[21] Tulner SAF, Schaap GR, Strackee SD, Besselaar PP, Luitse JSK, Marti RK. Long-term results of multiple-stage treatment for posttraumatic osteomyelitis of the tibia. J Trauma. 2004;56:633–642.

[22] Weiland AJ, Moore JR, Daniel RK. The efficacy of free tissue transfer in the treatment of osteomyelitis. J Bone Joint Surg Am. 1984;66:181–193.

Authors: Brianna Fram, Paul Tornetta III

QUESTION 6: What is the appropriate timing of conversion to internal fixation (in-fix) following external fixation (ex-fix)? How is this altered by pin site infection?

RECOMMENDATION: Timing of conversion should be based on patient characteristics including concurrent injuries and premorbid health and function, as well as injury features and location. One-stage conversion appears to have similar or even lower infection rates compared to two-stage conversion. In the absence of pin site infection, early conversion is preferred.

LEVEL OF EVIDENCE: Limited

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

RATIONALE

American development of external fixation is credited to Parkhill in 1897 and European development to Lambotte in 1900 [1]. Ex-fix is often used in polytraumatized patients as part of a damage-control orthopaedic approach, in injuries with extensive soft tissue compromise, or when appropriate personnel or resources for in-fix are not readily available [2,3]. It is applicable to periarticular fractures, long bone fractures and articular dislocations, making it an essential component of contemporary orthopaedic traumatology.

Recent literature review using the databases Embase, Scopus, Google Scholar and PubMed was performed with the search terms "internal fixation," "external fixation," "timing" and "conversion" in multiple combinations. Articles were reviewed for relevance and studies were then assessed for quality and assigned a level of evidence.

Following ex-fix, conversion to in-fix can have multiple benefits for patients. A prospective comparison of 39 patients with open lower leg fractures treated with primary ex-fix with randomized conversion to intramedullary nailing (IMN) or to cast immobilization showed significantly shorter mean time to union (26.3 vs. 35.4 weeks), higher overall consolidation rates (94% vs. 64%), and better knee and ankle range of motion (ROM) for IMN [4]. Regarding timing of conversion from external to internal fixation (which includes plate/screw constructs and intramedullary nail constructs), major questions within the field are as follows: (1) Should conversion be performed in one procedure (acute) or in two (staged)? (2) Does time in ex-fix affect outcomes following conversion? (3) Do pin site infections increase the risk of deep infection following in-fix? (4) Does timing of soft tissue coverage affect outcomes following conversion? [2].

Regarding staging, theoretically staged conversion should allow time for pin site granulation and decrease infection rates. Therefore, some authors recommend delayed internal fixation until pin sites heal closed [5]. However, data from level IV studies do not support this. Horst et al. reported on two protocols, one for immediate conversion and one for staged conversion from external to internal fixation. They included local excision of skin-pin interfaces and curettage of soft tissues around pin track sites. For immediate conversion, pin sites were disinfected and covered prior to re-prepping of the surgical field. Pin sites were left covered until all in-fix wounds were closed, and then pin sites were left open with antibacterial dressings. For staged conversion, ex-fix was exchanged for a cast and any required soft tissue coverage was performed prior to in-fix. After institution of this algorithm utilizing the immediate conversion protocol, they observed a decrease in time to conversion (mean 6.8 > 5.0 days), hospital length of stay (mean 25.4 > 16.3 days) and complication rate (21% > 8.3%) [6].

Monni et al. performed a retrospective review of 18 patients (24 limbs) undergoing conversion from external to internal fixation for traumatic bone defects or congenital deformities. Indications for conversion included patient dissatisfaction with ex-fix, pin track sepsis, persistent non-union or refracture. In-fix consisted of IMN or plate and screw constructs. Conversion was performed acutely (19 limbs) or staged (5 limbs). The outcome was considered excellent if patients were full weightbearing, pain free, had a mechanically well-aligned limb and did not need further surgery within the follow-up period. The outcome was considered good if patients required subsequent surgery to achieve union and the outcome was considered poor if an irreversible complication occurred. The acute group had 16 excellent and 1 good outcomes (89.4%), with 2 (10.6%) poor outcomes resulting in amputation, both after acute conversion to IMN for infected tibial nonunion. The delayed group had four (80%) excellent and one (20%) good outcomes. They cautioned against using IMNs in patients with a diagnosis of an actively septic nonunion and reported that conversion to in-fix generally produces good to excellent results [7]. Bandhari et al. found that shorter intervals between ex-fix removal and IMN, for planned or salvage procedures, correlated with reduced infection, but do comment that in level IV studies this may represent confounding [8].

