JB&JS OPEN ACCESS

A Cost-Effectiveness Analysis of Intramedullary Nailing Versus External Fixation for Open Tibial Fractures in Tanzania

Jamieson M. O'Marr, MD, MS, Patricia Rodarte, BS, Billy Haonga, MD, Patrick Ngunyale, MD, Heather Roberts, MD, Saam Morshed, MD, PhD, and David Shearer, MD, MS

Investigation performed at the University of California San Francisco, San Francisco, California, and the Muhimbili Orthopaedic Institute, Dar es Salaam, Tanzania

Background: Open tibial fractures are a cause of substantial orthopaedic morbidity in low- and middle-income countries. These injuries represent a substantial cost burden to both individual patients and society because of their high propensity for complications, such as infection, nonunion, and malunion. External fixation and intramedullary (IM) nailing are both utilized for definitive treatment of open tibial fractures, but given the differences in cost and lack of clear superiority of intramedullary nailing, cost-effectiveness becomes important to consider in low- and middle-income countries. The present study aimed to examine the cost-effectiveness of IM nailing versus external fixation within Tanzania.

Methods: This study utilized data from a randomized controlled trial conducted at a single tertiary hospital in Dar es Salaam, Tanzania. Direct cost data were collected via an internal audit of operating costs and hospital staff time. Indirect costs data were collected from patients in a long-term follow-up study assessing total lost work. A Markov model was utilized to run the cost-effectiveness simulations. The primary outcome was the incremental cost-effectiveness ratio (ICER) over a lifetime time horizon. Both the payer and societal perspectives were considered. To account for uncertainty, both 1-way and probabilistic sensitivity analyses were performed.

Results: From the payer perspective, the cost of external fixation ($396 USD) was lower than that of IM nailing ($529), primarily because of shorter operative times. However, IM nailing was associated with more quality-adjusted life-years (QALYs). From the payer perspective, the ICER was $499 per QALY with a donated nail and $701 per QALY with a purchased locally available nail. From the societal perspective, the ICER was lower among patients undergoing IM nailing, at $70 per QALY, largely because of shorter recovery times.

Conclusions: From both the payer and the societal perspective, IM nailing is considered highly cost-effective on the basis of the World Health Organization willingness-to-pay thresholds. This finding was consistent whether the IM nail was donated or purchased from local suppliers. These results are likely generalizable to other tertiary referral centers in low- and middle-income countries.

Level of Evidence: Economic Level II. See Instructions for Authors for a complete description of levels of evidence.

Open tibial fractures are a cause of substantial morbidity in developing countries because of their increasing incidence, which is driven by a global rise in road traffic accidents in these settings[1,2]. Open tibial fractures are surgical emergencies that require urgent treatment, including early systemic antibiotic prophylaxis, surgical wound debridement, soft-tissue coverage, and osseous stabilization[3,4]. Even with appropriate and timely treatment, open tibial fractures have a high risk of complications, with infection rates of up to 40%. Osseous nonunion can also occur, which can require

Disclosure: No external funding was received for this work. SIGN implants were donated as part of existing partnerships between SIGN Fracture Care and Muhimbili Orthopaedic Institute. The Article Processing Charge for open access publication was funded by the University of California San Francisco. The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A768).

reoperation or even amputation[5-7]. These injuries also have substantial economic impact on both individual patients and health systems at large, with up to 25% of patients not able to return to work at 1 year postoperatively[8].

Intramedullary (IM) nailing and external fixation (EF) are both acceptable treatment options for definitive stabilization of open tibial fractures. Recent meta-analyses comparing these treatment options have favored IM nailing due to its lower rates of malunion and reoperation[9,10]. Conversely, a study performed by our group in Tanzania demonstrated no difference between the 2 treatment options in terms of infection or nonunion, but with better health-related quality of life, alignment, and radiographic healing following IM nailing[11].

The cost difference between IM nailing and EF is another important consideration. Orthopaedic surgeons in resource-austere environments around the world have suggested that implant cost plays a substantial role in treatment decisions[12,13]. In certain contexts, patients and their families must purchase all necessary implants prior to surgery, which adds a substantial cost burden and sometimes delays treatment. In these environments, EF is generally more readily available because of the cheaper components and less resource-intensive implementation process[14]. In addition to comparing implant costs, it is important to consider the substantial other costs involved with open tibial fractures, including the cost of the operation, length of hospitalization, length of follow-up, and lost productivity for patients as they heal[15]. Although IM nailing device costs tend to be higher than EF costs, EF often requires multiple operations, which can reduce any potential cost savings.

Given the lack of clear superiority of either treatment over the other and the known differences in cost, cost-effectiveness becomes important to consider from both the payer and societal perspectives. We sought to compare the cost-effectiveness of IM nailing versus EF in Tanzania utilizing data obtained from a prior randomized trial and projected over time with use of a Markov model.

Materials and Methods

This secondary analysis utilized data collected in a prior randomized controlled trial conducted at a tertiary referral hospital in Dar es Salaam, Tanzania[11]. The initial trial data, including clinical outcomes, quality of life, and complications, were collected between December 2015 and March 2017, whereas long-term follow-up data were collected from January 2020 through February 2021[11,16]. Adult patients with OTA/AO type-42 open tibial fractures[17], Gustilo Types 1 through 3A, presenting within 24 hours were randomized to receive either a hand-reamed IM nail or a uniplanar external fixator. Patients who required flap coverage or who had a vascular injury were excluded. Patients attended follow-up appointments at 2, 6, 12, 26, and 52 weeks, at which clinical outcome data, health-related quality of life (EuroQol-5 Dimensions index [EQ-5D]), and employment information were collected. The study utilized hand-reamed solid interlocking nails (SIGN Fracture Care International) or uniplanar external fixators with 2 Schanz pins in both the proximal and distal segments, connected by a single stainless-steel bar (Samay Surgical). A long-term follow-up study was conducted in which patients from the original trial were evaluated 3 to 5 years postoperatively in order to assess health-related quality of life, subsequent procedures, and work status[16]. Ethical approval was obtained for both studies from the North American institution and the Tanzania National Institute for Medical Research (NIMR).

