infection free for at least one year [15]. Tong et al. [16] also reported 13 cases of femoral posttraumatic osteomyelitis. They compared bone transport to the induced membrane (IM) technique and found that the IM technique had better results in the femoral cases, especially the periarticular bone defects [16]. These publications [14–16] have promise but are retrospective with only small numbers.

The publications regarding the IM technique have many variations including timing to second stage, the presence of antibiotics in the spacer and the type of fixation used for stage one and two [17]. The important unifying principles are radical debridement of infection, proper installation of the cement spacer overlapping the normal bone ends, waiting for the soft-tissue envelope to heal with normal serologic markers and stable fixation during the interval prior to the second stage [18]. Infection eradication is the most essential element in achieving success. This technique therefore requires a minimum of two surgical procedures. The largest series published to date is by Karger et al. [19] with 84 cases. Fifty percent of the cases were for infection, the average number of operations to achieve union was 6.11, and 57% of the defects were larger than 5 cm. An abnormal soft-tissue envelope needs to be addressed with soft-tissue transfer (adjacent or free) in order to promote good soft-tissue healing and a stable wound bed for the second stage [20,21]. The Masquelet technique holds promise but the surgeon should proceed with caution as several surgical procedures may be needed to achieve the desired result. In theory, any size defect can be treated and there is no prolonged external fixation time as in bone transport. The time to achieve union with this technique appears to be independent of the length of the defect; however, a 2 cm defect and a 15 cm defect both may take as long as 10 months to heal [19]. The recommendation is moderate because of the lack of large prospective series reports in the literature and the number of average surgical procedures needed to achieve success.

Kadhim et al. [1] recently published a systematic review of nonunion with segmental bone defects that included 334 tibiae. The most successful method of reconstruction with respect to bone union and function was circular external fixation combined with internal fixation (either bridge plating or intramedullary nail). This provided a 99.8% success rate with respect to both union and function. Papakostidis et al. [22] also demonstrated in their systematic review that distraction osteogenesis with the Ilizarov method statistically significantly reduced the risk of infection in previously infected defects. They also showed that the risk of refracture following removal of external fixation was higher when tibial defects were larger than 8 cm [22].

Rohilla et al. [23] published a randomized prospective study with 70 patients comparing ring fixators and monolateral fixators for infected tibial defects. They concluded that for defects greater than 6 cm, a ring fixator had superior results [23]. They attributed this finding to the larger numbers of patients in the monolateral group who had residual problems with greater than 6 cm of lengthening such as infection, deformity and shortening. Also, the monolateral group had statistically significantly more problems with deep pin tract infections than the ring fixator group [23].

Many other studies have also documented the success of circular external fixation and bone transport in the tibia. Yin et al. [2] in 2014 reported 66 patients with infected segmental tibial bone defects with an average size of 6.3 cm (range, 3–13 cm). All tibiae were treated with bone transport with circular external fixation and united without recurrence of infection. Fifty-nine patients had excellent/good results according to the ASAMI classification [2]. Docking site bone graft was performed in only six patients. The most common complication was pin tract infection in 40 patients with 38 of the 40 being treated with orally-administered antibiotics and pin care. The mean external fixation index was 1.38 months/cm (range, 1.15–1.58 months/cm). Only two patients had refracture after frame removal, which was treated with reapplication of the external fixator [2]. Peng et al. [24] reported 58 cases of tibial infected nonunion with an average defect of 9.2 cm (range, 6–15 cm) that were treated with bone transport with circular external fixation. Fifty-three patients had excellent/good results using the Paley grade and 36 excellent/good functional results. There were no refractures and only one recurrent infection [24].

Hexapod external fixators have also been used for bone transport using the method of Ilzarov. Napora et al. [25] reported 75 infected segmental bone defects of the tibia (average size, 5.4 cm) treated with a hexapod external fixator. Seventy of 75 patients had eradication of infection and full union. Thirty-two patients required a free flap by plastic surgery, and 36 patients had adjunctive stabilization with either an intramedullary nail or plate fixation at or following removal. Many other articles detail the success of circular external fixation and bone transport in the tibia [26–31].