Farrell et al. reported on ex-fix with one-stage conversion to in-fix for nine calcaneus fractures. Ex-fix was applied within 24-48 hours and converted to open reduction and internal fixation (ORIF) through a sinus tarsi approach at an average of 4.8 days from ex-fix. There were no pin tract infections, deep infections or wound healing complications [9]. Natoli et al. reported on 16 complex distal radius fractures, 11 of which were open, and treated with an ex-fix and converted to ORIF at a mean of 8.5 days. One patient developed deep infection, and they did not report a relationship with open fractures, time to conversion of < or > 7 days, or ex-fix pins overlapping the definitive fixation [10]. Shah et al. reported on pilon and tibial plateau fractures treated with ex-fix converted to ORIF excluding cases with evidence of overt pin site infection. They demonstrated a 24% rate of deep

infection when definitive fixation overlapped pin sites, compared to 10% when it did not; a statistically significant increase [11].

Roussignol et al. performed a retrospective review of 55 patients treated with ex-fix and secondary IMN after traumatic tibial shaft fractures (16 closed, 39 open). Of note, they also excluded patients with external fixator pin site infections. They analyzed time to IMN (mean 9 +/-9.6 weeks), acute or delayed exchange (23 acute vs. 32 staged, mean 12-day interval), culture results of reaming products, post-IMN infection and time to union. There were four septic complications and one aseptic nonunion requiring re-nailing. Acute versus delayed IMN did not correlate with increased infection risk, with only open fracture grade correlating with infection risk, and the union rate was 96%. Based on these results, they therefore recommend acute (one-stage) exchange of ex-fix for IMN [12]. Bhandari et al. performed a literature review on ex-fix conversion to IMN in tibia and femur fractures, including one level II study and the remainder level IV studies. They looked at studies with planned conversion from ex-fix to IMN, and those where IMN was used to salvage failed treatment with ex-fix. In 6 studies totaling 185 patients for planned conversion for femur fracture, with a mean 10 days ex-fix and 1 day interval to IMN, the infection rate was 2.6%. For tibias, 9 studies on planned conversion (n = 268) averaged 8.6% infection and 92% union, with shorter ex-fix time (< 28 days) correlating with an 83% reduction in the risk of infection compared to > 28 days [8].

Regarding time in ex-fix, Monni et al. reported a mean ex-fix time of 185 days (range 61-370), with poor outcomes correlating with longer time [7]. Bhandari et al. performed a meta-analysis assessing when to perform conversion, with deep infection rates 83% lower when IMN was performed within 28 days compared to after 28 days [8]. These studies both suggest earlier conversion is preferable. However, Yokoyama et al. performed multivariate analysis of 42 cases of secondary IMN after open lower leg fracture treated with initial ex-fix, with 7 (16.7%) developing deep infection, and found only time to skin coverage, with a threshold of 1 week, was significantly correlated with deep infection. They did not find a relationship between infection and the duration of ex-fix (</= or > 3 weeks), the interval between ex-fix removal and IMN (</= or > 2 weeks), or the existence of superficial infection or pin tract infection [13]. Similarly, Roussignol et al. did not find a correlation between infection risk and time in ex-fix before IMN [7].

While most studies have excluded patients with active pin site infections, Yokoyama et al. did not find a relationship between superficial infection or pin tract infection and rates of deep infection after IMN [13].

Regarding timing of soft tissue coverage, the previously cited Yokoyama et al. noted restoration of soft tissue coverage within one week correlated with a decreased risk of infection [13]. Outside of external to internal fixation conversion, other literature has used the threshold of five days from initial injury to wound closure before rates of wound healing complications and infections increase [9]. Most orthopaedic literature supports earlier soft tissue coverage in open fractures as protective against infection, irrespective of fixation type [14].

