elution experiments. Although many surgeons believe that antibiotic beads used to treat osteomyelitis should be removed, one retrospective study suggested that improved outcomes followed leaving the beads in situ [14].

After removal of an intramedullary rod, placement of antibiotic beads offers no mechanical support. Beads within the intramedullary canal must be removed within 10 to 14 days or subsequent removal may be extremely difficult [15,16]. Antibiotic cement rods can be custom-made at the time of surgery using varying chest tubes as molds [16]. Following thorough medullary canal debridement, the antibiotic rod is inserted and does provide some mechanical stability**.** If additional debridements are necessary, the antibiotic rod is exchanged. At the time of definitive closure, the antibiotic rod is left intact in the canal, and the wound is closed directly over it. After a six- to eight-week interval, the rod can be removed and bony reconstruction can be undertaken.

REFERENCES

[1] Lowenberg DW, Watson JT, Levin LS. Advances in the understanding and treatment of musculoskeletal infections. Instr Course Lect. 2015;64:37–49.
[2] Strauss EJ, Petrucelli G, Bong M, Koval KJ, Egol KA. Blisters associated with lower-extremity fracture: results of a prospective treatment protocol. J Orthop Trauma. 2006;20:618–622. doi:10.1097/01.bot.0000249420.30736.91.
[3] Mader J, Cripps M, Calhoun J. Adult posttraumatic osteomyelitis of the tibia. Clin Orthop Relat Res. 1999;360:14–21.
[4] Friedrich B, Klaue P. Mechanical stability and post traumatic osteitis: an experimental evaluation of the relation between infection of bone and internal fixation. Injury. 1977;9:23–29.
[5] Merritt K, Dowd JD. Role of internal fixation in infection of open fractures: studies with Staphylococcus aureus and Proteus mirabilis. J Orthop Res. 1987;5:23–28. doi:10.1002/jor.1100050105.
[6] Berkes M, Obremskey WT, Scannell B, Ellington JK, Hymes RA, Bosse M. Maintenance of hardware after early postoperative infection following fracture internal fixation. J Bone Joint Surg Ser A. 2010;92:823–828. doi:10.2106/JBJS.I.00470.
[7] Steve WNU, Wei FC, Sliih CH. Management of femoral diaphyseal infected nonunion with antibiotic beads local therapy, external skeletal fixation, and staged bone grafting. J. Trauma. 1999;97–103. doi:10.1097/00005373-199901000-00016.
[8] Zimmerli W, Widmer AF BM. Role of Rifampin for treatment of orthopedic implant – related Staphylococcal infections a randomized controlled trial. JAMA. 1998;279:1537–1541.
[9] Rightmire E, Zurakowski D, Vrahas M. Acute infections after fracture repair: management with hardware in place. Clin Orthop Relat Res. 2008;466:466–472. doi:10.1007/s11999-007-0053-y.
[10] Tetsworth K, Cierny G. Osteomyelitis debridement techniques. Clin Orthop Relat Res. 1999:87–96.
[11] Heitmann C, Patzakis MJ, Tetsworth KD, Levin LS. Musculoskeletal sepsis: principles of treatment. Instr Course Lect. 2003; 52:733–743.
[12] Cierny G. Chronic osteomyelitis: results of treatment. Instr Course Lect. 1990;39:495–508.
[13] Cierny G. Infected tibial nonunions (1981-1995). The evolution of change. Clin Orthop Relat Res. 1999:97–105.
[14] Henry SL, Hood G a, Seligson D. Long-term implantation of gentamicin-polymethylmethacrylate antibiotic beads. Clin Orthop Relat Res. 1993:47–53.
[15] Patzakis M. Management of acute and chronic osteomyelitis. Oper Orthop. 1993: 3533–3560.
[16] Paley D, Herzenberg JE. Intramedullary infections treated with antibiotic cement rods: preliminary results in nine cases. J Orthop Trauma. 2002;16:723–729. doi:10.1097/00005131-200211000-00007.

Authors: Nando Ferreira, Arvind Nana, Michael T. Archdeacon

QUESTION 2: Which surgical treatment (plate, nail or external fixator) for open tibial shaft fractures results in lower rate of infection?

