BMC Musculoskeletal Disorders

RESEARCH

Open Access

Exploring versatile applications of a vacuum-assisted bone harvester in orthopedic surgery

Kevin A. Wu[1,2*], Devika Shenoy[2], Elizabeth Sachs[1,2], Jason A. Somarelli[3], Christian Pean[1], Malcolm DeBaun[1], Brian E. Brigman[1,3], Julia D. Visgauss[1,3] and William C. Eward[1,3]

Abstract

Background Orthopedic procedures often require removing bone or pathological tissue, with traditional methods involving instruments like curettes and rongeurs. However, these methods can be time-consuming and lead to increased blood loss. To mitigate these side effects, vacuum-assisted tools have been developed to aid in tissue removal. These devices enable surgeons to suction tissue without discarding it, potentially improving outcomes in conditions such as osteomyelitis or tumor removal while enabling collection of the material for downstream applications. Despite limited research, vacuum-assisted devices show promise beyond bone marrow harvesting. This study assesses infection and clearance rates, estimated blood loss, and total procedure time associated with the use of vacuum-assisted tissue removal, with a goal to understand if these devices can be used for tissue removal across a variety of pathologic conditions.

Methods A retrospective cohort study was conducted on patients undergoing orthopedic procedures with the Avitus® Bone Harvester repurposed from its original design from December 1, 2021, to July 1, 2023. Procedures were categorized into oncology, and debridement for infection cases. Infection cases were further categorized into those secondary to trauma and those involving primary infections (osteomyelitis and periprosthetic joint infection). Clinical variables, including demographics, intraoperative details, complications, and follow-up, were reviewed. Statistical analysis included descriptive statistics computed with R Studio.

Results The study included 44 patients, with debridement for infection cases being the most common (primary infection: 45.5%; infection secondary to trauma: 18.1%), followed by oncology cases (36.4%). In all oncology cases, a definitive diagnosis was established using the device, and no post-operative infections were reported. The infection clearance rate was 85.0% for primary infection cases and 50.0% for cases of infection following trauma. Across the entire cohort, the average blood loss was 314.52 mL (sd: 486.74), and the average total procedure time was 160.93 min (sd: 91.07). The overall reoperation rate was 47.7%, with an unplanned reoperation rate of 11.4%.

Conclusion The vacuum-assisted bone harvester was effectively utilized in a wide range of debridement and curettage procedures across diverse orthopedic surgeries. In oncology cases, the device enabled effective tissue removal with comparable recurrence rates, demonstrating its potential to minimize contamination while preserving tissue for accurate diagnoses. Additionally, a high rate of osteomyelitis eradication was observed in debridement for primary infection cases (85%). Despite the relatively high reoperation rate of 47.7%, it is crucial to interpret this figure

*Correspondence:
Kevin A. Wu
kevin.a.wu@duke.edu
Full list of author information is available at the end of the article

within the context of the varied reasons for reoperation. Many of these reoperations were planned as part of a staged approach to treatment or were unrelated to the device's performance. It is crucial to acknowledge that isolating the device's contribution to these results can be difficult. The utilization of the device should be guided by considerations of cost-effectiveness and patient-specific risk factors.

Keywords Vacuum-assisted bone harvester, Orthopedic surgery, Debridement, Infection, Oncology

Introduction

Removing bone or removing pathological tissue from within the bone is a common component of various orthopedic procedures across different subspecialities [1, 2]. Debridement and oncological cases require the progressive removal of diseased tissues while procedures such as arthroplasties require the removal of specific portions of bone and cartilage to allow sufficient room for the implants [1, 3]. Currently, instruments like a curette, rongeur, or an operating room suction, are commonly used for the removal of tissue or lesions within the bone [4, 5]. Although these methods are widely used, they can be time-intensive, resulting in increased blood loss, increased procedure time, and contamination of adjacent soft tissues as the instruments are repeatedly inserted into and withdrawn from the bone [5, 6]. Local recurrence of tumors after these traditional methods remains a challenge in oncology cases, possibly due to the need to insert and remove an instrument (such as a curette) repeatedly [7].

To aid in the removal of bone marrow from within the inner cortex of the bone, vacuum-assisted tools have been developed for orthopedic surgery [8]. Studies have previously demonstrated the benefits of utilizing a vacuum-assisted bone harvester for autologous bone graft and marrow harvesting in ankle arthrodesis, reducing operative time and blood loss compared to traditional methods [9]. These devices allow surgeons to suction tissue without discarding it, eliminating the need for repeated instrument removals. This controlled suction capability makes the device suitable for tissue debridement in conditions like osteomyelitis or tumor removal as they may be more efficient than traditional methods. However, challenges include the potential for increased blood loss due to suction-induced disruption of blood vessels, technical complexities requiring specialized training, and equipment-related risks.

Despite the potential uses of vacuum-assisted bone harvesters, there is limited research on the use of these devices in orthopedic procedures beyond bone marrow or graft harvesting. Several case reports have explored the use of a vacuum-assisted device in trauma and debridement scenarios [10–13]. Potential benefits have suggested that the device can decrease the risk of contamination of healthy tissue as well as aid in surgical efficiency. However, these studies suffer from limitations such as inadequate sample size and the absence of generalizability in their outcomes. Additionally, they have noted the possibility of tissue trauma due to the suctional capabilities of the device.

Infection remains a significant concern in orthopedic surgery [14, 15]. A recent meta-analysis examining reinfection rate after revision surgery for infected TKA and THA found an infection rate of 13.7–19.0% and 6.9–9.9% for two-stage knee and hip procedures [15]. Correspondingly, eradication of infection continues to be a challenge in orthopedic surgery. Given the critical importance of both treating and preventing infections as well as debriding diseased tissue in orthopedic surgery, further study of vacuum-assisted devices is essential to better inform clinicians and researchers. The purpose of this study was to assess the outcomes of a cohort with diverse uses and explore the different ways to utilize a vacuum-assisted bone harvester in orthopedic surgeries. This study aimed to determine the infection and clearance rates, blood loss, and total procedure time associated with the use of vacuum-assisted bone harvester in oncological and infectious cases during orthopedic surgery. The findings contribute to understanding whether vacuum-assisted bone harvester can be effectively used for tissue removal in these pathological conditions. Findings may inform new surgical techniques and approaches.