Model Parameters

To project the outcomes of the clinical trial beyond the study follow-up period, a Markov model was created. The model contained 3 types of parameters: costs, utilities, and probabilities. The direct medical expenditures contained in our model included those for personnel time, medical supplies, operative supplies, medications, and surgical implants. Because these costs were not recorded during the initial randomized trial comparing EF and IM nailing, these data were gathered from a separate cohort of patients enrolled in a clinical trial at the same site evaluating the use of local antibiotics to prevent infection in open tibial fractures that were suitable for fixation and primary closure (i.e., the pGO-Tibia trial)[18]. For this separate trial, a time and motion analysis was conducted in which all personnel involvement and supply usage were directly observed by a research coordinator, including the amount of time each member of the care team (i.e., anesthetist, attending surgeon, resident physician, nurse, radiologist, radiologist technician, and hospital assistant) spent conducting patient care. Person-hours for each personnel type were summed separately for both the operating room, including perioperative and postoperative times, and the remaining hospital stay. Average salaries for each position were obtained from the hospital and used to calculate the total cost of care for each patient. All cost data were collected within 1 year of the health utilities and outcome data. No reoperation cost data were available in Africa; thus, estimates were based on a review of literature in other contexts, which showed costs of reoperation for a major complication ranging from 2 to 6.5 times those of the index operation[19-21].

The quantities of all medical supplies and medications were similarly observed and recorded. Costs for each item were obtained from the hospital invoice list. Hospital overhead costs were accounted for by using the "ratio of costs to charges" method, in which the annual hospital expenditures for additional staff and resources are used to estimate the cost per patient for the average length of stay.

The cost of surgical implants was obtained directly from the suppliers. From the payer perspective, hospital charges were used to determine the cost of the implant. The societal perspective considered the implant's total cost of production for a health system. The IM nails used in the study were supplied by SIGN Fracture Care International (SIGN), a nonprofit company that manufactures and donates implants and instrumentation to participating programs in low- and middle-income countries, and by Samay Surgical. Donated implants were considered free from the payer perspective, whereas from the societal perspective, the actual manufacturing cost and provision of the

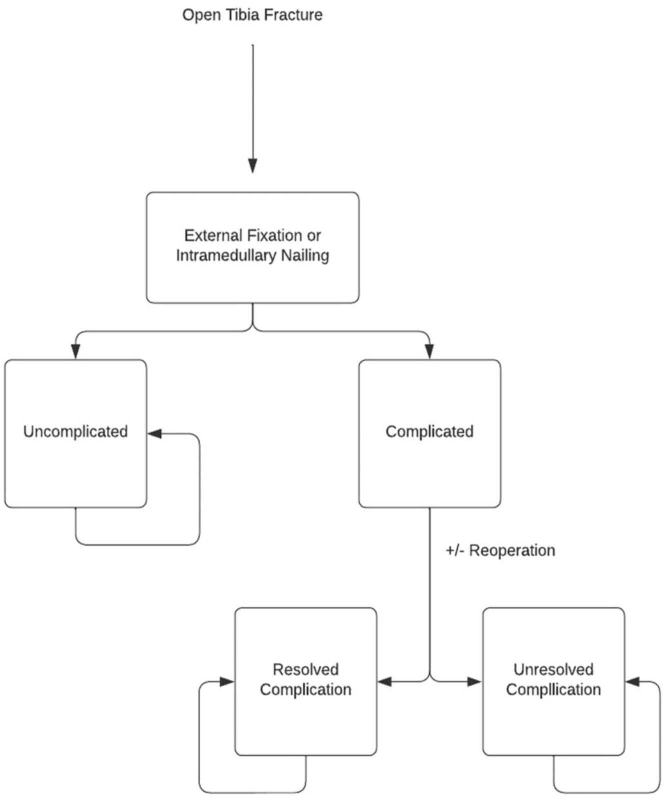

Fig. 1
Markov model.

implant to the patient were used. The external fixators used in the study were manufactured by Samay Surgical, an Indian company. Based on local practice, we assumed that the external fixator bars and clamps would be reused 3 times. The cost for the Samay external fixator was used for calculations from both the payer and societal perspectives. To allow for a more realistic comparison, we also used the cost of a Samay-manufactured IM nail rather than the SIGN nail in a sensitivity analysis from the payer perspective. Instrumentation costs were assumed to be equal between both groups and were approximated with an instrument lifetime of 10 years with 300 uses per year.

The indirect expenditures contained in our model included the lost productivity of the patient prior to returning to work. This measure of lost productivity was obtained during the long-term follow-up of the original IM nailing versus EF trial[16]. All patients who reported being employed, either formally or informally, prior to their injury were asked when they returned to work after their initial injury. The final costs of lost productivity for the patients were calculated using the standardized wage for Tanzania in 2018 U.S. dollar (USD) equivalents.