RECOMMENDATION: There is little to no difference in terms of infection rates for Gustilo-Anderson types I–II treated by either circular external fixator, unreamed intramedullary nail or reamed intramedullary nail. For Gustilo-Anderson IIIA-B fractures, circular external fixation appears to provide the lowest infection rates when compared to all other fixation methods.

LEVEL OF EVIDENCE: Moderate

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

RATIONALE

A systematic review was undertaken on all English language articles on infection rates following the treatment of open tibial shaft fractures. The literature search included Google Scholar and the Medline, Embase and Cochrane databases. The search terms included open tibia, tibia fracture and tibial diaphysis with the Boolean terms 'AND' and 'OR.' All abstracts were reviewed, and the full articles were obtained for all potentially suitable articles.

Review articles and those that included peri-articular open fractures and pediatric fractures were excluded. A total of 54 articles were excluded for review. Information regarding Gustilo-Anderson types and infection rates were extracted from all included articles (Table 1).

Statistical analysis revealed that across all Gustilo-Anderson types, circular external fixation and intramedullary nailing have significantly lower infection rates compared to plate fixation or monolateral external fixation. Across all types, there is minimal to no difference between circular external fixation and unreamed intramedullary nailing or reamed intramedullary nailing (Table 2).

When Gustilo-Anderson type IIIB injuries are isolated, circular external fixation appears to have a significantly lower risk of risk of infection when compared to reamed and undreamed intramedullary nail fixation (Table 4).

In conclusion, from the available published English literature on infections rates for open tibial shaft fractures treated by various different fixation methods, plate fixation and monolateral external fixation have significantly higher infection rates when compared to circular external fixation or intramedullary nailing. There appears to be little to no difference for Gustilo-Anderson types I – IIIA treated by either circular external fixator, unreamed intramedullary nail or reamed intramedullary nail. For Gustilo-Anderson type IIIB fractures, circular external fixation appears to provide the lowest infection rates when compared to all other fixation methods.

REFERENCES

[1] Gopal S, Majumder S, Batchelor AG, Knight SL, De Boer P, Smith RM. Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia. J Bone Joint Surg Br. 2000;82:959–966.
[2] Clifford RP, Beauchamp CG, Kellam JF, Webb JK, Tile M. Plate fixation of open fractures of the tibia. J Bone Joint Surg Br. 1988;70:644–648.
[3] Bach AW, Hansen ST. Plates versus external fixation in severe open tibial shaft fractures. A randomized trial. Clin Orthop Relat Res. 1989:89–94.

TABLE 1. Summary of infection rates with different fixation methods from the literature review

Fixation	Type	Cases (n)	Infected Cases (n)	%
Plate [1–4]	GA I	49	3	6.1
	GA II	80	7	8.8
	GA IIIA	36	9	25.0
	GA IIIB	34	5	14.7
Monolateral external fixation [1,3–19]	GA I	9	0	0.0
	GA II	76	2	2.6
	GA IIIA	373	41	11.0
	GA IIIB	238	50	21.0
Circular external fixation [17,18,20–28]	GA I	10	0	0.0
	GA II	63	0	0.0
	GA IIIA	145	3	2.1
	GA IIIB	198	6	3.0
Unreamed Nail [1,4,5,7,9–13,16,19,29–51]	GA I	533	6	1.1
	GA II	734	19	2.6
	GA IIIA	554	32	5.8
	GA IIIB	558	102	18.3
Reamed Nail [6,18,21,32,33,38,40,41,48,52–54]	GA I	401	6	1.5
	GA II	493	15	3.0
	GA IIIA	230	5	2.2
	GA IIIB	240	40	16.7

TABLE 2. Infection rate ratio (IRR) differences between all treatment types for all GA types (I, II, IIIA and IIIB)

Treatment	IRR	95% CI	p-value
Circular fixator	Reference		
Plate	5.57	2.73 - 11.38	<0.001
Monolateral fixator	6.17	3.12 - 12.23	<0.001
Unreamed nail	3.10	1.03 - 9.25	0.044
Reamed nail	2.24	0.73 - 6.89	0.161

TABLE 3. Infection rate ratio (IRR) differences between all treatment types for GA types I, II and IIIA

Treatment	IRR	95% CI	p-value
Circular fixator	Reference		
Plate	8.34	2.78 – 25.23	<0.001
Monolateral fixator	6.82	2.57 – 18.12	<0.001
Unreamed nail	2.27	0.74 – 6.96	0.044
Reamed nail	1.68	0.63 – 4.47	0.161