Methods

Study design

This was a retrospective cohort study of patients who underwent an orthopedic procedure at our institution using the Avitus® Bone Harvester (Zimmer Biomet, Warsaw, IN) from December 1st, 2021, and July 1st, 2023 (Fig. 1). Patients were identified as using the Avitus® Bone Harvester using the Duke Enterprise Data Unified Content Explorer (DEDUCE), and operative notes were crossed referenced during manual chart review to corroborate the use of the device [16]. Institutional Review Board (IRB) approval was obtained prior to the start of the study (Pro00113599). Manual chart review of the patient charts was done by trained personnel (research assistants and clinical research coordinators) listed on the approved protocol. The extracted data was then verified by fellowship-trained orthopedic surgeons. To preserve

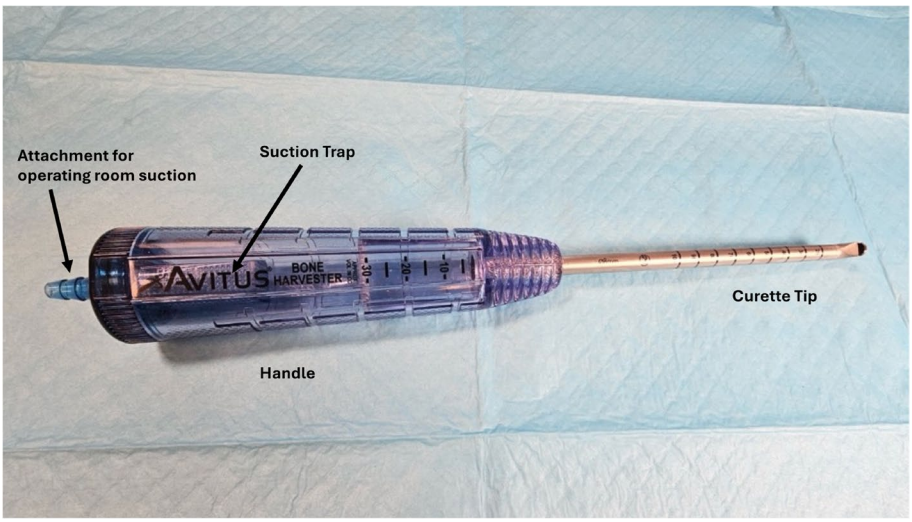

Fig. 1 The Avitus® Bone Harvester. The device is made up of a curette attached to a handle that can be linked up to standard operating room suction. The handle contains a suction trap that allows it to store debrided tissue

patient privacy, all data was stored on Duke University's Protected Analytics Computing Environment (PACE). A total of 48 cases using the Avitus® Bone Harvester were identified during the study period. Four cases were excluded as they utilized the device for its original purpose of autologous bone graft and marrow, resulting in a final cohort of 44 patients. In the final cohort, the Avitus® Bone Harvester was repurposed from its original bone and marrow harvesting indication for another function. Since March 1st, 2021, the Avitus® Bone Harvester has been approved for indications including to debride and capture infected, necrotic or diseased cancellous bone. Orthopedic procedures were classified based on CPT code as oncology or debridement for infection cases. Infection cases were further categorized into those secondary to trauma and those involving primary infections (osteomyelitis and periprosthetic joint infection).

Outcomes measures

Several key outcome measures were assessed in this study, including postoperative outcomes such as infection rates, infection clearance(specifically in debridement for infection cases), persistent pain, unplanned reoperation rates, as well as intraoperative measures such as estimated blood loss (EBL) and operative time [17–20]. Given reported recurrence rates for osteomyelitis as high as 20% to 30%, achieving a persistent infection rate below 30% was considered successful in this study [21, 22].

Clinical variables

A retrospective chart review of medical records was performed to obtain various patient characteristics and demographic data including age, race, gender, smoking status, and diabetes status. Intraoperative data such as EBL and operative time was recorded from operative notes. EBL was calculated by measuring the volume of fluid collected in the suction canister and subtracting the volume of fluid used for irrigation. Around 500 mL of EBL is considered safe in elective orthopedic surgeries and that number remains higher for emergent procedures following traumatic injuries where bleeding may not be controlled [23, 24]. Operative time was determined by measuring the duration from skin incision to closure. The presence of intraoperative complications was noted. The need for any reoperation related to the index surgery was recorded and the time to surgery was noted as well. In oncology cases, post operative outcomes such as local tumor recurrence and metastasis were recorded. The utilization and type of adjuvant therapy were also recorded for any oncology cases. Persistent pain was defined as postoperative pain existing beyond 24 weeks and was recorded.

The device was used to debride tissue once adequate dissection to the tissue of interest was achieved. The decision of when or whether to use the device was at the discretion of the attending surgeon, who evaluated the diseased tissue.

Vacuum-assisted bone harvester

The Avitus® Bone Harvester is a manually-powered surgical device originally crafted for extracting autologous bone and marrow grafts in orthopedic procedures [8] (Fig. 2). It is coupled with a pilot hole creator with an anchor tip (Avitus® Pilot Hole Creator) to bore a small

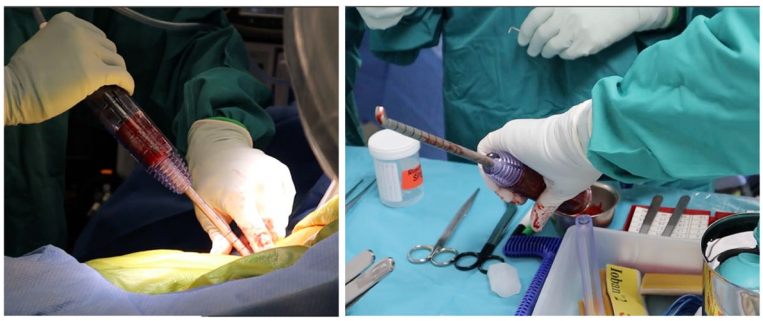

Fig. 2 The tip of the vacuum-assisted bone harvester can be directed to the corticotomy site, enabling the surgeon to suction the lesion while preserving the specimen in the back handle. The device's back handle facilitates the safe storage and easy retrieval of the specimen for sterile transport to pathology

circular cortical bone window (Fig. 3). The device has a sharp curette-like tip connected to the harvester, featuring a suctional component linkable to standard operating room suction. The back end of the harvester serves as a suction trap with a storage compartment for extracted tissue. The device is available in two shaft diameters: 8 mm and 6 mm and is paired with pilot hole diameters of 11 mm and 8 mm, respectively.

Statistical analysis

Descriptive statistics were computed following standard procedures, encompassing measures such as the mean, standard deviation (SD), and frequency. Mean and SD were chosen to be reported after discussion with the team to allow for an easier comparison with the wider literature. All statistical analyses were conducted in R (version 3.1; The R Foundation, Vienna, Austria).

Results

Patient characteristics

The study included 44 patients with a mean age of 53.66 ± 18.34 years and an average follow up time of 1.29 years (range: 0.72 – 2.62 years) (Table 1). The cohort contained 22 male and 22 female patients. There were 4 current smokers (9.1%), 15 previous smokers (34.1%) and 25 patients who never smoked (56.8%). Preoperatively, there were 19 patients (43.2%) who had a diagnosis of diabetes.

The most common type of surgical case in which the device was used was for debridement of infection cases ($n=28$; 63.6%), followed by oncology cases ($n=16$; 36.4%) (Table 2). Cases of debridement of infection were broken down into primary cases following osteomyelitis or periprosthetic joint infection ($n=20$; 45.5%) and following trauma cases ($n=8$; 18.2%). The most common problem experienced by patients in the cohort was persistent pain ($n=8$; 18.2%), followed by persistent infection ($n=7$; 15.9%). Persistent pain was exclusively observed in oncology and primary infection cases. In oncology cases, pain occurred at the incision site, while in primary infection cases, pain was attributed to chronic osteomyelitis that could not be resolved. All cases of persistent infection were attributed to preexisting infections and not the device.

After their original index surgery in which the device was used, 21 patients (47.7%) ultimately required a reoperation related to their original surgery. Out of the 21 reoperations, 16 (76.2%) were planned as secondary surgeries before the original index surgery, while 5 (23.8%) occurred after the original surgery was intended to be the only procedure. Distinguishing between planned and unplanned surgeries is important as infection and trauma cases are often planned to be multistage procedures. Planned surgeries were most common in primary infection cases ($n=7$), followed by infection following trauma cases ($n=5$), which required a series of planned surgeries. For patients who underwent a reoperation, the average time to reoperation was 118.35 (sd: 128.51) days.