The utilities of the potential model outcomes and their probabilities of occurrence were obtained from the IM nailing versus EF trial and its long-term follow-up[11,16]. Utilities were estimated across the follow-up time points using the EuroQol-5D data[11]. The disutility of reoperation was estimated to be 0.2, which implies a 2-month period of severely impaired quality of life and is consistent with arthroplasty literature[22,23]. Finally, age-adjusted life tables for Tanzania were obtained from the World Health Organization (WHO) Global Health Observatory data repository and were used for the probability of death in our model[24].

Economic Model

The Markov model was created using TreeAge Pro 2022 (TreeAge Software) to represent our scenario considering IM nailing versus EF (Fig. 1). For each treatment strategy, the hypothetical cohort could enter 1 of 3 states in the first year: the uncomplicated group, the complicated group, or death. After the first year, patients remained in the uncomplicated group or entered either the resolved complication or unresolved complication group. All groups were maintained after this until patients entered the death state in their respective group. Discounting was applied using the standard 3% per year[25]. All costs were adjusted for inflation and converted to 2018 U.S. dollars for ease of interpretation. The cycle length was 1 year.

The model was run from both the payer (excluding indirect costs) and societal (including indirect costs) perspectives using a fee-for-service assumption based on the typical health-care system in Tanzania. To account for the alternative scenario in which a donated SIGN nail was not available, the payer perspective was also evaluated using the cost for a tibial IM nail provided by Samay Surgical. The primary outcome was the incremental cost-effectiveness ratio (ICER) over a lifetime time horizon.

For the purposes of our economic model, the willingness-to-pay threshold was set according to the 2005 cost-effectiveness guidelines by the WHO. The WHO defines the cost-effectiveness of an intervention at 3 levels according to a country's gross

TABLE I Patient Characteristics of the Original Study Population[11]*

	IM Nailing (N = 110)	EF (N = 108)
Age *(yr)*	33.4 ± 11.9	31.7 ± 9.6
Male sex	97 (88.1%)	89 (82.4%)
No formal employment	90 (81.8%)	80 (74.1%)
Current smoker	16 (14.5%)	24 (22.2%)
Current alcohol use	45 (40.9%)	35 (32.4%)
Body mass index *(kg/m²)*	25.2 ± 5.2	24.7 ± 4.6
Diabetes mellitus	7 (6.4%)	1 (0.9%)
No medical insurance	87 (79.1%)	90 (83.3%)
OTA/AO classification		
Type A	36 (32.7%)	35 (32.4%)
Type B	33 (30.0%)	28 (26.0%)
Type C	9 (8.2%)	8 (7.4%)
Wound length *(cm)*	3.7 ± 2.7	3.7 ± 2.4

*Values are given as the mean ± standard deviation or as the count with the percentage in parentheses. IM = intramedullary, EF = external fixation.

JBJS Open Access • 2025:e24.00006. openaccess.jbjs.org

TABLE II Inputs for the Markov Model

	IM Nailing	EF	Data Sources
Costs* *(USD)*			
Direct costs			
Operative supplies (excluding implant)	161 ± 9	108 ± 18	Time and motion analysis
Operative personnel	110 ± 9	104 ± 21	Time and motion analysis
Hospital ward personnel	36 ± 2	43 ± 5	Time and motion analysis
Implant	0‡	34§	SIGN and Samay
Reoperation costs†	2-6.5	2-6.5	[19-21]
Indirect costs			
Lost productivity: uncomplicated	2,513 ± 121	2,578 ± 85	[16]
Lost productivity: complication	2,807 ± 271	3,285 ± 412	[16]
Utilities*			
1st year: uncomplicated	0.80 ± 0.13	0.78 ± 0.14	[11]
1st year: complicated	0.64 ± 0.14	0.62 ± 0.21	[11]
Ongoing utility: uncomplicated	0.99 ± 0.01	0.99 ± 0.01	[16]
Ongoing utility: resolved complication	0.98 ± 0.02	0.97 ± 0.02	[16]
Ongoing utility: unresolved complication	0.86 ± 0.09	0.80 ± 0.15	[16]
Disutility of reoperation	−0.2	−0.2	[22,23]
Probabilities*			
Probability of death	Variable	Variable	Age-adjusted life tables from WHO Global Health Observatory data repository
Probability of complication	21.8% ± 0.9%	23.5% ± 0.9%	[11]
Probability of complication resolution	83.3% ± 6.8%	40.0% ± 14.1%	[11]
Probability of reoperation	27.7% ± 3.7%	22.0% ± 3.8%	[11]

*Values for cost data other than reoperation costs are given as the mean ± the standard error of the mean or as a fixed value. Values for utility and probability data are given as the mean ± standard deviation or as a fixed value, except for the probability of death. †Reoperation costs are represented as a multiplier range that is based on the cost of the index procedure. ‡Costs were $0 for a donated SIGN nail, $31 for a Samay nail, and $168 for production of a SIGN nail. §Cost of $34 includes the payer and society costs for a single use of the EF set.

domestic product (GDP) per capita[26,27]. An intervention was considered highly cost-effective if it was <1 times the GDP per capita, cost-effective if it was <3 times the GDP per capita, and not cost-effective if it was >3 times the GDP per capita. According to the World Bank, the GDP per capita for Tanzania in 2021 was $1,099 USD; thus, that value was set as the willingness-to-pay threshold.