TABLE 4. Chi squared analyses of infection rates of reamed and unreamed nail vs. circular fixators for Type IIIB open fractures

Treatment	OR	95% CI	p-value
Circular fixator	Reference		
Unreamed nail	6.40	2.65 – 15.44	<0.001
Reamed nail	7.19	3.09 – 16.59	<0.001

[4] Bilat C, Leutenegger A, Rüedi T. Osteosynthesis of 245 tibial shaft fractures: early and late complications. Injury. 1994;25:349–358.
[5] Henley MB, Chapman JR, Agel J, Harvey EJ, Whorton AM, Swiontkowski MF. Treatment of type II, IIIA, and IIIB open fractures of the tibial shaft: a prospective comparison of unreamed interlocking intramedullary nails and half-pin external fixators. J Orthop Trauma. 1998;12:1–7.
[6] Shannon FJ, Mullett H, O'Rourke K. Unreamed intramedullary nail versus external fixation in grade III open tibial fractures. J Trauma. 2002;52:650–654.
[7] Inan M, Halici M, Ayan I, Tuncel M, Karaoglu S. Treatment of type IIIA open fractures of tibial shaft with Ilizarov external fixator versus unreamed tibial nailing. Arch Orthop Trauma Surg. 2007;127:617–623. doi:10.1007/s00402-007-0332-9.
[8] Hutson JJ, Dayicioglu D, Oeltjen JC, Panthaki ZJ, Armstrong MB. The treatment of gustilo grade IIIB tibia fractures with application of antibiotic spacer, flap, and sequential distraction osteogenesis. Ann Plast Surg. 2010;64:541–552. doi:10.1097/SAP.0b013e3181cf9fb5.
[9] Alberts KA, Loohagen G, Einarsdottir H. Open tibial fractures: faster union after unreamed nailing than external fixation. Injury. 1999;30:519–523.
[10] Tornetta P, Bergman M, Watnik N, Berkowitz G, Steuer J. Treatment of grade-IIIb open tibial fractures. A prospective randomised comparison of external fixation and non-reamed locked nailing. J Bone Joint Surg Br. 1994;76:13–19.
[11] Holbrook JL, Swiontkowski MF, Sanders R. Treatment of open fractures of the tibial shaft: Ender nailing versus external fixation. A randomized, prospective comparison. J Bone Joint Surg Am. 1989;71:1231–1238.
[12] Mohseni MA, Soleimanpour J, Mohammadpour H, Shahsavari A. AO tubular external fixation vs. unreamed intramedullary nailing in open grade IIIA-IIIB tibial shaft fractures: a single-center randomized clinical trial. Pak J Biol Sci. 2011;14:490–495.
[13] Tu YK, Lin CH, Su JI, Hsu DT, Chen RJ. Unreamed interlocking nail versus external fixator for open type III tibia fractures. J Trauma. 1995;39:361–367.
[14] Court-Brown CM, Wheelwright EF, Christie J, McQueen MM. External fixation for type III open tibial fractures. J Bone Joint Surg Br. 1990;72:801–804.
[15] Edwards CC, Simmons SC, Browner BD, Weigel MC. Severe open tibial fractures. Results treating 202 injuries with external fixation. Clin Orthop Relat Res. 1988:98–115.
[16] Webb LX, Bosse MJ, Castillo RC, MacKenzie EJ, LEAP Study Group. Analysis of surgeon-controlled variables in the treatment of limb-threatening type-III open tibial diaphyseal fractures. J Bone Joint Surg Am. 2007;89:923–928. doi:10.2106/JBJS.F.00776.
[17] Esmaeilnejad Ganji SM, Bahrami M, Joukar F. Ilizarov versus AO external fixator for the treatment of tibia open fractures. Iran Red Crescent Med J. 2011;13:868–872.
[18] Naique SB, Pearse M, Nanchahal J. Management of severe open tibial fractures: the need for combined orthopaedic and plastic surgical treatment in specialist centres. J Bone Joint Surg Br. 2006;88:351–357. doi:10.1302/0301-620X.88B3.17120.
[19] Schandelmaier P, Krettek C, Rudolf J, Kohl A, Katz BE, Tscherne H. Superior results of tibial rodding versus external fixation in grade 3B fractures. Clin Orthop Relat Res. 1997:164–172.