In the overall cohort, the average blood loss reported in cases using the device was 314.52 (sd: 486.74) mL, while the average total procedure time was 160.93 (sd: 91.07) minutes. One patient suffered an intraoperative complication unrelated to the use of the device.

Oncology cases

There were 16 oncology cases in the cohort (Table 3). The average follow-up for the oncology cases was 1.27 (range: 0.72 – 2.62) years. In general, there were two broad oncologic applications of the device: 1) Biopsy and intralesional removal of benign-aggressive tumors; and 2) Biopsy and intralesional removal of solid tumors that had metastasized to bone. The device was never used for the treatment of nonmetastatic primary bone tumors (as intralesional treatment would be contraindicated). There were 5 patients with bone metastases who had received preoperative chemotherapy

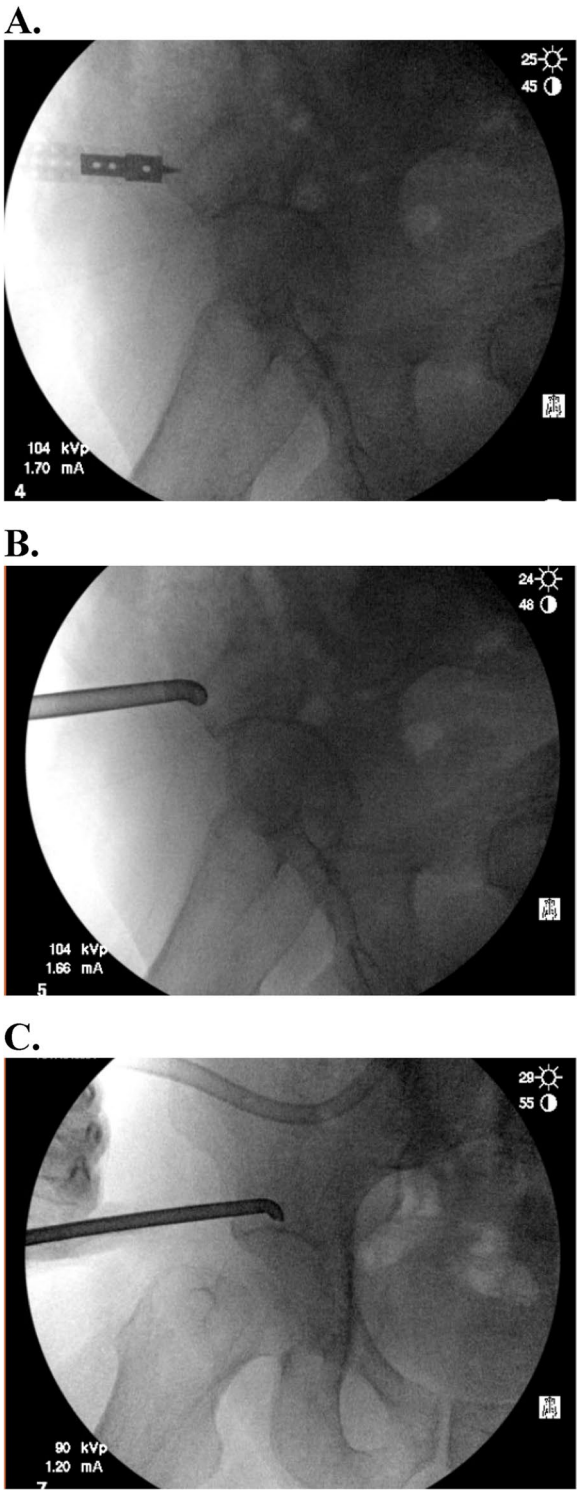

Fig. 3 Intraoperative fluoroscopic images demonstrating the use of the device. **A** A pilot hole creator with an anchor tip (Avitus® Pilot Hole Creator) is used to create a circular cortical bone window. **B** The tip of the vacuum-assisted device is guided to the corticotomy site. **C** The device is inserted to allow for the aspiration of the intramedullary contents

Table 1 Patient characteristics and demographics

Factor	Study Cohort (*n* = 44)
Gender, n	22 males, 22 females
Age, y (sd)	53.66 (18.34)
Smoking, n (%)	
Current Smoker	4 (9.1)
Never a Smoker	25 (56.8)
Previous Smoker	15 (34.1)
Diabetes Status	
Yes	19 (43.2)
No	25 (56.8)
Race, n (%)	
White	25 (56.8)
Black	13 (29.6)
Asian	2 (4.6)
Other	4 (9.1)
Follow up, y (sd)	1.29 (0.47)

n Number, *sd* Standard deviation, *y* Years

Table 2 Indications and operative outcomes

	Study Cohort (*n* = 44)
Indications, n (%)	
Infection	28 (63.6)
Primary Infection	20 (45.5)
Infection following Trauma	8 (18.2)
Oncology	16 (36.4)
Outcomes	
Total Procedure Blood Loss, mL(sd)	314.52 (486.74)
Total Procedure Time, mins (sd)	160.93 (91.07)
Outcome, n (%)	17 (38.6)
Infection	7 (15.9)
Primary Infection Cases	3
Infection following Trauma Cases	4
Oncology Cases	0
Persistent Pain	8 (18.2)
Primary Infection Cases	2
Infection following Trauma Cases	0
Oncology Cases	6
Reoperation, n (%)	21 (47.7)
Primary Infection Cases	7
Infection following Trauma Cases	8
Oncology Cases	6
Time to Reoperation, days (sd)	118.35 (128.51)

n Number, *sd* Standard deviation, *mins* minutes, *ml* Milliliters

prior to undergoing the procedure using the device. In all 16 cases, pathology was able to render a definitive diagnosis after receiving the biopsy sample from the vacuum-assisted device. The three most common

Table 3 Oncology cases outcomes

Breakdown	Oncology Cases (*n* = 16)
Benign-aggressive tumor	9 (56.3)
Metastatic bone tumors	7 (43.8)
Outcomes	
Total Procedure Blood Loss, mL (sd)	153.75 (200.52)
Total Procedure Time, min (sd)	149.63 (60.87)
Complications, n (%)	
Persistent Pain	6 (37.5)
Infection	0 (0.0)
Reoperation, n (%)	6 (37.5)
Time to Reoperation, days(sd)	238.33 (161.91)

n Number, *sd* Standard deviation, *mins* Minutes, *ml* Milliliters

neoplasms diagnosed were giant cell tumor ($n=4$; 25.0%), multiple myeloma ($n=2$; 12.5%), and Ewing Sarcoma ($n=2$; 12.5%). One case of local recurrence ($n=1$, 25.0%) occurred after an operation to remove a giant cell tumor. The patient required an additional surgery and at the most recent follow up, there was radiographic concern for additional recurrence of disease. There were 7 cases (43.8%) of metastatic carcinoma within the cohort, which included metastases from a primary lung cancer and a papillary thyroid carcinoma.

The most common problem encountered following the oncology cases was persistent pain beyond 24 weeks affecting 37.5% ($n=6$) of the patients. Ultimately, there were 5 ($n=37.5\%$) cases that required a reoperation, which included additional excisions and prophylactic nailing. Three of the cases (60.0%) were planned reoperations with one prophylactic nailing. The prophylactic nailing case was planned before the start of the case to deal with the patient's persistent hip pain in context of their known metastases to the bone. The device was used to obtain a specimen, which was used to confirm a diagnosis of metastatic carcinoma with squamous features. Two cases (40.0%) were unplanned additional procedures, including one for a local giant cell tumor recurrence and one for a pathological fracture at a second location distinct from the original surgical site. There were no cases of infection in the oncology cases.