One-way and multivariable sensitivity analyses were performed. A 1-way sensitivity analysis was used to evaluate the impact of implant costs. To assess the cost-effectiveness based on the values of multiple variables simultaneously, a probabilistic sensitivity analysis was performed with 10,000 iterations. In a probabilistic sensitivity analysis, variables are represented as distributions rather than point estimates, thereby creating a range of potential ICERs. Beta distributions were used for probabilities and utilities, and gamma distributions were used for costs.

Results

Most of the model parameters for utilities, complication rates, and resolution rates were derived from the trial assessing EF versus IM nailing for the treatment of open tibial fractures conducted by Haonga et al[11]. The demographics for this study cohort can be found in Table I. A long-term follow-up study evaluating outcomes and return to work beyond the original 1-year follow-up was conducted by Cortez et al[16]. This additional study was able to contact 52.5% of the original participants, and no differences were found between the contacted group and the lost-to-follow-up group across key demographic and injury characteristics.

The model parameters for costs, utilities (indicating effectiveness), and probabilities of outcomes can be found in Table II. Operative costs for IM nailing tended to be higher because of the longer operative time required for insertion of the implant. However, patients treated with IM nailing tended to have shorter lengths of hospital stay and less lost productivity compared with patients treated with EF. The utilities at 1 year appeared nearly equivalent, but patients in the IM nailing group tended to have a faster recovery of quality of life compared with the EF group (Fig. 2). Finally, the IM nailing group had a slightly lower probability of a complication and were

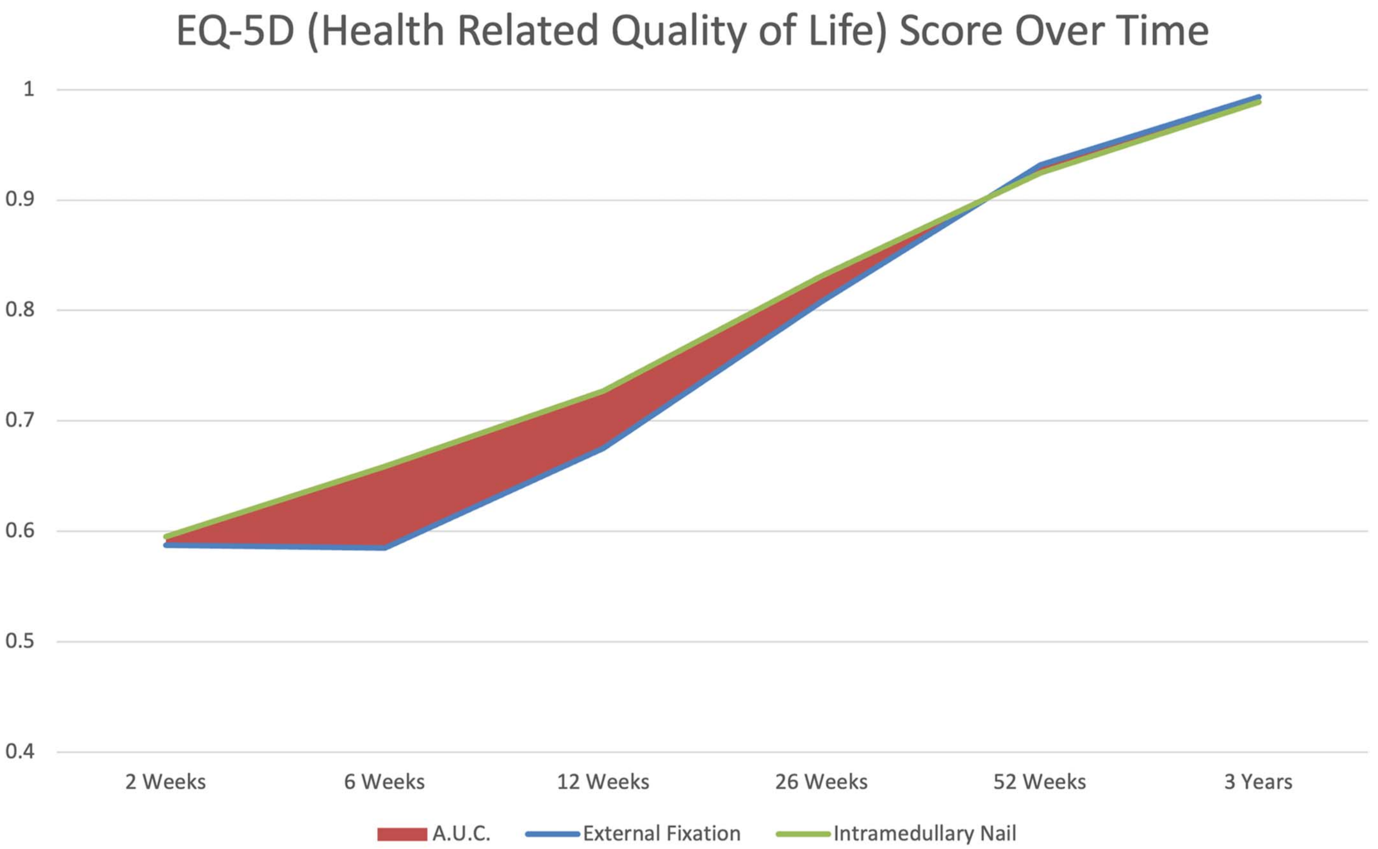

Fig. 2
EuroQol-5 Dimensions (EQ-5D) over time. A.U.C. = Area between the EQ-5D outcomes from IM and EF.

more likely to have a resolution of their complication than the EF group (Table II).