REFERENCES

[1] Hernigou P. History of external fixation for treatment of fractures. Int Orthop. 2017;41:845–853. doi:10.1007/s00264-016-3324-y.
[2] Nieto H, Baroan C. Limits of internal fixation in long-bone fracture. Orthop Traumatol Surg Res. 2017;103:S61–S66. doi:10.1016/j.otsr.2016.11.006.
[3] Sirkin M, Sanders R, DiPasquale T, Herscovici D. A staged protocol for soft tissue management in the treatment of complex pilon fractures. J Orthop Trauma. 2004;18:S32–S 38.
[4] Antich-Adrover P, Martí-Garin D, Murias-Alvarez J, Puente-Alonso C. External fixation and secondary intramedullary nailing of open tibial fractures. A randomised, prospective trial. J Bone Joint Surg Br. 1997;79:433–437.
[5] Blachut PA, Meek RN, O'Brien PJ. External fixation and delayed intramedullary nailing of open fractures of the tibial shaft. A sequential protocol. J Bone Joint Surg Am. 1990;72:729–735.
[6] Horst K, Andruszkow H, Weber C, Dienstknecht T, Hildebrand F, Tarkin I, et al. Standards of external fixation in prolonged applications to allow safe conversion to definitive extremity surgery: the Aachen algorithm for acute ex fix conversion. Injury. 2015;46 Suppl 3:S13–S18. doi:10.1016/S0020-1383(15)30005-X.
[7] Monni T, Birkholtz FF, de Lange P, Snyckers CH. Conversion of external fixation to internal fixation in a non-acute, reconstructive setting: a case series. Strategies Trauma Limb Reconstr. 2013;8:25–30. doi:10.1007/s11751-013-0157-8.
[8] Bhandari M, Zlowodzki M, Tornetta P, Schmidt A, Templeman DC. Intramedullary nailing following external fixation in femoral and tibial shaft fractures. J Orthop Trauma. 2005;19:140–144.
[9] Godina M. Early microsurgical reconstruction of complex trauma of the extremities. Plast Reconstr Surg. 1986;78:285–292.
[10] Natoli RM, Baer MR, Bednar MS. Conversion of external fixation to open reduction and internal fixation for complex distal radius fractures. Orthop Traumatol Surg Res. 2016;102:339–343. doi:10.1016/j.otsr.2016.01.013.
[11] Shah CM, Babb PE, McAndrew CM, Brimmo O, Badarudeen S, Tornetta P, et al. Definitive plates overlapping provisional external fixator pin sites: is the infection risk increased? J Orthop Trauma. 2014;28:518–522. doi:10.1097/BOT.0000000000000077.
[12] Roussignol X, Sigonney G, Potage D, Etienne M, Duparc F, Dujardin F. Secondary nailing after external fixation for tibial shaft fracture: risk factors for union and infection. A 55 case series. Orthop Traumatol Surg Res. 2015;101:89–92. doi:10.1016/j.otsr.2014.10.017.
[13] Yokoyama K, Uchino M, Nakamura K, Ohtsuka H, Suzuki T, Boku T, et al. Risk factors for deep infection in secondary intramedullary nailing after external fixation for open tibial fractures. Injury. 2006;37:554–560. doi:10.1016/j.injury.2005.08.026.
[14] Mathews JA, Ward J, Chapman TW, Khan UM, Kelly MB. Single-stage orthoplastic reconstruction of Gustilo-Anderson Grade III open tibial fractures greatly reduces infection rates. Injury. 2015;46:2263–2266. doi:10.1016/j.injury.2015.08.027.

Authors: Arnold Suda, Stephen Quinnan, Brendan Gleason

QUESTION 7: What are the alternatives to segmental resection in septic non-union?

RECOMMENDATION: Surgical alternatives to segmental resection include bone grafting, unroofing, decortication, distraction osteogenesis or intramedullary reaming to address the site of osteomyelitis. All dead bone and soft tissue should be removed.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 91%, Disagree: 0%, Abstain: 9% (Super Majority, Strong Consensus)

RATIONALE

Operative debridement of necrotic tissue has been a surgical principle of infection treatment for centuries. Reports from the 1960s demonstrated that it is sometimes possible to heal a fracture nonunion with bone grafting and stabilization without disruption