Research Question

Is there a minimum volume of saline required for effective debridement of open fractures?

1. Background

Irrigation is a fundamental component of open fracture debridement and aims to reduce bacterial contamination, remove foreign material, dilute wound exudates, and create an optimal environment for fracture healing. Together with meticulous surgical debridement and timely antibiotic administration, wound irrigation forms one of the cornerstones of modern open fracture management. Despite its universal acceptance, considerable uncertainty remains regarding several aspects of irrigation practice, including the optimal solution, delivery pressure, timing, and volume of irrigation.

Historically, surgeons have advocated the use of "copious" or "liberal" irrigation during debridement of open fractures. However, these terms have never been clearly defined, resulting in significant variability in clinical practice. Traditional teaching commonly recommends 3 L of saline for Gustilo-Anderson type I fractures, 6 L for type II fractures, and 9 L for type III fractures. These recommendations have been widely adopted in orthopaedic practice despite limited evidence supporting their effectiveness. Contemporary reviews have highlighted that these volume thresholds are largely based on expert opinion and historical convention rather than prospective clinical studies.

Several experimental investigations have demonstrated that increasing irrigation volumes may reduce bacterial contamination in animal models. However, the translation of these findings into clinically meaningful outcomes such as infection prevention, fracture union, and reoperation rates remains unclear. Furthermore, no consensus exists regarding the minimum volume required to achieve effective decontamination while preserving tissue viability.

The Fluid Lavage of Open Wounds (FLOW) trial successfully addressed questions related to irrigation pressure and irrigation solution but did not evaluate irrigation volume, leaving one of the most commonly debated aspects of open fracture care unanswered. Current practice guidelines, including those from the British Orthopaedic Association Standards for Trauma (BOAST), recommend high-volume low-pressure saline irrigation but do not define either a minimum or optimal irrigation volume.

Given the widespread use of empiric irrigation protocols and the absence of clear evidence-based recommendations, determination of whether a minimum volume of saline is required for effective debridement remains an important clinical question. The objective of this review was therefore to evaluate the available evidence regarding irrigation volume in open fracture debridement and determine whether a minimum volume can be recommended.

2. Data Extraction Table

Study	Study Design	Population/ Model	Intervention/ Focus	Relevant Findings Regarding Irrigation Volume	Limitations	Level of Evidence
Owens & Wenke, 2007	Experimental animal study	Goat contaminated wound model	Irrigation with 6 L normal saline at different time intervals after contamination	Earlier irrigation resulted in greater bacterial clearance (70%, 52%, and 37% reduction at 3, 6, and 12 hours respectively). Study used a fixed volume of 6 L and did not compare irrigation volumes.	Animal model; no comparison of different irrigation volumes; no clinical outcomes.	V
Obremskey et al., 2014	OTA surgeon survey	379 orthopaedic trauma surgeons	Survey of open fracture management practices	Demonstrated significant variation in irrigation practices among surgeons, reflecting lack of evidence-based consensus. No specific volume recommenda	Survey study; reflects opinion and practice patterns only.	V

Study	Study Design	Population/ Model	Intervention/ Focus	Relevant Findings Regarding Irrigation Volume	Limitations	Level of Evidence
				tion identified.		
BOAST Open Fracture Guideline, 2020	Clinical guideline	Open fracture management	Recommendations for irrigation and debridement	Recommends high-volume, low-pressure saline irrigation but does not define a minimum or optimal irrigation volume.	Guideline based on available evidence and expert consensus.	V
Gupta et al., 2021	Narrative review	Literature review of open fracture irrigation	Irrigation solution, pressure, timing, and volume	Traditional recommendations of 3 L, 6 L, and 9 L according to Gustilo grade described. Authors state that no outcome data support these recommendations and acknowledge lack of standardization regarding irrigation volume.	Narrative review; no new primary data.	V

Study	Study Design	Population/ Model	Intervention/ Focus	Relevant Findings Regarding Irrigation Volume	Limitations	Level of Evidence
Dheenadhayalan et al., 2023	Narrative review	Open fracture management review	Contemporary management recommendations	Supports copious irrigation as part of debridement but does not identify evidence supporting a specific minimum volume. Highlights continued uncertainty regarding irrigation protocols.	Narrative review; indirect evidence.	V
Lacey et al., 2024	Audit of BOAST adherence	133 open lower limb fractures	Assessment of adherence to BOAST guidelines	Reinforces contemporary practice of high-volume saline lavage. No volume threshold evaluated.	Audit study; not designed to assess irrigation volume.	IV

No study directly compared different irrigation volumes in human open fractures or evaluated a minimum saline volume required to reduce infection, improve fracture healing, or decrease reoperation rates. The available evidence consists predominantly of expert opinion, narrative reviews, guidelines, surveys, and experimental studies, resulting in a very low certainty of evidence.

Results

A focused review of the available literature identified no clinical studies specifically designed to determine the minimum volume of saline required for effective irrigation and debridement of open fractures. The available evidence consists primarily of narrative reviews, expert opinion, practice surveys, animal studies, and guideline recommendations.

The most comprehensive contemporary review by Gupta et al. highlighted that the quantity and duration of wound irrigation remain non-standardized and largely dependent on surgeon preference. The authors noted that previous literature has recommended “liberal,” “copious,” or “adequate” irrigation without defining specific volumes. Traditional recommendations of 3 L, 6 L, and 9 L of normal saline for Gustilo-Anderson type I, II, and III fractures respectively continue to be widely used; however, these recommendations are based on convention and expert opinion rather than outcome-based clinical evidence. No human clinical trials have demonstrated superiority of these volumes in reducing infection, nonunion, or reoperation rates.

