Open fractures are widely considered as orthopaedic emergencies requiring immediate intervention. Approximately 3–4% of all fractures are open [1, 2]. Open fractures to the lower extremities are commonly seen at the Accident and Emergency department of the National Orthopaedic Hospital, Igbobi-Lagos with an average annual incidence of 1.5%.

The initial management of open fractures often affects the ultimate outcome. The most important initial step in the surgical wound management of open fractures is regarded as copious fluid irrigation along with meticulous debridement of surrounding contaminated soft tissues [1, 3–5]. Conclusions drawn from Gustilo and Anderson’s classic article emphasize emergency treatment including copious irrigation and debridement [6].

Wound irrigation to remove debris and lessen bacterial contamination is an essential component of open fracture care [7, 8]. When performed properly, wound irrigation can enhance wound healing by reducing infection and its attendant morbidities.

Isotonic saline is regarded as the most appropriate and preferred irrigant because it is a nontoxic solution that does not damage the healing tissue [8–11]. Although widely used, its cost may preclude judicious use where large amounts are required and the need for a more affordable alternative cannot be overemphasized.

Distilled water is routinely used in the hospital laboratory on a daily basis for titration of solutions and evaluation of blood samples. It is produced by condensing steam, is nonpyrogenic and without antimicrobial agents or buffers. It is often used in irrigation as a less expensive alternative to isotonic saline, especially in developing countries [8–11].

The choice of irrigation solution, optimal amount required and method of delivery remain controversial [9, 12]. Given that wound irrigation is more dependent on mechanics than the antibacterial or chemical properties of the irrigation solutions, copious amounts are recommended and therefore less
expensive and readily available solutions may be employed in
the irrigation of open fractures.

This study aimed to evaluate and compare the effects of
isotonic saline and distilled water as irrigating solutions in
open injuries of the lower extremities.

Materials and methods

This was a prospective, randomized, interventional,
hospital-based study. Patients of all ages presenting at the
Accident and Emergency department of the National
Orthopaedic Hospital, Igbobi-Lagos with open fractures of
the lower extremities were recruited over a period of 12 months.
Approval was obtained from the Research and Ethics
Committee of the Hospital prior to commencement of the
study.

All patients who presented with open fractures were treated
as emergency, using the Advanced Trauma Life Support
(ATLS) protocol. Patients of all ages with Gustilo-Anderson
I–IIIa open fractures of the lower extremities presenting within
24 h who consented were included in the study. Patients with
potentially life-threatening injuries that required emergency
interventions were excluded from the study.

Patients who met the inclusion criteria were then recruited
into the study. An informed consent to participate in the study
was taken. Using a simple ballot technique, patients were
grouped into groups A and B. Patients in group A had wound
irrigation done with isotonic saline, while group B patients
had irrigation done with distilled water. Broad spectrum
parenteral antibiotics were administered and continued for
72 h (Cefuroxime and Metronidazole). This was subsequently
followed by oral forms in the presence of signs and symptoms
of infection. Adequate analgesics were administered to
patients, and opioids were used for this study. The wound
was covered with sterile dressings. The fractured limb was
immobilized with external splints, and appropriate plain radiogra-
graphs were obtained.

Patients were then prepared for emergency wound
debridement and copious irrigation in the theatre under aseptic
conditions using general or regional anaesthesia. The operation
site was cleansed with antiseptic lotion and sterile drapes
applied. Dead tissues, nonviable tissues and devitalized desic-
cated bone were removed, and the edges of the wound excised.
The wound was graded according to the Gustilo and Anderson
classification after the debridement by the operating surgeon.
The wound was then irrigated with at least three litres of
isotonic saline or distilled water, according to guidelines listed
in Table 1 which was pasted in the operating theatre.
The wound was irrigated using a 20 mL piston syringe.

The timing and technique of fracture stabilization was
determined by the consultant. Wound closure, where possible,
was done using Prolene sutures on a cutting needle. Thereafter,
sterile dressings were applied. Post-operatively, antibiotics and
analgesics were continued as prescribed above. The affected
limb was elevated in bed, and the vital signs monitored
regularly.