Another treatment option is acute shortening with lengthening. One paper [32] with a total of 42 patients reported similar results when comparing acute shortening with lengthening to bone transport. The only difference was a statistically significantly smaller number of major and minor complications per patient. This technique is helpful only when the fibula is broken and the soft-tissue envelope is amenable to shortening using a transverse incision. Excessive shortening greater than 4 cm can lead to ischemia of the leg due to arterial kinking and the authors highlight the need to monitor the vascular status of the limb whenever shortening is employed.

Some literature has been published on the IM or Masquelet technique for infected tibial segmental bone defects. There is some variability with respect to the technique among the papers, and some critical differences may lead to poorer outcomes using the technique. Tong et al. [16] compared the Masquelet technique for infected segmental tibial bone defects to Ilizarov bone transport. The average bone defect size was 6.8 cm (range, 2.7–15.7 cm). Twenty-six patients had tibial defects with 13 patients in each group. The IM group was treated with external fixation for stage two as well. In this series, there was no statistically significant difference between bone results in the 13 bone transport cases and 13 IM cases. It is interesting to note, however, that a recurrent infection in the IM group was treated with bone transport to union. Functional results were better in the IM group because of the statistically significantly smaller external fixation time (10.2 months [range, 8–14 months] versus 17.2 months [range, 11–24 months]). Seventeen excellent/good functional results were observed for the Masquelet technique versus nine excellent/good functional results for bone transport.

Karger et al. [19] in 2012 published the largest series of the IM technique for segmental bone defects. They included a total of 84 cases that included 61 tibial defects. Of the 61 tibial cases, there was an average time to union of 14.6 months with an average of 11.5 interventions. Full weight bearing was started at a mean of 17.4 months after the initial treatment of the bone defect. Eight tibial cases failed, and six required amputation. Qiu et al. [20] reported 40 tibial post-traumatic osteomyelitis defects. There were 2 groups: a cement bead group (18 patients) and a cement-spacer group (22 patients). The volumes of the bone defects for each group were 32.4 cm^3 (range, 15–40 cm^3) and 40.4 cm^3 (range, 20–70 cm^3), respectively. Nineteen of these bone voids were partial defects. The bone healing time was 8.5 months in the spacer group and 7.5 months in the bead group. Infection control was also similar in the two groups: 88.9% for the bead and 90.9% for the spacer groups. Eighteen patients had soft-tissue coverage by plastic surgery. Stable fixation was obtained at the initial débridement with either internal or external fixation and there were no amputations [20]. This study demonstrates that the IM technique can be successful for small defects.

Sadek et al. [33] also demonstrated that the IM technique for tibial defects smaller than 6 cm was comparable to Ilizarov bone transport in a small, case-matched series totaling 30 patients (14 and 16 patients per group). Giannoudis et al. [34] reported 43 long bones that were treated with the IM technique; however, only 11 were tibial defects with an average defect size of 4 cm (range, 2–7.5 cm). All bones united with one complication of recurrent infection treated with repeat debridement. This study highlights one of the problems with the IM technique papers in that many different anatomic regions are considered together. Morelli et al. [35] performed a systematic review of the IM technique with 17 papers that met the inclusion criteria; however, only 10 of these papers reported individual patient data for a total of 137 cases. Persistent infection or nonunion was present in 18% of cases requiring repeat surgical interventions. There has been much enthusiasm for this technique because it is technically less challenging for the surgeon and it appeals to patients because it does not have prolonged external fixation time. This technique, however, has pitfalls with many variations of the technique being reported with variable outcomes. Surgeons should proceed with caution as recurrent infection and nonunion may require repeat operations and ultimately increase total treatment time.

Now turning attention to the upper extremity, Adani et al. [36] published a series of 13 cases of VFBG for humeral segmental defects, of which 8 were infected. The average defect in these cases was 12.3 cm (range, 10–16 cm). Five of eight patients required additional procedures (e.g., bone grafting, plate revision, new VFBG). The repeat VFBG was secondary to a vascular pedicle failure. According to Tang criteria, functional recovery was excellent/good in all eight cases and radiographically excellent/good results were seen in five of eight cases.