Animal studies have investigated the effect of irrigation on bacterial clearance. Owens and Wenke demonstrated improved bacterial removal with earlier irrigation in a contaminated wound model using 6 L of saline. However, the study was not designed to compare different irrigation volumes and therefore cannot establish a minimum effective volume. Similarly, experimental studies cited in contemporary reviews have shown progressive reductions in bacterial burden with increasing irrigation volume, but these findings have not been validated in clinical open-fracture populations.

The British Orthopaedic Association Standards for Trauma (BOAST) recommend low-pressure irrigation using a high volume of saline during debridement but do not specify a minimum or optimal volume. This omission reflects the lack of supporting evidence. Likewise, recent narrative reviews and practice guidelines continue to recommend copious irrigation while acknowledging the absence of evidence-based volume thresholds.

The OTA survey of orthopaedic trauma surgeons further demonstrated substantial variation in irrigation practices, suggesting a lack of consensus regarding appropriate irrigation volumes. This variability likely reflects the absence of high-quality evidence guiding clinical decision-making.

Overall, no randomized controlled trials, comparative cohort studies, or systematic reviews were identified that establish a minimum saline volume required for effective debridement. The currently available literature consistently identifies irrigation volume as an unresolved issue in open-fracture management.

Discussion

Irrigation remains one of the fundamental components of open-fracture debridement. The principal objectives are dilution of bacterial contamination, removal of foreign material, reduction of necrotic debris, and optimization of the wound environment before stabilization and soft-tissue reconstruction. Despite the universal acceptance of irrigation as an essential step in open-fracture care, remarkably little evidence exists regarding the amount of saline required to achieve these objectives.

Historically, surgeons have followed the principle that greater irrigation volumes result in improved wound cleansing. Consequently, recommendations such as 3 L for Gustilo type I fractures, 6 L for type II fractures, and 9 L for type III fractures became widely adopted. These recommendations are frequently taught during orthopaedic training and incorporated into institutional protocols. However, careful review of the literature reveals that these thresholds originated from expert opinion rather than prospective clinical investigation.

One of the most important observations from this review is the complete absence of high-quality clinical studies evaluating irrigation volume as an independent variable. Unlike irrigation pressure and solution type, which have been evaluated in large multicentre trials such as FLOW, irrigation volume has never been subjected to rigorous clinical investigation. Consequently, the orthopaedic community continues to rely on historical practice patterns despite the absence of supporting outcome data.

Several factors may explain why such evidence is lacking. Open fractures are highly heterogeneous injuries. The degree of contamination, mechanism of injury, wound size, soft-tissue damage, fracture configuration, and host factors vary considerably between patients. It is therefore unlikely that a single universal irrigation volume would be appropriate for all injuries. A heavily contaminated agricultural injury may require substantially more irrigation than a low-energy puncture wound communicating with a fracture. This heterogeneity makes prospective evaluation challenging and may explain why investigators have focused on other aspects of wound irrigation.

Experimental studies provide indirect support for increased irrigation volumes. Animal models demonstrate progressive reductions in bacterial counts as irrigation volume increases. However, these studies have significant limitations. Experimental wounds do not accurately replicate the complexity of human open fractures, and bacterial reduction does not necessarily translate into clinically meaningful outcomes such as lower infection rates, improved fracture healing, or reduced need for reoperation. Furthermore, none of the available experimental studies identify a threshold volume beyond which additional irrigation ceases to provide benefit.

Current guidelines appropriately avoid recommending specific volumes. BOAST guidelines advocate high-volume low-pressure saline irrigation while deliberately avoiding quantitative thresholds. This reflects recognition that adequacy of debridement and contamination removal are more important than achieving a predetermined volume target. Similarly, contemporary reviews recommend tailoring irrigation to the characteristics of the wound rather than adhering to rigid numerical protocols.

An important concept emerging from the literature is that irrigation should not be viewed as a substitute for meticulous surgical debridement. Removal of devitalized tissue remains the

single most important intervention for infection prevention. Excessive emphasis on irrigation volume risks creating the misconception that larger volumes can compensate for inadequate debridement. Available evidence does not support such an assumption.

The greatest contribution of this review may therefore be identification of a significant knowledge gap. Despite decades of open-fracture research, no study has established the minimum volume of saline necessary for effective debridement. This represents an important opportunity for future investigation. Prospective studies evaluating irrigation volume in relation to infection, nonunion, reoperation, and patient-reported outcomes are needed. Such studies should stratify injuries according to contamination severity and fracture characteristics to determine whether specific patient subgroups may benefit from different irrigation strategies.

Until such evidence becomes available, surgeons should continue to perform copious irrigation using normal saline while tailoring volume to wound size, contamination burden, soft-tissue injury, and adequacy of debridement. Current practice should remain guided by clinical judgment rather than arbitrary volume thresholds.

Consensus Statement

There is insufficient evidence to define a minimum volume of saline required for effective debridement of open fractures. Existing recommendations regarding irrigation volume are based primarily on expert opinion and historical practice rather than comparative clinical studies. Irrigation volume should be individualized according to wound size, contamination burden, fracture severity, and adequacy of debridement.

Recommendation

Copious low-pressure irrigation with normal saline is recommended during open-fracture debridement. No minimum volume threshold can currently be recommended based on available evidence.

Level of Evidence

Very Low.

Strength of Recommendation

Consensus recommendation based on expert opinion and indirect evidence.

Research Gap

There is a complete absence of prospective comparative clinical studies evaluating irrigation volume in open fractures. Determination of the minimum effective irrigation volume represents a major priority for future research.