The wound was inspected after 24 h, as well as the 3rd and
5th post-operative days for signs and symptoms of infection.

The Cutting and Harding criteria were used to define the
presence of infection clinically. These criteria included
abscess, cellulitis, wound discharge, discoloration, delayed
healing, friable granulation tissue, unexpected pain and
tenderness, pocketing at the base of the wound, epithelial
bridging, abnormal smell and wound breakdown [22]. Wound
healing was defined, following wound inspection, as the
presence of epithelial tissue covering the wound. These criteria
had earlier been used by Griffiths et al. [25].

Wound swabs for microscopy, culture and sensitivity were
taken to examine if signs of infection were present; otherwise
sterile saline dressings were applied. Repeat wound
debridement was done in the theatre as required. Continued
use of antibiotics was determined by the sensitivity patterns
of cultured organisms.

Wounds that showed evidence of infection by the 5th day
were left open and appropriate dressings continued, until the
wound was cleansed for a secondary wound closure. Sutures
were removed between the 10th and 14th post-operative day,
or if complete wound dehiscence occurred. Patients were
followed up as either outpatients or inpatients.

The primary outcome measures of each patient group were
wound infection and wound healing. The influence of time
interval between injury and presentation, Gustilo grade, choice
of irrigation solution and timing of wound closure on wound
infection were evaluated.

Data was entered in a personal computer and analysed
using the Statistical Package for Social Sciences (SPSS)
version 17. Normally distributed numeric variables were
summarized using their mean and standard deviations
(Mean ± SD). For skewed numeric variables such as time
intervals, the median and range were used. The chi-square
($\chi^2$) test was used to detect the association and comparison
of proportions between categorical variables. The Fisher’s
exact test was used in place of the chi-square test where
expected frequencies were small or less than five. The relative
risk (RR) of wound infection by irrigation fluid was calculated
and the 95% Confidence Interval (CI) determined.

For independent samples, t-test was used to compare the
mean of normally distributed numerical variables between
the two study groups and where the variables were skewed,
its nonparametric equivalent, the Mann-Whitney U test was
used.

Finally, a multivariate binary logistic regression analy-
sis was performed by entering wound infection as the
dependent variable to determine its independent predictors.
The generated odds ratio (OR) and 95% CI were approximated
to the relative risk (RR). The results were presented in tables
and appropriate charts. The level of significance was set at
p-value < 0.05.

| Gustilo type | Irrigation |
|--------------|------------|
| I            | 3 L of Isotonic saline/distilled water |
| II           | 6 L of Isotonic saline/distilled water |
| IIIa         | 9 L of Isotonic saline/distilled water |
In total, 120 patients were recruited. Twenty-three patients were lost to follow-up and 97 patients were studied. They comprised 50 patients randomized into the Isotonic Saline (NS) group and 47 patients into the Distilled Water (DW) group.

The mean age of NS group was 37.1 ± 13.6 years. Although this was higher than the value for the DW group (34.6 ± 11.9 years), this difference was not significant ($p = 0.330$). The largest proportion of subjects in each of the two groups (32.0% NS and 53.0% DW group) belonged to the 30–39 year age group. There were significantly higher proportions of men in both study groups ($p = 0.022$). See Table 2. The tibia was affected in 44 out of the 94 patients studied. This accounts for the most common lower limb bone affected. The mechanism of injury of patients in both groups was compared and no significant difference was found (Figures 1 and 2).

Among patients who developed wound infection, there was no significant difference in both groups (RR 0.774, 95% CI 0.466–1.283). Of the 22 NS patients with wound infection, 9 (40.9%) developed osteomyelitis compared to five (31.2%) out of the 16 with wound infection among the DW group. This difference was not statistically significant (Chi-square test applied). Staphylococcus spp. was the commonest organism in six out of 16 (37.5%) of the NS group with a positive culture growth. It was also the commonest in three out of seven (42.9%) in the DW group. Klebsiella spp. and Proteus spp. were the commonest gram-negative organisms cultured.