One series in the literature has 12 pediatric patients with humeral osteomyelitis with an average defect size of 5.5 cm [37]. Initial treatment consisted of excision of infected bone, autograft nonvascularized fibular strut and plate fixation, and limb shortening. Ten of 12 patients healed after the initial surgery. One patient required additional bone grafting. One patient developed a recurrent infection and required re-debridement and re-bone grafting with ultimate success. The average residual shortening of the limb was 3.5 cm (range, 2–6 cm).

Rafiq Barawi [37] published the results of 10 patients with infected humeral defects averaging 6 cm (range, 3–9 cm) treated with Ilizarov bone transport. All 10 cases had Paley class excellent/good results radiographically and functionally at latest follow-up, with an average external fixation index of 1.16 months/cm. Liu et al. [38] reported 11 patients with humeral osteomyelitis and segmental defects. The average gap was 1.9 cm (range, 1–2.7 cm) with an average humeral shortening of 5.6 cm (range, 3.5–8.0 cm). The average humeral lengthening was 9.5 cm (range, 5.5–13.4 cm). The average external fixation index was 1.16 months/cm (range, 1–1.35 month/cm). Ten of 11 patients healed, and all patients were eradicated of infection. All patients had excellent/good results. No docking site bone graft was performed in any of the cases. The most common complication was pin tract infection. Two pins were exchanged in two patients for loosening.

Adani et al. [39] published a series of 12 cases using VFBG in the forearm where 10 of the 12 cases had osteomyelitis. The average defect was 8.4 cm (range, 6–13 cm). Two cases required additional bone grafting and both of these cases had a history of osteomyelitis. A third case was considered a failure secondary to thrombosis of the artery of the VFBG. Therefore, 9 of 10 cases of forearm osteomyelitis healed with 2 requiring additional bone graft procedures. The average time to healing was 4.8 months (range, 2.5–8 months). Internal fixation was used for 9 of 10 cases. Seven of nine patients had excellent/good results clinically and eight of nine patients had excellent/good results radiographically.

The alternative treatment is the IM technique as applied in the forearm. Prasarn et al. [40] published a series of 15 cases of infected forearm nonunion treated with debridement and nonvascularized iliac crest bone graft with open wound healing by secondary intention. All bones united and were free of infection with an average time to union of 13.2 weeks (range, 10–15 weeks). The average defect size was 2.1 cm (range, 1–7 cm). Allende [41] in 2010 published 20 cases with healing of infection and nonunion at an average of 5 months. Luo et al. [42] published a series of 7 forearm infections with an average defect size of 5.8 cm (range, 4–8 cm) treated with the IM technique. The average number of procedures to achieve success in these patients was 3.43 (range, 2–5 procedures). The authors emphasize that a number of debridements may be required to achieve an uninfected environment. Serial debridement's were also determined by Masquelet [18] to be critical to achieve an uninfected wound bed and ultimate success with the technique. One patient required repeat bone grafting [42]. At latest follow-up averaging 86.7 months (range, 41–150 months), all patients were healed, uninfected and had statistically significant improvement in functional scores.

Two studies reported the results of bone transport in forearm nonunions. Zhang et al. [43] published a series of 16 cases with an average defect of 3.8 cm (range, 2.2–7.5 cm) with a mean external fixation index of 1.6 months/cm (range, 1.14–2.0 months/cm). All patients healed, and there was no recurrence of infection. No docking site was bone grafted. Liu et al. [44] reported on 21 patients with infected forearm nonunion who underwent treatment with monolateral fixation. The average defect was 3.1 cm (range, 1.8–4.6 cm), and the external fixation index was 1.4 months/cm. Four patients had docking site bone grafting. Three patients had regenerate bone grafting, and 3 patients had recurrent infection requiring repeat debridement. Mean follow-up was 77.5 months. All forearms healed and were free of infection.

REFERENCES

[1] Kadhim M, Holmes L, Gesheff MG, Conway JD. Treatment options for nonunion with segmental bone defects: systematic review and quantitative evidence synthesis. J Orthop Trauma. 2017;31:111–119. doi:10.1097/BOT.0000000000000700.