Outputs of the model can be found in Table III. From the payer perspective, with a donated SIGN nail, the EF treatment option cost less ($396 versus $529) but was less effective (21.6 versus 21.3 quality-adjusted life-years [QALYs]). The ICER from the payer perspective was $499 per QALY with the donated SIGN nail and $701 per QALY with the purchased Samay nail.

TABLE III Incremental Cost-Effectiveness and Net Monetary Benefit*

Procedure	Cost *(USD)*	Incremental Cost *(USD)*	Effectiveness *(QALY)*	Incremental Effectiveness *(QALY)*	ICER *(USD/QALY)*	Net Monetary Benefit *(USD)*
Payer perspective						
SIGN IM nail (nail cost, $0)						−$396.23
External fixation	$396		21.3			−$528.67
IM nailing	$529	$132.4	21.6	0.27	$499	
Samay IM nail (nail cost, $31)						
External fixation	$396		21.3			−$396.23
IM nailing	$582	$185.8	21.6	0.27	$701	−$582.03
Societal perspective						
External fixation	$3,025		21.3			−$3,024.52
IM nailing (nail production cost, $168)	$3,043	$18.6	21.6	0.27	$70	−$3,043.12

*ICER = incremental cost-effectiveness ratio.

From the societal perspective, in which indirect costs included the full production costs of the implant, the ICER was $70 per QALY.

Sensitivity analyses were performed for implant costs. One-way sensitivity analysis for the cost of the IM nailing demonstrated that with a willingness-to-pay of $1,099 USD (the GDP per capita of Tanzania), a cost of up to $442 would be acceptable (Fig. 3). A probabilistic sensitivity analysis with this willingness-to-pay threshold favored IM nailing in 60.0% of iterations (Fig. 4).

Discussion

The aim of this study was to assess the cost-effectiveness of IM nailing versus EF for the treatment of diaphyseal open tibial fractures in a resource-limited setting. Utilizing the WHO willingness-to-pay threshold for Tanzania ($1,099), IM nailing had an ICER value consistently below this threshold and thus was cost-effective compared with EF from both the payer and societal perspectives with all evaluated implants. However, there was considerable uncertainty surrounding these findings in the probabilistic sensitivity analysis because of the relatively modest clinical benefits of IM nailing versus EF and because the original trial was underpowered.

To our knowledge, the present study is the first to evaluate the cost-effectiveness of IM nailing versus EF for the treatment of diaphyseal open tibial fractures over a multiyear time horizon in a low-resource environment. The results of this study are important, as complications resulting from open tibial fractures can have effects that last for years, if not for the remainder of a patient's life[28]. These results reinforce preliminary findings from Tanzania, which suggested that IM nailing may indeed be more cost-effective than EF[29]. These findings are also consistent with a meta-analysis conducted by Fu et al. in a high-resource environment, which showed favorable results for IM nailing over EF in the treatment of open tibial fractures[30]. The preference of our model for IM nailing stems largely from the faster recovery and return to work compared with EF; however, the quality-of-life benefit of IM nailing over EF was not significant over long-term follow-up.

The present study had several limitations. Our results are dependent on the accuracy of the model inputs collected during the previously mentioned clinical studies. Some variables, such as the cost of reoperation, were not collected during those studies and were estimated according to the best available literature. Long-term estimates of quality of life were limited by a low rate of long-term follow-up (~50% at 3 to 5 years). Not all costs were adequately accounted for, including outpatient costs of care and indirect costs such as lost work for caregivers.