[20] Wani N, Baba A, Kangoo K, Mir M. Role of early Ilizarov ring fixator in the definitive management of type II, IIIA and IIIB open tibial shaft fractures. Int Orthop. 2011;35:915–923. doi:10.1007/s00264-010-1023-7.
[21] Ramos T, Eriksson BI, Karlsson J, Nistor L. Ilizarov external fixation or locked intramedullary nailing in diaphyseal tibial fractures: a randomized, prospective study of 58 consecutive patients. Arch Orthop Trauma Surg. 2014;134:793–802. doi:10.1007/s00402-014-1970-3.
[22] Keeling JJ, Gwinn DE, Tintle SM, Andersen RC, McGuigan FX. Short-term outcomes of severe open wartime tibial fractures treated with ring external fixation. J Bone Joint Surg Am. 2008;90:2643–2651. doi:10.2106/JBJS.G.01326.
[23] Nieuwoudt L, Ferreira N, Marais L. Short-term results of grade III open tibia fractures treated with circular fixators. SA Orthop J. 2016;15. doi:10.17159/2309-8309/2016/v15n3a2.
[24] Dickson DR, Moulder E, Hadland Y, Giannoudis PV, Sharma HK. Grade 3 open tibial shaft fractures treated with a circular frame, functional outcome and systematic review of literature. Injury. 2015;46:751–758. doi:10.1016/j.injury.2015.01.025.
[25] Kumar P, Singh GK, Bajracharya S. Treatment of grade IIIB opens tibial fracture by Ilizarov hybrid external fixator. Kathmandu Univ Med J. 2007;5:177–180.
[26] Hosny G, Fadel M. Ilizarov external fixator for open fractures of the tibial shaft. Int Orthop. 2003;27:303–306. doi:10.1007/s00264-003-0476-3.
[27] Foster P a. L, Barton SB, Jones SCE, Morrison RJM, Britten S. The treatment of complex tibial shaft fractures by the Ilizarov method. J Bone Joint Surg Br. 2012;94:1678–1683. doi:10.1302/0301-620X.94B12.29266.
[28] Sen C, Kocaoglu M, Eralp L, Gulsen M, Cinar M. 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. 2004;18:150–157.
[29] Bonatus T, Olson SA, Lee S, Chapman MW. Nonreamed locking intramedullary nailing for open fractures of the tibia. Clin Orthop Relat Res. 1997:58–64.
[30] Tielinen L, Lindahl JE, Tukiainen EJ. Acute unreamed intramedullary nailing and soft tissue reconstruction with muscle flaps for the treatment of severe open tibial shaft fractures. Injury. 2007;38:906–912. doi:10.1016/j.injury.2007.02.052.
[31] Sanders R, Jersinovich I, Anglen J, DiPasquale T, Herscovici D. The treatment of open tibial shaft fractures using an interlocked intramedullary nail without reaming. J Orthop Trauma. 1994;8:504–510.
[32] Papakostidis C, Kanakaris NK, Pretel J, Faour O, Morell DJ, Giannoudis PV. Prevalence of complications of open tibial shaft fractures stratified as per the Gustilo-Anderson classification. Injury. 2011;42:1408–1415. doi:10.1016/j.injury.2011.10.015.
[33] Finkemeier CG, Schmidt AH, Kyle RF, Templeman DC, Varecka TF. A prospective, randomized study of intramedullary nails inserted with and without reaming for the treatment of open and closed fractures of the tibial shaft. J Orthop Trauma. 2000;14:187–193.
[34] Kakar S, Tornetta P. Open fractures of the tibia treated by immediate intramedullary tibial nail insertion without reaming: a prospective study. J Orthop Trauma. 2007;21:153–157. doi:10.1097/BOT.0b013e3180336923.
[35] Joshi D, Ahmed A, Krishna L, Lal Y. Unreamed interlocking nailing in open fractures of tibia. J Orthop Surg Hong Kong. 2004;12:216–221. doi:10.1177/230949900401200215.
[36] Kulshrestha V. Incidence of infection after early intramedullary nailing of open tibial shaft fractures stabilized with pinless external fixators. Indian J Orthop. 2008;42:401–409. doi:10.4103/0019-5413.43382.