[2] Yin P, Zhang Q, Mao Z, Li T, Zhang L, Tang P. The treatment of infected tibial nonunion by bone transport using the Ilizarov external fixator and a systematic review of infected tibial nonunion treated by Ilizarov methods. Acta Orthop Belg. 2014;80:426–435.

[3] Wan J, Ling L, Zhang X, Li Z. Femoral bone transport by a monolateral external fixator with or without the use of intramedullary nail: a single-department retrospective study. Eur J Orthop Surg Traumatol. 2013;23:457–464. doi:10.1007/s00590-012-1008-x.

[4] Agrawal HK, Garg M, Singh B, Jaiman A, Khatkar V, Khare S, et al. Management of complex femoral nonunion with monorail external fixator: a prospective study. J Clin Orthop Trauma. 2016;7:191–200. doi:10.1016/j.jcot.2016.02.013.

[5] Zhang Q, Zhang W, Zhang Z, Zhang L, Chen H, Hao M, et al. Femoral nonunion with segmental bone defect treated by distraction osteogenesis with monolateral external fixation. J Orthop Surg Res. 2017;12:183. doi:10.1186/s13018-017-0684-y.

[6] Minami A, Kasashima T, Iwasaki N, Kato H, Kaneda K. Vascularised fibular grafts. An experience of 102 patients. J Bone Joint Surg Br. 2000;82:1022–1025.

[7] Gao-Hong R, Run-Guang L, Gui-Yong J, Chao-Jie C, Zhi-Gang B. A solution to the vessel shortage during free vascularized fibular grafting for reconstructing infected bone defects of the femur: bridging with vein transplantation. Injury. 2017;48:486–494. doi:10.1016/j.injury.2016.10.027.

[8] Yajima H, Tamai S, Mizumoto S, Ono H. Vascularised fibular grafts for reconstruction of the femur. J Bone Joint Surg Br. 1993;75:123–128.

[9] Han CS, Wood MB, Bishop AT, Cooney WP. Vascularized bone transfer. J Bone Joint Surg Am. 1992;74:1441–1449.

[10] Song HR, Kale A, Park HB, Koo KH, Chae DJ, Oh CW, et al. Comparison of internal bone transport and vascularized fibular grafting for femoral bone defects. J Orthop Trauma. 2003;17:203–211.

[11] Vail TP, Urbaniak JR. Donor-site morbidity with use of vascularized autogenous fibular grafts. J Bone Joint Surg Am. 1996;78:204–211.

[12] Lin CH, Wei FC, Chen HC, Chuang DC. Outcome comparison in traumatic lower-extremity reconstruction by using various composite vascularized bone transplantation. Plast Reconstr Surg. 1999;104:984–992.

[13] de Boer HH, Wood MB, Hermans J. Reconstruction of large skeletal defects by vascularized fibula transfer. Factors that influenced the outcome of union in 62 cases. Int Orthop. 1990;14:121–128.

[14] Wu H, Shen J, Yu X, Fu J, Yu S, Sun D, et al. Two stage management of Cierny-Mader type IV chronic osteomyelitis of the long bones. Injury. 2017;48:511–518. doi:10.1016/j.injury.2017.01.007.