Infection Cases

The most common type of procedure in which the device was used in was in patients with known or suspected infection ($n=28$) (Table 4). These cases were further broken down into primary infection (osteomyelitis and periprosthetic joint infection) ($n=20$) and infection following trauma cases ($n=8$) (Table 4).

Table 4 Outcomes from infection cases

Outcomes	Primary Infection Cases (*n* = 20)	Infection following Trauma Cases (*n* = 8)
Total Procedure Blood Loss, mL (sd)	442.4 (644.86)	316.67 (306.05)
Total Procedure Time, min (sd)	154.50 (78.97)	199.63 (154.80)
Persistent Infection, n (%)	3 (15.0)	4 (50.0)
Persistent Pain, n (%)	2 (10.0)	0 (0.0)
Reoperation, n (%)	8 (40.0)	7 (87.5)
Time to Reoperation, days(sd)	102.40 (97.74)	38.29 (45.57)

n Number, *sd* Standard deviation, *mins* Minutes, *ml* Milliliters

Primary infection cases

The device was used in 20 cases of primary infection. These included 13 cases of periprosthetic joint infection with 6 TKA (30.0%%) and 7 THA (45.0%%) as well as 7 cases (45.0%%) of osteomyelitis. Patients experiencing periprosthetic joint infections typically underwent a 2-stage revision to treat the infection with explantation of the implant and placement of an antibiotic spacer. In these patients, the bone harvester was used to debride the inner cortex once the implant was removed.

The most common outcome was clearance of the primary infection ($n=17$; 85%). Three cases experienced persistent infection (15.0%). These original cases were debridement surgeries for osteomyelitis with a dirty-infected classification [25]. There was persistent pain experienced by two patients (10.0%), which was attributed to their persistent infection. Reoperation was common in these patients ($n=8$; 40.0%) as several opted to undergo reimplantation of their implants while others required additional debridement surgeries for persistent infection. Out of the cases requiring reoperation, 7 (87.5%) of them were planned before the index surgery for additional debridement and reimplantation. One case (12.5%) was an unplanned debridement due to persistent infection following the original debridement for osteomyelitis. This instance is reported for transparency purposes, with no conclusions drawn regarding the effectiveness of the device based on this single case, as attributing unplanned debridement solely to the device use may not be appropriate given the underlying osteomyelitis.

Infection following trauma cases

Within the infection cohort, there were 8 cases of infection following trauma cases. In all 8 cases, the device was used to debride infected tissue after a traumatic event or fracture. There were 4 cases (50.0%) that involved upper

extremity fractures and 4 cases (50.0%) that involved lower extremity fractures. During the operation, the average blood loss recorded was 316.67 mL (sd: 306.05) and the average total procedure time recorded was 199.63 min (sd: 154.80).

Infection was successfully cleared in 50.0% of patients ($n=4$), while the remaining 50.0% ($n=4$) experienced persistent infection. In all cases of persistent infection, the device was used for tissue removal in cases with a contaminated classification [25]. None of the infections were attributed to the device as they were pre-existing. Correspondingly, the clearance of infection was comparable to rates demonstrated in the literature (Table 5). There were 7 patients (87.5%) who eventually required a reoperation related to their original surgery which included operations to address persistent infection and additional fixation. Of the 7 reoperations, 5 (71.4%) were initially intended as a series of planned procedures, while 2 (28.6%) necessitated additional, unplanned surgeries.

Discussion

Our study indicates that a vacuum-assisted bone harvesting device may be used in multiple types of orthopedic surgeries across different subspecialties. The vacuum-assisted device was most commonly used in debridement cases for infection (45.5%) followed by oncology cases for tumor removal and biopsy (36.4%). The wide range of procedures suggests that a vacuum-assisted bone harvesting device has a variety of application beyond bone and marrow harvesting. The device presents several theoretical advantages. However, further research is needed to see if they have any tangible benefits.

The device may offer some advantages, particularly in cases where infected or diseased tissues require removal. A noteworthy feature is its ability to collect disease tissue within the handle, facilitating both the effective removal of the targeted tissue from healthy surroundings and its extraction from the surgical field. Vacuum-assisted bone harvesters may theoretically minimize the risk of contamination to other parts of the surgical field, including non-affected tissues, enhancing the overall surgical precision and mitigating potential complications associated with tissue removal [34]. This is supported by the comparable rates of osteomyelitis clearance and tumor reoccurrence demonstrated in the study. However, additional studies are needed to explore the full impact of the device design on outcomes. Additionally, the device enables surgeons to perform multiple collections of tissue without the need for repeated removal and reinsertion of the device. This feature is particularly useful in oncology, where repeated introduction and removal of a device can disseminate tumor cells within the operative field. These features can additionally help make tissue debridement more efficient which can possibly reduce surgical time compared to traditional curettage techniques.

There was a comparable local reoccurrence rate (1/4; 25.0%) after tumor removal observed in our cohort compared to traditional intralesional methods at a similar follow-up although the numbers in this study are too small to make a meaningful comparison [35–37]. Traditional intralesional curettage methods continue to have issues with local reoccurrence despite advancements in adjuvant therapies and surgical techniques [38, 39]. Utilizing the vacuum-assisted device offers several advantages over traditional methods for intralesional curettage, which may contribute to the low rate seen in this series. A theoretical advantage of this device is its ability to simultaneously remove and scrape, which improves the speed of the procedure. Compared to traditional curettage, where the removal of tissue requires the instrument to be removed and cleaned before re-insertion into the bone, this device remains inside the lesion for continuous evacuation of tissue. This may be significant, as repeated introduction and removal of an instrument could spread tumor cells through the surrounding tissue and contribute to the high local recurrence rates observed in lesions treated with curettage. Additionally, the device's sharp curette end enables bone scraping while providing suction, preventing tissue from being inadvertently forced deeper into the bone. The suction ability of the device theoretically can allow it to be more effective at extracting a higher quantity of tumor cells, all while preserving a similar incision site. However, future research is needed to quantify those differences. Conditions prone to local recurrence, like giant cell tumor, could benefit from a suction device that captures more tumor cells, as thorough tumor removal is paramount to minimize the risk of local recurrence [40, 41]. The device's back handle prevents contamination of the surgical table with tumor cells while containing them for histological evaluation. In our study, the collected specimens were able to be used to establish a diagnosis with minimal artifact.