[37] Gaebler C, Berger U, Schandelmaier P, Greitbauer M, Schauwecker HH, Applegate B, et al. Rates and odds ratios for complications in closed and open tibial fractures treated with unreamed, small diameter tibial nails: a multicenter analysis of 467 cases. J Orthop Trauma. 2001;15:415–423.
[38] Keating JF, O'Brien PJ, Blachut PA, Meek RN, Broekhuyse HM. Locking intramedullary nailing with and without reaming for open fractures of the tibial shaft. A prospective, randomized study. J Bone Joint Surg Am. 1997;79:334–341.
[39] Whittle AP, Russell TA, Taylor JC, Lavelle DG. Treatment of open fractures of the tibial shaft with the use of interlocking nailing without reaming. J Bone Joint Surg Am. 1992;74:1162–1171.
[40] Oh CW, Park BC, Ihn JC, Park HJ. Primary unreamed intramedullary nailing for open fractures of the tibia. Int Orthop. 2001;24:338–341.
[41] Ziran BH, Darowish M, Klatt BA, Agudelo JF, Smith WR. Intramedullary nailing in open tibia fractures: a comparison of two techniques. Int Orthop. 2004;28:235–238. doi:10.1007/s00264-004-0567-9.
[42] Bone LB, Kassman S, Stegemann P, France J. Prospective study of union rate of open tibial fractures treated with locked, unreamed intramedullary nails. J Orthop Trauma. 1994;8:45–49.
[43] Shepherd LE, Costigan WM, Gardocki RJ, Ghiassi AD, Patzakis MJ, Stevanovic MV. Local or free muscle flaps and unreamed interlocked nails for open tibial fractures. Clin Orthop. 1998:90–96.
[44] Darder-García A, Darder-Prats A, Gomar-Sancho F. Nonreamed flexible locked intramedullary nailing in tibial open fractures. Clin Orthop Relat Res. 1998:97–104.
[45] Stegemann P, Lorio M, Soriano R, Bone L. Management protocol for unreamed interlocking tibial nails for open tibial fractures. J Orthop Trauma. 1995;9:117–120.
[46] Cole JD, Ansel LJ, Schwartzberg R. A sequential protocol for management of severe open tibial fractures. Clin Orthop Relat Res. 1995:84–103.
[47] Singer RW, Kellam JF. Open tibial diaphyseal fractures. Results of unreamed locked intramedullary nailing. Clin Orthop Relat Res. 1995:114–118.
[48] SPRINT Investigators, Bhandari M, Guyatt G, Tornetta P, Schemitsch E, Swiontkowski M, et al. Study to prospectively evaluate reamed intramedullary nails in patients with tibial fractures (S.P.R.I.N.T.): study rationale and design. BMC Musculoskelet Disord. 2008;9:91. doi:10.1186/1471-2474-9-91.
[49] Fischer MD, Gustilo RB, Varecka TF. The timing of flap coverage, bone-grafting, and intramedullary nailing in patients who have a fracture of the tibial shaft with extensive soft-tissue injury. J Bone Joint Surg Am. 1991;73:1316–1322.
[50] Kaltenecker G, Wruhs O, Quaicoe S. Lower infection rate after interlocking nailing in open fractures of femur and tibia. J Trauma. 1990;30:474–479.
[51] McGraw JM, Lim EV. Treatment of open tibial-shaft fractures. External fixation and secondary intramedullary nailing. J Bone Joint Surg Am. 1988;70:900–911.
[52] Djahangiri A, Garofalo R, Chevalley F, Leyvraz P-F, Wettstein M, Borens O, et al. Closed and open grade I and II tibial shaft fractures treated by reamed intramedullary nailing. Med Princ Pract. 2006;15:293–298. doi:10.1159/000092993.
[53] Dunbar RP, Nork SE, Barei DP, Mills WJ. Provisional plating of Type III open tibia fractures prior to intramedullary nailing. J Orthop Trauma. 2005;19:412–414.
[54] Oh CW, Bae SY, Jung DY, Oh JK. Treatment of open tibial shaft fractures using tightly fitted interlocking nailing. Int Orthop. 2006;30:333–337. doi:10.1007/s00264-006-0093-z.