[15] Yu X, Wu H, Li J, Xie Z. Antibiotic cement-coated locking plate as a temporary internal fixator for femoral osteomyelitis defects. Int Orthop. 2017;41:1851–1857. doi:10.1007/s00264-016-3258-4.
[16] Tong K, Zhong Z, Peng Y, Lin C, Cao S, Yang Y, et al. Masquelet technique versus Ilizarov bone transport for reconstruction of lower extremity bone defects following posttraumatic osteomyelitis. Injury. 2017;48:1616–1622. doi:10.1016/j.injury.2017.03.042.
[17] Azi ML, Teixeira AA de A, Cotias RB, Joeris A, Kfuri M. Membrane induced osteogenesis in the management of posttraumatic bone defects. J Orthop Trauma. 2016;30:545–550. doi:10.1097/BOT.0000000000000614.
[18] Masquelet AC. Induced membrane technique: pearls and pitfalls. J Orthop Trauma. 2017;31 Suppl 5:S36–S38. doi:10.1097/BOT.0000000000000979.
[19] Karger C, Kishi T, Schneider L, Fitoussi F, Masquelet A-C, French Society of Orthopaedic Surgery and Traumatology (SoFCOT). Treatment of posttraumatic bone defects by the induced membrane technique. Orthop Traumatol Surg Res. 2012;98:97–102. doi:10.1016/j.otsr.2011.11.001.
[20] Qiu XS, Chen YX, Qi XY, Shi HF, Wang JF, Xiong J. Outcomes of cement beads and cement spacers in the treatment of bone defects associated with posttraumatic osteomyelitis. BMC Musculoskelet Disord. 2017;18:256. doi:10.1186/s12891-017-1614-1.
[21] Gupta G, Ahmad S, Mohd Zahid null, Khan AH, Sherwani MKA, Khan AQ. Management of traumatic tibial diaphyseal bone defect by "induced-membrane technique." Indian J Orthop. 2016;50:290–296. doi:10.4103/0019-5413.181780.
[22] Papakostidis C, Bhandari M, Giannoudis PV. Distraction osteogenesis in the treatment of long bone defects of the lower limbs: effectiveness, complications and clinical results; a systematic review and meta-analysis. Bone Joint J. 2013;95-B:1673–1680. doi:10.1302/0301-620X.95B12.32385.
[23] Rohilla R, Wadhwani J, Devgan A, Singh R, Khanna M. Prospective randomised comparison of ring versus rail fixator in infected gap nonunion of tibia treated with distraction osteogenesis. Bone Joint J. 2016;98-B:1399–1405. doi:10.1302/0301-620X.98B10.37946.
[24] Peng J, Min L, Xiang Z, Huang F, Tu C, Zhang H. Ilizarov bone transport combined with antibiotic cement spacer for infected tibial nonunion. Int J Clin Exp Med. 2015;8:10058–10065.
[25] Napora JK, Weinberg DS, Eagle BA, Kaufman BR, Sontich JK. Hexapod frame stacked transport for tibial infected nonunions with bone loss: analysis of use of adjunctive stability. J Orthop Trauma. 2017;31:393–399. doi:10.1097/BOT.0000000000000840.
[26] Abuomira IEA, Sala F, Elbatrawy Y, Lovisetti G, Alati S, Capitani D. Distraction osteogenesis for tibial nonunion with bone loss using combined Ilizarov and Taylor spatial frames versus a conventional circular frame. Strategies Trauma Limb Reconstr. 2016;11:153–159. doi:10.1007/s11751-016-0264-4.
[27] Aktuglu K, Günay H, Alakbarov J. Monofocal bone transport technique for bone defects greater than 5 cm in tibia: our experience in a case series of 24 patients. Injury. 2016;47 Suppl 6:S40–S46. doi:10.1016/S0020-1383(16)30838-5.
[28] 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;76:811–820.
[29] El-Alfy BS. Unhappy triad in limb reconstruction: management by Ilizarov method. World J Orthop. 2017;8:42–48. doi:10.5312/wjo.v8.i1.42.
[30] Hohmann E, Birkholtz F, Glatt V, Tetsworth K. The "road to union" protocol for the reconstruction of isolated complex high-energy tibial trauma. Injury. 2017;48:1211–1216. doi:10.1016/j.injury.2017.03.018.
[31] McNally M, Ferguson J, Kugan R, Stubbs D. Ilizarov treatment protocols in the management of infected nonunion of the tibia. J Orthop Trauma. 2017;31 Suppl 5:S47–S54. doi:10.1097/BOT.0000000000000987.
[32] Tetsworth K, Paley D, Sen C, Jaffe M, Maar DC, Glatt V, et al. Bone transport versus acute shortening for the management of infected tibial non-unions with bone defects. Injury. 2017;48:2276–2284. doi:10.1016/j.injury.2017.07.018.
[33] Sadek AF, Laklok MA, Fouly EH, Elshafie M. Two stage reconstruction versus bone transport in management of resistant infected tibial diaphyseal nonunion with a gap. Arch Orthop Trauma Surg. 2016;136:1233–1241. doi:10.1007/s00402-016-2523-8.
[34] Giannoudis PV, Harwood PJ, Tosounidis T, Kanakaris NK. Restoration of long bone defects treated with the induced membrane technique: protocol and outcomes. Injur.y 2016;47 Suppl 6:S53–S61. doi:10.1016/S0020-1383(16)30840-3.
[35] Morelli I, Drago L, George DA, Gallazzi E, Scarponi S, Romanò CL. Masquelet technique: myth or reality? A systematic review and meta-analysis. Injury. 2016;47 Suppl 6:S68–S76. doi:10.1016/S0020-1383(16)30842-7.
[36] Adani R, Delcroix L, Innocenti M, Tarallo L, Baccarani A. Free fibula flap for humerus segmental reconstruction: report on 13 cases. Chir Organi Mov. 2008;91:21–26. doi:10.1007/s12306-007-0004-5.
[37] Rafiq O. Management of bone defect of humerus by Ilizarov method. Genij Ortopedii. 2016:36–39. doi:10.18019/1028-4427-2016-2-36-39.
[38] Liu T, Zhang X, Li Z, Zeng W, Peng D, Sun C. Callus distraction for humeral nonunion with bone loss and limb shortening caused by chronic osteomyelitis. J Bone Joint Surg Br. 2008;90:795–800. doi:10.1302/0301-620X.90B6.20392.
[39] Adani R, Delcroix L, Innocenti M, Marcoccio I, Tarallo L, Celli A, et al. Reconstruction of large posttraumatic skeletal defects of the forearm by vascularized free fibular graft. Microsurgery. 2004;24:423–429. doi:10.1002/micr.20067.
[40] Prasarn ML, Ouellette EA, Miller DR. Infected nonunions of diaphyseal fractures of the forearm. Arch Orthop Trauma Surg. 2010;130:867–873. doi:10.1007/s00402-009-1016-4.
[41] Allende C. Cement spacers with antibiotics for the treatment of posttraumatic infected nonunions and bone defects of the upper extremity. Tech Hand Up Extrem Surg. 2010;14:241–247. doi:10.1097/BTH.0b013e3181f42bd3.
[42] Luo TD, Nunez FA, Lomer AA, Nunez FA. Management of recalcitrant osteomyelitis and segmental bone loss of the forearm with the Masquelet technique. J Hand Surg Eur Vol. 2017;42:640–642. doi:10.1177/1753193416650171.
[43] Zhang Q, Yin P, Hao M, Li J, Lv H, Li T, et al. Bone transport for the treatment of infected forearm nonunion. Injury. 2014;45:1880–1884. doi:10.1016/j.injury.2014.07.029.
[44] Liu T, Liu Z, Ling L, Zhang X. Infected forearm nonunion treated by bone transport after debridement. BMC Musculoskelet Disord. 2013;14:273. doi:10.1186/1471-2474-14-273.