Lesions within the bone remain a challenge because the bone marrow is a highly vascularized tissue, and extensive or prolonged disruption of the tissue may lead to excessive bleeding [42]. Utilizing a traditional curette for the removal of vascularized tissue, such as a tumor can cause more bleeding [43]. Aiba et al. examined treating simple bone cysts using endoscopic curettage as a minimally invasive measure and found advantages with less bleeding [44]. Similarly, using a vacuum-assisted bone harvester may represent another minimally-invasive measure to reduce the risk of operative blood loss. First, while traditional curettage requires creation of a generous window to visualize retrieval of the tissue being removed, the Avitus® device can be inserted through a relatively

Table 5 Comparison of chronic osteomyelitis eradication rates

Author	Year	Number of Patients	Patient Population	Technique	Outcome
Drampalos et al. [26]	2020	52	Patients with Cierny-Mader Type III (34 patients (65%)) and IV (18 (35%)) chronic osteomyelitis	Single-stage protocol involving debridement followed by the application of CERAMENT™/G biocomposite post-resection for Cierny-Mader (C-M) stage III and IV chronic osteomyelitis	Recurrent infection in 7.7% ($n=4$ patients) Three cases involved recurrence of osteomyelitis, and one case was a soft tissue or flap infection
Jiang et al. [27]	2015	394	The most common form of osteomyelitis was traumatic, which included cases caused by medical interventions, representing 66.50% (262 cases). Chronic osteomyelitis due to hematogenous spread was found in 15.98% (63 cases), while those linked to diabetic foot accounted for 17.51% (69 cases)	Radical debridement, antibiotic use, and/or reconstruction of bone/soft tissue defect. Some patients received limb amputation	Infection was not cured in 22.26%
Lam et al. [28]	2019	67	Included patients with Cierny-Mader Type I osteomyelitis 3 cases (4%), those with Type II in 2 cases (3%), Type III in 6 cases (9%), and the majority, Type IV (non-union), in 56 cases (84%)	Single-staged or multi-staged approach depending on clinical picture Twenty-six patients were treated with a single-stage approach, whereas 41 received a multi-stage approach. Approximately 70% of the cases did not require soft tissue coverage. Antibiotic beads and antibiotic-coated nails were used in 21% and 15% of cases, respectively. On average, patients received intravenous or oral antibiotics for 5.9 weeks (standard deviation 0.5). Patients with nonunion were prescribed an additional chronic antibiotic for an average of 2.7 months	Infection was not controlled in 9% Six patients experienced persistent non-union, and four of these were the same individuals who did not achieve infection control
Li et al. [29]	2019	18	Included in the study were cases of open fractures resulting from chronic tibia osteomyelitis	Multi-stage approach with debridement followed by elective bone cement extraction, bone grafting, and internal fixation	Recurrence in 5.6% Two patients developed necrosis at the distal margin of the flap following surgery, and another two had venous crisis caused by compression from tight sutures on the pedicle flap two days after the operation
Lindfors et al. [30]	2017	116	Patients included had infection secondary to of trauma (83%), hematogenous (12%), and following elective orthopedic surgery (5%)	A single-stage procedure without local antibiotics (85%) or a two-stage procedure involving antibiotic beads during the initial surgery (15%)	Infection was not cured in 10.3%
Opara and Nwagbara [31]	2018	21	Osteomyelitis affected the distal third of the tibia in twelve patients, the middle third in eight patients, and the proximal third in five patients. Seventeen patients developed osteomyelitis following open tibial fractures, with thirteen cases caused by road accidents and four by gunshot injuries. Four other patients developed osteomyelitis through hematogenous spread	Sural Island Musculo fasciocutaneous flap coverage	Recurrent infection in 9.5%

Table 5 (continued)

Author	Year	Number of Patients	Patient Population	Technique	Outcome
Rod-Fleury et al. [32]	2011	49	Majority of cases were classified as Cierny-Mader grade IV (39 cases, 80%). Location included tibia (17 cases), femur (6), radius (4), fibula (4), humerus (3), ulna (2), ischium (2), clavicle (1), talus (1), and calcaneum (9)	Post-debridement and antibiotic therapy	There were 20.0% infection cases that did not achieve remission Of the 49 episodes, 80% remained in remission; however, 31 of these cases experienced long-term mechanical complications of lesser severity. The median length of hospital stay was six weeks, and the median follow-up period was 7.2 years (ranging from 2 to 10 years). Ten cases recurred after a median interval of ten months. Notably, four of these recurrences were caused by different pathogens from the original diagnosis (three methicillin-resistant and one methicillin-susceptible Staphylococcus aureus)
Zhou et al. [33]	2020	42	There were 35 patients (36 limbs) classified as Cierny-Mader type IIIA and 7 identified as Cierny-Mader type IIIB (6 with type IIIBS and 1 with type IIIBL). Most cases were associated with pain, draining sinus, swelling, and mild movement limitation, while 14 patients showed only localized pain, redness, or swelling	Local debridement combined with antibiotic-loaded calcium sulfate implantation	There were 30.0% of patients with prolonged sinus drainage following surgical treatment Postoperative complications in these cases primarily involved prolonged aseptic drainage in 30% (13/43), mild pain after long-distance walking in 10.5% (4/38), limb weakness or discomfort in 7.9% (4/38), fibrous scar formation in 5.2% (2/38), joint stiffness in 2.6% (1/38), and mild claudication in 2.6% (1/38)
Current Study	2024	20	Included 13 cases of periprosthetic joint infection, comprising 6 total knee arthroplasties (30.0%) and 7 total hip arthroplasties (45.0%), as well as 7 cases of osteomyelitis (45.0%)	Single Stage debridement using a vacuum assisted bone harvester to debride	Persistent infection in 15.0% ($n = 3$ patients)

small circular window (11 mm or 8 mm) because everything is being collected into a closed-capture suction system. A circular osteotomy induces less stress on the cortex compared to a square osteotomy [45]. Our oncology cases reported the lowest intraoperative blood loss in our cohort, despite the fact that curettage of bone tumors is usually associated by significant hemorrhage.

Conversely, it is important to acknowledge that because the vacuum-assisted bone harvester includes suction, there is a theoretical concern about increased blood loss due to continuous disruption of delicate blood vessels during tissue removal and the negative pressure effects on tissue integrity [46]. However, it is worth noting that suction is also integral to traditional tissue debridement procedures for managing fluids and debris [7]. The unique design of the vacuum-assisted bone harvester allows for uninterrupted suction throughout the procedure, eliminating the need for frequent instrument changes for separate suctioning processes. This operational efficiency aims to minimize procedural interruptions, potentially reducing overall blood loss. Moreover, the controlled suction of the vacuum-assisted bone harvester facilitates precise tissue removal, potentially mitigating bleeding compared to manual debridement methods that involve more mechanical manipulation and pressure on tissues.

The reinfection rate within our cohort of periprosthetic joint infection was comparable to that in the previous literature, which suggests that this device performs equivalently in this setting of debridement for periprosthetic joint infection. The benefits of safely removing the infected tissue may not be as significant in these cases because the surgical field is already contaminated with microbial infection [47]. However, single stage debridement alone for osteomyelitis has a reoccurrence rate above 40% [48–50]. Our series demonstrated an 85.0% rate of infection clearance for patients experiencing primary infection which is comparable to techniques that utilize multi-stage debridement (Table 5). However, it is important to note that literature contained heterogenous study designs that made it challenge to compare rates. Due to the current study design, it is challenging to attribute the rate of debridement cases solely to the device. However, there may be a benefit as the device allows diseased tissue to be removed while minimizing contamination of adjacent tissue that can occur with repeated insertion and removal. This can reduce operative time which has previously been linked to an increased infection risk [51–53]. Additionally, the device may be beneficial in cases where there is increase surgical site soft tissue to minimize iatrogenic tissue trauma [52, 54]. With equivalent reported reinfection rates in periprosthetic joint infection, the vacuum-assisted bone harvester can theoretically reduce the risk of leaving behind infected tissue. The curette tip may allow for the removal of tissue and may have a potential benefit of being able to debride more tissue than traditional methods.