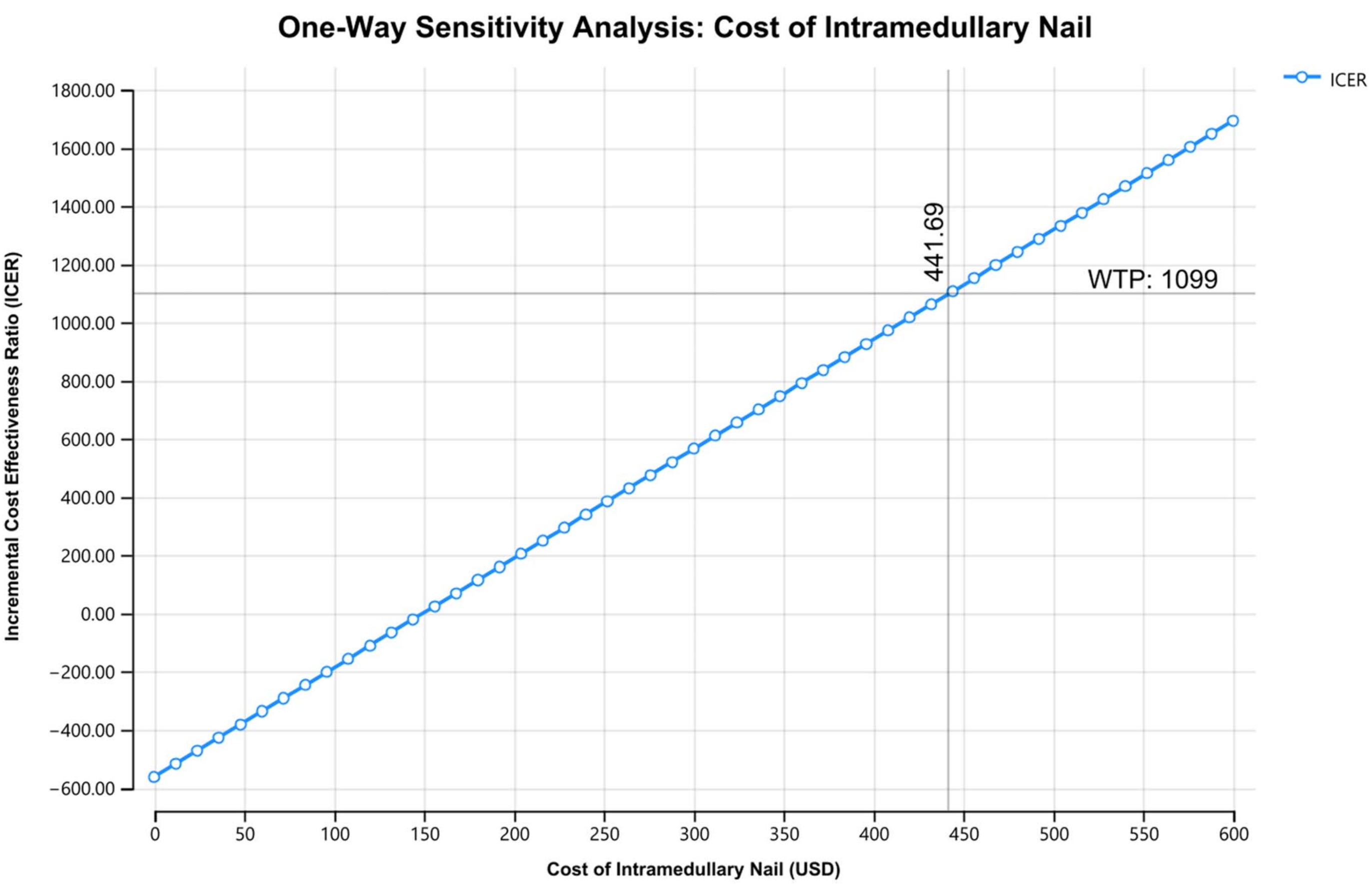

Fig. 3
One-way sensitivity analysis of the cost of the intramedullary nail. WTP = willingness-to-pay.

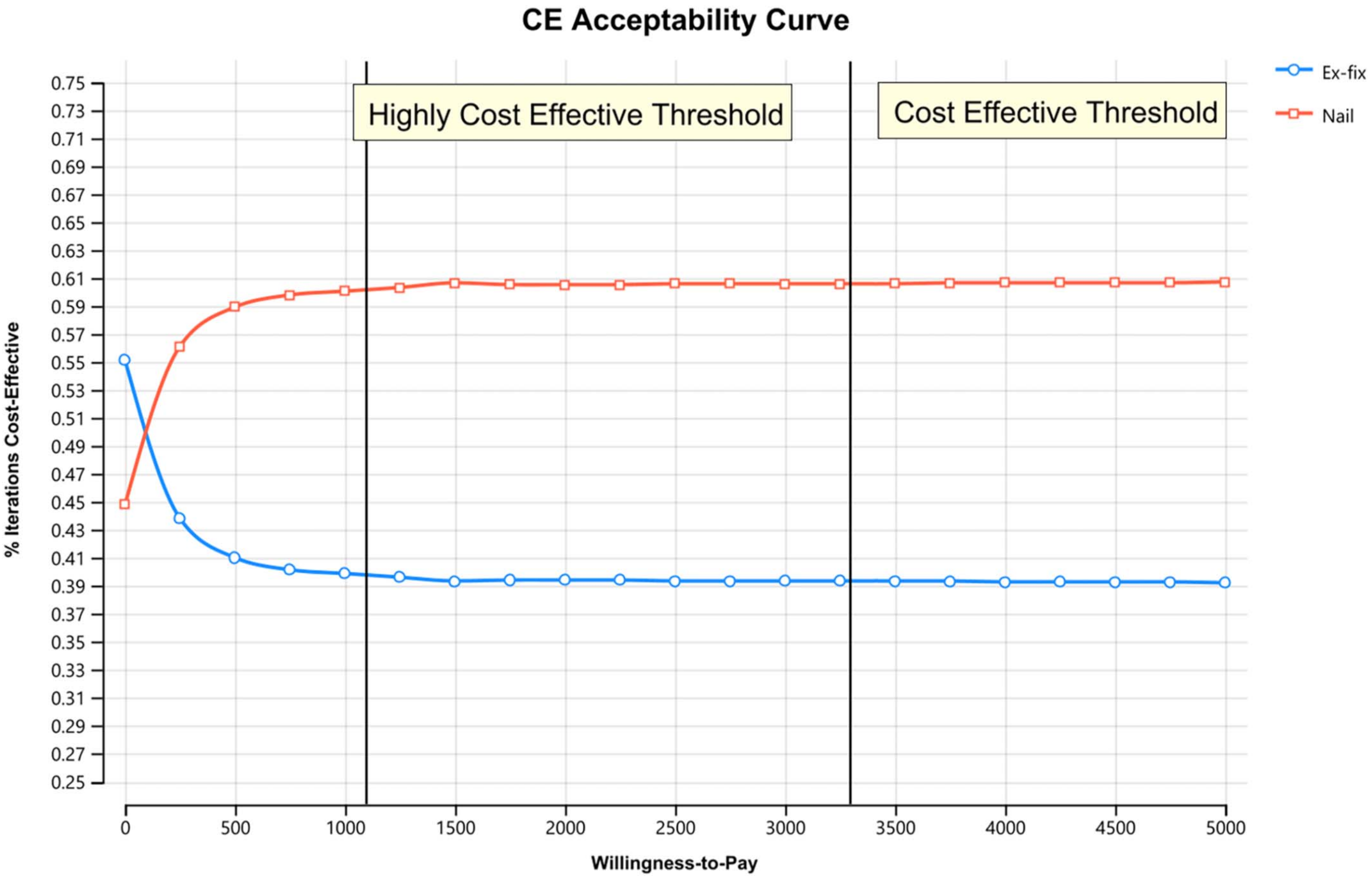

Fig. 4

Cost-effectiveness (CE) acceptability curve. Ex-fix = external fixation.