• • • • •

Authors: Kevin Tetsworth, Peter Giannoudis, Rajendra Shetty, G. Kleftouris

QUESTION 9: What is the optimum waiting time for bone grafting in staged management of septic nonunion?

RECOMMENDATION: **The interval between the first and second stages should be dependent upon infection control and the status of the local soft tissue of the individual patient, rather than any specific time. Therefore, the precise time is unknown. The current recommendations are that if conditions are favorable, the second stage can be performed between 6 and 12 weeks after the first stage. This recommendation may not apply to the Masquelet technique.**

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

Successful treatment of infected long bone nonunions remains a great challenge for the orthopaedic trauma and limb reconstruction surgeon. They are frequently associated with bone and soft tissue loss, failed internal fixation, broken implants, poor vascularity, drainage from sinuses, osteopenia, osteomyelitis, adjacent joint stiffness, deformities, length discrepancies, prior surgery and polymicrobial infection with resistant organisms [1–4]. Available evidence on the operative management of infected long bone nonunions indicates that staged reconstruction (incorporating debridement, antibiotic beads, soft tissue coverage and provisional stabilization, followed by delayed osseous reconstruction and definitive stabilization [3–6]) can achieve union in 93–100% of cases. With expert care under staged protocols by surgeons specializing in musculoskeletal sepsis, persistence of infection is present in only 2-9% of cases [5,6],