Although there was a higher rate of persistent infection in trauma cases compared to the rest of the cohort, we demonstrate equivocal infection clearance rates to traditional methods [55–57]. The higher rate of infection in trauma cases compared to the entire cohort could be attributed to several factors. First, the trauma cases in which patients experienced post operative infection were already contaminated. The high-energy nature of these injuries often leads to significant contamination of both bone and soft tissue, increasing infection risks [57, 58]. Moreover, the trauma cases sampled in our cohort were relatively high acuity, with multiple fractures simultaneously, which can increase the risk of postoperative infection [59]. The presence of these multiple traumatic sites exposes each area to the environment, potentially contaminating the surgical site despite preoperative precautions [60, 61]. Though these postoperative infections were unlikely to be caused by the device, we deemed it important to report them. The device was found to be non-inferior compared to other methods and offered the benefit of ease of use.

This study has several implications for research and clinical practice. Although utilizing the device may be beneficial, it is necessary to consider the cost of the using such a device. Considering patient-specific risk factors and their ability to pay can help orthopedic surgeons navigate the cost-effectiveness of using new devices for patients [62, 63]. Patients who may be at higher risk of bleeding may benefit from utilizing a vacuum-assisted bone harvester for tissue removal. The device could be considered as an additional precaution in patients with an elevated risk of infection [64]. Patients may experience greater advantages when employing the device in oncology cases as opposed to infection cases. In oncology cases, there is a great deal of emphasis placed on minimizing contamination of the surgical field [47]. In scenarios of infection, where such contamination may already be present or inevitable, the utility of a device is primarily based on efficacy and ease of use [65].

To establish a conceptual framework for the use of vacuum-assisted bone harvesters in tissue debridement for oncology and infectious diseases, we acknowledge several key factors that contribute to successful outcomes. These factors include the disease's pathology, the operator's skills, the surgical doctor's skills, the preparedness of the surgical team, and the quality of the vacuum-assisted bone harvester's tool [65, 66]. In our study, we chose outcome measures such as infection rates, persistent pain, reoperation frequency, time to reoperation, and other

complications to provide a comprehensive overview of the procedure's impact on patient outcomes. Comparable infection rates and reduced persistent pain suggest good postoperative recovery, while a low number of unplanned reoperations indicate the initial procedure's success and durability. These indirect measures, though not exhaustive, offer valuable insights into the overall effectiveness of vacuum-assisted bone harvesters in achieving desired surgical results. Additionally, we recognize that factors related to blood loss, procedure time, pain, infection, and reoperation are crucial in the contexts of oncology and infectious diseases [17, 18]. While our study did not include direct measures such as the quality and quantity of harvested tissues, future research should incorporate these metrics to provide a more detailed evaluation of vacuum-assisted bone harvesters' effectiveness.

There are several limitations that exist for this study. First, this study is retrospective and descriptive in nature. While it would have been valuable to compare the infection rate associated with the traditional method of tissue harvesting to that of vacuum-assisted tissue removal, we did not have a comparable control cohort for patients undergoing similar orthopedic procedures without using a vacuum-assisted device. Incorporating such a cohort would have been challenging due to the variability in surgical techniques, patient conditions, and types of procedures performed. These differences could introduce confounding factors that would make direct comparisons difficult. Our study focused on evaluating the use of vacuum-assisted tissue removal across various pathological conditions without a direct comparison to traditional methods. This approach allowed us to lay the groundwork for understanding the device's performance and potential benefits. Thus, future studies should include prospective analyses with suitable control cohorts to make stronger conclusions about the benefits of utilizing this device. By building on this foundational work, subsequent research can provide more comprehensive insights and help clinicians and surgeons make informed decisions regarding tissue removal techniques. Another limitation of our study was the lack of available patient-reported outcomes, particularly in cases involving trauma where such data were not routinely collected. Patient-reported outcomes provide valuable insights into postoperative pain, functional recovery, and quality of life, which are essential for comprehensive outcome assessment. The absence of these data limits our ability to fully capture patient perspectives and experiences following surgical interventions, highlighting the need for future studies to incorporate these measures to enrich our understanding of surgical outcomes.

While we used operative time as an outcome measure in this study, a more accurate assessment would focus solely on debridement time. However, due to the retrospective study's design, we did not have the ability to measure debridement time. Future studies should incorporate this specific metric for more precise evaluations of utilizing the device. Another limitation exists because the study encompasses a variety of orthopedic procedures, including oncology, trauma, and infection cases. The heterogeneity in procedures makes it challenging to isolate specific factors contributing to observed outcomes. The range of procedures, however, allows the study to examine the versatile nature of the device and provides important groundwork for future studies.

Conclusion

The use of a vacuum-assisted bone harvester offers several advantages in debridement surgeries, providing a rapid and efficient method for tissue removal while minimizing contamination of adjacent tissues. The study found that in cases using the device, there was an overall infection clearance rate of 85% for primary infection cases and 50% for trauma-related infections. The average blood loss was 314.52 mL, and the total procedure time averaged 160.93 min. Despite the relatively high reoperation rate of 47.7%, it is crucial to interpret this figure within the context of the varied reasons for reoperation. Many of these reoperations were planned as part of a staged approach to treatment or were unrelated to the device's performance. This study highlights the use of the device in various orthopedic procedures, including complex oncologic resections and reconstructions. The device achieves thorough curettage by combining a suction mechanism and sharp curette tip. The suction efficiently removes material, while the sharp tip enables precise scraping and removal, minimizing residual tissue. This dual functionality enhances the device's effectiveness compared to traditional methods. Further research into its applications and integration into standard surgical practices could validate its utility and expand its adoption in clinical settings.

Acknowledgements
Not applicable

Authors' contributions
KAW: Concept/design, Data analysis/interpretation, Drafting article, Critical revision of article, Approval of article, Statistics. DS: Data collection and investigation, Approval of article. ES: Data collection and investigation, Approval of article. JAS: Critical revision of article, Approval of article. CP: Critical revision of article, Approval of article. MD: Critical revision of article, Approval of article. BEB: Critical revision of article, Approval of article. JDV: Critical revision of article, Approval of article. WCE: Concept/design, Drafting article, Critical revision of article, Approval of article.

Funding
None to declare.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This trial was approved by the institutional review board of Duke University Hospital (Pro00113599) and carried out by the ethical standards set out in the Helsinki Declaration. Informed consent was received from all participants. All participants approved the use of their medical records.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Orthopaedic Surgery, Duke University Hospital, 2927 40 Duke Medicine Circle 124 Davison Building, Durham, NC 27710, USA. [2]Duke University School of Medicine, Durham, NC, USA. [3]Duke Cancer Institute, Duke University Hospital, Durham, NC, USA.