Perhaps most importantly, the sample size of the original trial was too small to make estimates of model parameters with a high degree of accuracy. We attempted to address this uncertainty by utilizing sensitivity analyses, which showed 60% confidence in the major conclusion of the study. The EQ-5D has a ceiling effect and may thus not have captured important differences, such as the effect of the higher rate of malunion observed in the original study with EF. Cost data were not gathered in the original trial and had to be estimated from a later trial evaluating local antibiotics. Because the method of fixation was not randomized in the subsequent trial, there may have been confounding bias in direct cost estimates.

There were several important assumptions made in the modeling process. First, many of the subtle differences in outcomes, such as between an infected nonunion versus an aseptic nonunion, could not be addressed because of the sample size. These outcomes were thus lumped together as major complications and considered to be either resolved or unresolved based on the results of the long-term follow-up of the original clinical trial. The outcomes beyond 3 to 5 years were assumed to be unchanged, which also may not be accurate. Finally, our model utilized cost estimates from only third-party suppliers as there was no local producer of orthopaedic implants. As surgical demand and capacity continue to grow, future local manufacturers may have different charges that would affect any new models.

In conclusion, IM nailing for the treatment of open tibial shaft fractures appears to be a highly cost-effective treatment strategy relative to EF in Tanzania, assuming a willingness-to-pay threshold of $1,099 (the per capita GDP of that country). This is relevant to in-country stakeholders and physicians who are treating these injuries, as it justifies the slightly higher initial costs to obtain long-term benefits. The benefits of IM nailing were driven by early improvements in quality of life and by cost savings related to an earlier return to work. However, these benefits were relatively small, and the sample size of the original trial was insufficient to make this conclusion with a high degree of certainty; thus, future larger trials are needed. ■

Jamieson M. O'Marr, MD, MS[1]
Patricia Rodarte, BS[1]
Billy Haonga, MD[2,3]
Patrick Ngunyale, MD[2]
Heather Roberts, MD[1]
Saam Morshed, MD, PhD[1]
David Shearer, MD, MS[1]

[1]Institute for Global Orthopaedics and Traumatology, University of California San Francisco, San Francisco, California

[2]Muhimbili Orthopaedic Institute, Dar es Salaam, Tanzania

[3]Muhimbili University of Health and Allied Science, Dar es Salaam, Tanzania

Email for corresponding author: jamieson.omarr@ucsf.edu

References

1. Mock C, Cherian MN. The global burden of musculoskeletal injuries: challenges and solutions. Clin Orthop Relat Res. 2008 Oct;466(10):2306-16.

2. Clelland SJ, Chauhan P, Mandari FN. The epidemiology and management of tibia and fibula fractures at Kilimanjaro Christian Medical Centre (KCMC) in Northern Tanzania. Pan Afr Med J. 2016 Sep 29;25:51.

3. O'Neill KM, Greenberg SLM, Cherian M, Gillies RD, Daniels KM, Roy N, Raykar NP, Riesel JN, Spiegel D, Watters DA, Gruen RL. Bellwether Procedures for Monitoring and Planning Essential Surgical Care in Low- and Middle-Income Countries: Caesarean Delivery, Laparotomy, and Treatment of Open Fractures. World J Surg. 2016 Nov;40(11):2611-9.

4. Holler JT, MacKechnie MC, Albright PD, Morshed S, Shearer DW, Terry MJ. The Impact of Inadequate Soft-tissue Coverage following Severe Open Tibia Fractures in Tanzania. Plast Reconstr Surg Glob Open. 2020 Dec 21;8(12):e3272.

5. Harris AM, Althausen PL, Kellam J, Bosse MJ, Castillo R; Lower Extremity Assessment Project (LEAP) Study Group. Complications following limb-threatening lower extremity trauma. J Orthop Trauma. 2009 Jan;23(1):1-6.

6. Brinker MR, Hanus BD, Sen M, O'Connor DP. The devastating effects of tibial nonunion on health-related quality of life. J Bone Joint Surg Am. 2013 Dec 18; 95(24):2170-6.

7. Lua J, Tan VH, Sivasubramanian H, Kwek E. Complications of Open Tibial Fracture Management: Risk Factors and Treatment. Malays Orthop J. 2017 Mar;11(1):18-22.

8. Schade AT, Khatri C, Nwankwo H, Carlos W, Harrison WJ, Metcalfe AJ. The economic burden of open tibia fractures: A systematic review. Injury. 2021 Jun;52(6): 1251-9.

9. Giovannini F, de Palma L, Panfighi A, Marinelli M. Intramedullary nailing versus external fixation in Gustilo type III open tibial shaft fractures: a meta-analysis of randomised controlled trials. Strategies Trauma Limb Reconstr. 2016 Apr;11(1):1-4.

10. Foote CJ, Guyatt GH, Vignesh KN, Mundi R, Chaudhry H, Heels-Ansdell D, Thabane L, Tornetta P, Bhandari M. Which Surgical Treatment for Open Tibial Shaft Fractures Results in the Fewest Reoperations? A Network Meta-analysis. Clin Orthop Relat Res. 2015 Jul;473(7):2179-92.