Received: 24 April 2024 Accepted: 16 August 2024
Published online: 31 August 2024

References

1. Diefenbeck M, Haustedt N, Schmidt HG. Surgical debridement to optimise wound conditions and healing. Int Wound J. 2013;10 Suppl 1(Suppl 1):43–7.
2. Piccioli A, Ventura A, Maccauro G, Spinelli MS, Del Bravo V, Rosa MA. Local adjuvants in surgical management of bone metastases. Int J Immunopathol Pharmacol. 2011;24(1 Suppl 2):129–32.
3. Anastasio AT, Wu KA, Kim BI, Nunley JA, DeOrio JK, Easley ME, Adams SB. A propensity score matched exploration of infection in primary total ankle arthroplasty. Foot Ankle Int. 2023;44(11):1158–65.
4. Schreuder HW, Pruszczynski M, Veth RP, Lemmens JA. Treatment of benign and low-grade malignant intramedullary chondroid tumours with curettage and cryosurgery. Eur J Surg Oncol. 1998;24(2):120–6.
5. Steffner R. Benign bone tumors. Cancer Treat Res. 2014;162:31–63.
6. Rossi G, Mavrogenis AF, Angelini A, Rimondi E, Battaglia M, Ruggieri P. Vascular complications in orthopaedic surgery. J Long Term Eff Med Implants. 2011;21(2):127.
7. Yenigül AE, Sofulu Ö, Erol B. Treatment of locally aggressive benign bone tumors by means of extended intralesional curettage without chemical adjuvants. SAGE Open Med. 2022;10:20503121221094200.
8. Coleman BE. A Clinical Review of Autogenous Bone Grafting for Orthopaedics and the Avitus® Bone Harvester. Avitus® Orthopaedics, Inc.; 2018. White Paper.
9. Lukasiewicz AM, Bagi PS, Yu KE, Tyagi V, Walls RJ. Novel Vacuum-assisted method for harvesting autologous cancellous bone graft and bone marrow from the proximal tibial metaphysis. Foot Ankle Orthop. 2021;6(1):2473011420981901.
10. Greco VE, Hammarstedt JE, O'Connor S, Regal S. Masquelet technique and proximal tibial autograft utilizing avitus® bone harvester for severely comminuted open distal radius fracture with extensive bone loss: a case report. J Orthop Case Rep. 2022;12(4):49–53.
11. Wu KA, Cardona DM, Eward WC: Novel Technique for biopsying osteofibrous dysplasia using a vacuum-assisted bone harvester: a case report. J Orthopaedic Case Rep. 2024;14(11).
12. Godoy G. Mycobacterial complicated distal femoral osteomyelitis treated with aggressive radical debridement utilizing avitus® suction curettage and distal femoral replacement-a case study. Avitus® Orthopaedics, Inc.; 2023. White Paper.
13. Jardaly A, Torrez TW, Kothari EA, Andrews NA, Gilbert SR. Over-Reaming the Humerus to Place an IM Lengthening Nail: Don't Do This Case Report. JPOSNA. 2022;4(2):1–7.
14. Wu KA, Kugelman DN, Seidelman JL, Seyler TM. Native Joint Septic Arthritis. Antibiotics. 2024;13(7):1–14.
15. Goud AL, Harlianto NI, Ezzafzafi S, Veltman ES, Bekkers JEJ, van der Wal BCH. Reinfection rates after one- and two-stage revision surgery for hip and knee arthroplasty: a systematic review and meta-analysis. Arch Orthop Trauma Surg. 2023;143(2):829–38.
16. Horvath MM, Rusincovitch SA, Brinson S, Shang HC, Evans S, Ferranti JM. Modular design, application architecture, and usage of a self-service model for enterprise data delivery: the Duke Enterprise Data Unified Content Explorer (DEDUCE). J Biomed Inform. 2014;52:231–42.
17. Adams OE, Cruz SA, Balach T, Dirschl DR, Shi LL, Lee MJ. Do 30-day reoperation rates adequately measure quality in orthopedic surgery? Jt Comm J Qual Patient Saf. 2020;46(2):72–80.
18. Keating ME, Meding JB. Perioperative blood management practices in elective orthopaedic surgery. JAAOS. 2002;10(6):393–400.
19. Camilleri-Brennan J, James S, McDaid C, Adamson J, Jones K, O'Carroll G, Akhter Z, Eltayeb M, Sharma H. A scoping review of the outcome reporting following surgery for chronic osteomyelitis of the lower limb. Bone Jt Open. 2023;4(3):146–57.
20. Panteli M, Giannoudis PV. Chronic osteomyelitis: what the surgeon needs to know. EFORT Open Rev. 2016;1(5):128–35.
21. 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(11):2263–6.
22. Lazzarini L, Mader JT, Calhoun JH. Osteomyelitis in long bones. J Bone Joint Surg Am. 2004;86(10):2305–18.
23. Suh YS, Nho JH, Choi HS, Ha YC, Park JS, Koo KH. A protocol avoiding allogeneic transfusion in joint arthroplasties. Arch Orthop Trauma Surg. 2016;136(9):1213–26.
24. Nelson CL, Bowen WS. Total hip arthroplasty in Jehovah's Witnesses without blood transfusion. J Bone Joint Surg Am. 1986;68(3):350–3.
25. Kamel C, McGahan L, Mierzwinski-Urban M, Embil J. CADTH Rapid Response Reports. In: Preoperative Skin Antiseptic Preparations and Application Techniques for Preventing Surgical Site Infections: A Systematic Review of the Clinical Evidence and Guidelines. edn. Ottawa: Canadian Agency for Drugs and Technologies in Health Copyright © CADTH (June 2011); 2011.
26. Drampalos E, Mohammad HR, Pillai A. Augmented debridement for implant related chronic osteomyelitis with an absorbable, gentamycin loaded calcium sulfate/hydroxyapatite biocomposite. J Orthop. 2020;17:173–9.
27. Jiang N, Ma YF, Jiang Y, Zhao XQ, Xie GP, Hu YJ, Qin CH, Yu B. Clinical characteristics and treatment of extremity chronic osteomyelitis in southern china: a retrospective analysis of 394 consecutive patients. Medicine (Baltimore). 2015;94(42):e1874.
28. Lam A, Richardson SS, Buksbaum J, Markowitz J, Henry MW, Miller AO, Rozbruch SR, Fragomen AT. Chronic osteomyelitis of the tibia and ankle treated with limb salvage reconstruction. J Bone Jt Infect. 2019;4(6):306–13.
29. Li J, Zhang H, Qi B, Pan Z. Outcomes of vacuum sealing drainage treatment combined with skin flap transplantation and antibiotic bone cement on chronic tibia osteomyelitis: a case series study. Med Sci Monit. 2019;25:5343–9.
30. Lindfors N, Geurts J, Drago L, Arts JJ, Juutilainen V, Hyvönen P, Suda AJ, Domenico A, Artiaco S, Alizadeh C, et al. Antibacterial bioactive glass, S53P4, for chronic bone infections - a multinational study. Adv Exp Med Biol. 2017;971:81–92.
31. Opara KO, Nwagbara IC. The use of sural island musculo fasciocutaneous flap, in the management of chronic osteomyelitis of the tibia. Niger J Clin Pract. 2018;21(6):698–702.
32. Rod-Fleury T, Dunkel N, Assal M, Rohner P, Tahintzi P, Bernard L, Hoffmeyer P, Lew D, Uçkay I. Duration of post-surgical antibiotic therapy for adult chronic osteomyelitis: a single-centre experience. Int Orthop. 2011;35(11):1725–31.
33. Zhou CH, Ren Y, Ali A, Meng XQ, Zhang HA, Fang J, Qin CH. Single-stage treatment of chronic localized tibial osteomyelitis with local debridement and antibiotic-loaded calcium sulfate implantation: a retrospective study of 42 patients. J Orthop Surg Res. 2020;15(1):201.

34. Debnath UK, Thakral R, Burrow ZP. Techniques of Bone Grafting and Bone Augmentation. In: Handbook of Orthopaedic Trauma Implantology. edn.: Springer; 2023: 405–422.
35. Saikia KC, Bhattacharyya TD, Bhuyan SK, Bordoloi B, Durgia B, Ahmed F. Local recurrences after curettage and cementing in long bone giant cell tumor. Indian J Orthop. 2011;45(2):168–73.
36. Şirin E, Akgülle AH, Topkar OM, Sofulu Ö, Baykan SE, Erol B. Mid-term results of intralesional extended curettage, cauterization, and polymethylmethacrylate cementation in the treatment of giant cell tumor of bone: A retrospective case series. Acta Orthop Traumatol Turc. 2020;54(5):524–9.
37. Errani C, Tsukamoto S, Ciani G, Donati DM. Present day controversies and consensus in curettage for giant cell tumor of bone. J Clin Orthop Trauma. 2019;10(6):1015–20.
38. van der Heijden L, Dijkstra PDS, Blay JY, Gelderblom H. Giant cell tumour of bone in the denosumab era. Eur J Cancer. 2017;77:75–83.
39. Ogilvie CM, Cheng EY. What's New in Primary Bone Tumors. J Bone Joint Surg Am. 2016;98(24):2109–13.
40. Ghert MA, Rizzo M, Harrelson JM, Scully SP. Giant-cell tumor of the appendicular skeleton. Clin Orthop Relat Res. 2002;400:201–10.
41. Wijsbek AE, Vazquez-Garcia BL, Grimer RJ, Carter SR, Abudu AA, Tillman RM, Jeys L. Giant cell tumour of the proximal femur: Is joint-sparing management ever successful? Bone Joint J. 2014;96-b(1):127–31.
42. Filipowska J, Tomaszewski KA, Niedźwiedzki Ł, Walocha JA, Niedźwiedzki T. The role of vasculature in bone development, regeneration and proper systemic functioning. Angiogenesis. 2017;20(3):291–302.
43. Zheng K, Yu X, Hu Y, Zhang Y, Wang Z, Wu S, Shen J, Ye Z, Tu C, Zhang Y. Clinical guideline for microwave ablation of bone tumors in extremities. Orthop Surg. 2020;12(4):1036–44.
44. Aiba H, Kobayashi M, Waguri-Nagaya Y, Goto H, Mizutani J, Yamada S, Okamoto H, Nozaki M, Mitsui H, Miwa S, et al. Treatment of simple bone cysts using endoscopic curettage: a case series analysis. J Orthop Surg Res. 2018;13(1):168.
45. Clark CR, Morgan C, Sonstegard DA, Matthews LS. The effect of biopsy-hole shape and size on bone strength. J Bone Joint Surg Am. 1977;59(2):213–7.
46. Gregoretti S. Suction-induced hemolysis at various vacuum pressures: implications for intraoperative blood salvage. Transfusion. 1996;36(1):57–60.
47. Pastorino A, Tavarez MM. Incision and Drainage. StatPearls. 2024.
48. Pincher B, Fenton C, Jeyapalan R, Barlow G, Sharma HK. A systematic review of the single-stage treatment of chronic osteomyelitis. J Orthop Surg Res. 2019;14(1):393.
49. Kim G, Lee KE, Shah A, Seidelman J, Wu KA, Cardona DM, Wahid L. Tuberculosis Osteomyelitis of the Wrist. Perm J. 2024:1–5.
50. Nasser AAH, Fenton P, Bose D. Single stage versus two-stage orthoplastic management of bone infection. Injury. 2022;53(3):984–91.
51. Cheng H, Chen BP, Soleas IM, Ferko NC, Cameron CG, Hinoul P. Prolonged operative duration increases risk of surgical site infections: a systematic review. Surg Infect (Larchmt). 2017;18(6):722–35.
52. Wu KA, Helmkamp J, Levin JM, Hurley ET, Goltz DE, Cook CE, Pean CA, Lassiter TE, Boachie-Adjei YD, Anakwenze O, et al. Association between radiographic soft-tissue thickness and increased length of stay, operative time, and infection rate after reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2024;33(6):1267–75.
53. Leong G, Wilson J, Charlett A. Duration of operation as a risk factor for surgical site infection: comparison of English and US data. J Hosp Infect. 2006;63(3):255–62.
54. Wu KA, Anastasio AT, Krez AN, Kutzer KM, DeOrio JK, Easley ME, Nunley JA, Adams SB. Association of radiographic soft tissue thickness with revision total ankle arthroplasty following primary total ankle arthroplasty: a minimum of 5-year follow-up. Foot Ankle Orthop. 2024;9(2):24730114241255350.
55. Heinz NR, Clement ND, Young RN, Duckworth AD, White TO, Molyneux SG. Rate and factors associated with surgical site infection following aseptic revision fixation of orthopaedic trauma injuries. Eur J Orthop Surg Traumatol. 2023;33(8):3511–7.
56. Koval KJ, Helfet DL. Tibial plateau fractures: evaluation and treatment. J Am Acad Orthop Surg. 1995;3(2):86–94.
57. Knight R, Spoors LM, Costa ML, Dutton SJ. Wound Healing In Surgery for Trauma (WHIST): statistical analysis plan for a randomised controlled trial comparing standard wound management with negative pressure wound therapy. Trials. 2019;20(1):186.
58. Melvin SJ, Dombroski DG, Torbert JT, Kovach SJ, Esterhai JL, Mehta S. Open tibial shaft fractures: I. evaluation and initial wound management. JAAOS. 2010;18(1):10–9.
59. Komori A, Iriyama H, Kainoh T, Aoki M, Naito T, Abe T. The impact of infection complications after trauma differs according to trauma severity. Sci Rep. 2021;11(1):13803.
60. Coombs J, Billow D, Cereijo C, Patterson B, Pinney S. Current concept review: risk factors for infection following open fractures. Orthop Res Rev. 2022;14:383–91.
61. Tornetta PI, Della Rocca GJ, Morshed S, Jones C, Heels-Ansdell D, Sprague S, Petrisor B, Jeray KJ, Del Fabbro G, Bzovsky S, et al. Risk factors associated with infection in open fractures of the upper and lower extremities. J Am Acad Orthop Surg Glob Res Rev. 2020;4(12):e20.00188.
62. Burnham JM, Meta F, Lizzio V, Makhni EC, Bozic KJ. Technology assessment and cost-effectiveness in orthopedics: how to measure outcomes and deliver value in a constantly changing healthcare environment. Curr Rev Musculoskelet Med. 2017;10(2):233–9.
63. Chambers JD, Silver MC, Berklein FC, Cohen JT, Neumann PJ. Are medical devices cost-effective? Appl Health Econ Health Policy. 2022;20(2):235–41.
64. Wu KA, Anastasio AT, Krez AN, O'Neill C, Adams SB, DeOrio JK, Easley ME, Nunley JA. Diabetic management and infection risk in total ankle arthroplasty. Foot Ankle Surg. 2024.
65. Chauveaux D. Preventing surgical-site infections: measures other than antibiotics. Orthop Traumatol Surg Res. 2015;101(1):S77–83.
66. Ramdas K, Saleh K, Stern S, Liu H. Variety and experience: learning and forgetting in the use of surgical devices. Manage Sci. 2018;64(6):2590–608.

Publisher's Note