11. Haonga BT, Liu M, Albright P, Challa ST, Ali SH, Lazar AA, Eliezer EN, Shearer DW, Morshed S. Intramedullary Nailing Versus External Fixation in the Treatment of Open Tibial Fractures in Tanzania: Results of a Randomized Clinical Trial. J Bone Joint Surg Am. 2020 May 20;102(10):896-905.

12. Albright PD, MacKechnie MC, Roberts HJ, Shearer DW, Padilla Rojas LG, Segovia J, Quintero JE, Amadei R, Baldy Dos Reis F, Miclau T 3rd; and the ACTUAR Open Tibia Study Group. Open Tibial Shaft Fractures: Treatment Patterns in Latin America. J Bone Joint Surg Am. 2020 Nov 18;102(22):e126.

13. O'Hara NN, Mugarura R, Potter J, Stephens T, Rehavi MM, Francois P, Blachut PA, O'Brien PJ, Mezei A, Beyeza T, Slobogean GP. The Socioeconomic Implications of Isolated Tibial and Femoral Fractures from Road Traffic Injuries in Uganda. J Bone Joint Surg Am. 2018 Apr 4;100(7):e43.

14. Pairon P, Ossendorf C, Kuhn S, Hofmann A, Rommens PM. Intramedullary nailing after external fixation of the femur and tibia: a review of advantages and limits. Eur J Trauma Emerg Surg. 2015 Feb;41(1):25-38.

15. Beveridge M, Howard A. The burden of orthopaedic disease in developing countries. J Bone Joint Surg Am. 2004 Aug;86(8):1819-22.

16. Cortez A, Urva M, Haonga B, Donnelley CA, von Kaeppler EP, Roberts HJ, Shearer DW, Morshed S. Outcomes of Intramedullary Nailing and External Fixation of Open Tibial Fractures: Three to Five-Year Follow-up of a Randomized Clinical Trial. J Bone Joint Surg Am. 2022 Nov 2;104(21):1877-85.

17. Meinberg EG, Agel J, Roberts CS, Karam MD, Kellam JF. Fracture and Dislocation Classification Compendium-2018. J Orthop Trauma. 2018 Jan;32(Suppl 1): S1-170.

18. Haonga BT, Ngunyale P, von Kaeppler EP, Donnelley CA, Won NY, Eliezer EN, Brown K, Flores M, O'Marr JM, Rodarte P, Urva M, Cortez A, Porco T, Morshed S, Shearer DW. A pilot, masked, randomized controlled trial to evaluate local gentamicin versus saline in open tibial fractures (pGO-Tibia). OTA Int. 2023 Mar 27;6(2): e268.

19. Antonova E, Le TK, Burge R, Mershon J. Tibia shaft fractures: costly burden of nonunions. BMC Musculoskelet Disord. 2013 Jan 26;14(1):42.

20. Hoekstra H, Smeets B, Metsemakers WJ, Spitz AC, Nijs S. Economics of open tibial fractures: the pivotal role of length-of-stay and infection. Health Econ Rev. 2017 Sep 25;7(1):32.

21. Metsemakers WJ, Kuehl R, Moriarty TF, Richards RG, Verhofstad MHJ, Borens O, Kates S, Morgenstern M. Infection after fracture fixation: Current surgical and microbiological concepts. Injury. 2018 Mar;49(3):511-22.

22. Shearer DW, Youm J, Bozic KJ. Short-term complications have more effect on cost-effectiveness of THA than implant longevity. Clin Orthop Relat Res. 2015 May; 473(5):1702-8.

23. Cummins JS, Tomek IM, Kantor SR, Furnes O, Engesaeter LB, Finlayson SR. Cost-effectiveness of antibiotic-impregnated bone cement used in primary total hip arthroplasty. J Bone Joint Surg Am. 2009 Mar 1;91(3):634-41.

24. World Health Organization. Global Health Observatory. Accessed 2024 Jan 30. www.who.int/data/gho.

25. Shearer D, Bozic KJ. Fundamentals of Cost-Effectiveness Research. Accessed 2024 Nov 13. https://musculoskeletalkey.com/fundamentals-of-cost-effectiveness-research/.

26. Bertram MY, Lauer JA, De Joncheere K, Edejer T, Hutubessy R, Kieny MP, Hill SR. Cost-effectiveness thresholds: pros and cons. Bull World Health Organ. 2016 Dec 1;94(12):925-30.

27. Hutubessy R, Chisholm D, Edejer TTT. Generalized cost-effectiveness analysis for national-level priority-setting in the health sector. Cost Eff Resour Alloc. 2003 Dec 19;1(1):8.

28. Giannoudis PV, Harwood PJ, Kontakis G, Allami M, Macdonald D, Kay SP, Kind P. Long-term quality of life in trauma patients following the full spectrum of tibial injury (fasciotomy, closed fracture, grade IIIB/IIIC open fracture and amputation). Injury. 2009 Feb;40(2):213-9.

29. Haonga BT, Areu MMM, Challa ST, Liu MB, Elieza E, Morshed S, Shearer D. Early treatment of open diaphyseal tibia fracture with intramedullary nail versus external fixator in Tanzania: Cost effectiveness analysis using preliminary data from Muhimbili Orthopaedic Institute. SICOT J. 2019;5:20.

30. Fu Q, Zhu L, Lu J, Ma J, Chen A. External Fixation versus Unreamed Tibial Intramedullary Nailing for Open Tibial Fractures: A Meta-analysis of Randomized Controlled Trials. Sci Rep. 2018 Aug 24;8(1):12753.