Primary wound closure was done in 31 (62.0%) NS patients and 33 (70.2%) DW patients. Other methods of wound closure used were delayed primary closure and split thickness skin graft. Wound healing rates in both groups were not significantly different though the mean time to wound healing was 3.1 ± 1.8 weeks in the NS group and 2.7 ± 1.5 weeks in the DW group. See Table 3.

A multivariate binary logistic regression analysis showed that only the grade of fracture (Gustilo Grade II) was found to be independently associated with wound infection. Patients with Gustilo type II fracture were significantly less likely to have wound infection compared to those with Grade IIIa (RR 0.078, 95% CI 0.023–0.262). Although the DW group had a 10% reduced risk of wound infection compared to the NS group, this was not statistically significant (RR 0.9, 95% CI 0.279–2.906). See Table 4.

### Discussion

The fate of an open fracture depends a lot on the initial treatment administered to the wound [13]. In the treatment of open fractures, copious use of solution in order to reduce the degree of pollution by contaminants is a critical step in the debridement of the wound [7]. The choice of irrigation solution is therefore very important in the final outcome of a wound.

The age of patients in this study ranged from 18 to 73 years, however, male patients in the active age group of 30–39 years were predominantly affected. This finding is similar to the work done in Nigeria by Ikem et al. [14] and Thanni and Kehinde [15]. They found that males within this age group formed a larger portion of patients with open fractures. Injuries, especially to the active working population in any country, bear a significant socioeconomic burden on the community.

Most patients in this study had open fractures from traffic accidents. Others were secondary to gunshot, falls from height and sport injuries. Road accidents are leading causes of trauma injuries in the world and one of the leading causes of fractures in Nigeria [16]. Most of these injuries occur in unsterile environments and lead to contamination of the wound from...
the environment, thus making wound irrigation essential to open fracture care.

The most frequently injured lower limb bone in this study was the tibia, accounting for a total of 44 injuries (45.7%), while femoral and ankle fractures followed at 23.4% and 25.5%, respectively. The subcutaneous nature of the tibia in a bipedal man as compared to the large protective tissue envelope of the femur may account for this, as documented in the literature [17–19].

We noted that the Gustilo grade was significantly associated with the rate of wound infection in both groups. It was noted that higher Gustilo grades were associated with higher wound infection rates ($p = 0.000$ in the NS group and $p = 0.025$ in the DW group). Gustilo and Anderson, Patzakis and Wilkins and other researchers documented a similar finding in their studies [6, 20, 21]. This may be as a result of the extent of tissue damage and tissue necrosis. The total extent of tissue injury may not be apparent at the time of first surgery leading to retention of necrotic tissue which is a nidus of infection. Wound irrigation on its own would serve to reduce contamination while debridement would remove dead tissue.

Wound infection was assessed using the Cutting and Harding criteria [22]. When the infection rates were compared, wound infection was more common among patients who used isotonic solution. Despite this finding, there was no significant difference in the infection rates in patients who had isotonic saline for wound irrigation and those who had distilled water for wound irrigation ($p = 0.315$). This suggests that irrigation
fluid volume, rather than the type of irrigation fluid, is the more important factor in the reduction of bacteria load in open fractures. Similar findings have been noted in earlier studies [8, 11, 23, 24].

Wound healing was defined as epithelial covering of the wound as described earlier in a study by Griffiths et al. [25]. The mean time to wound healing was 3.1 weeks in the isotonic saline group and 2.7 weeks in the distilled water group. Although the wound healing rate appeared faster in the distilled water group, this finding was not statistically significant (p = 0.389). Isotonic saline is favoured as it does not interfere with the normal healing process. However, findings in this study are similar to the findings of Museru et al. [8], where they found that distilled water did not negatively affect wound healing. We postulate that this can be alluded to the fact the hypotonic effect of distilled water is transient.

Guiding principles in open fractures are constantly evolving, however, it is widely accepted that wound irrigation plays a very fundamental role. The irrigating solution acts simply as a mechanical cleanser, therefore the volume used is crucial. Isotonic saline is generally preferred because, due to its tonicity, it is less toxic to tissues than other commercial irrigants. It may be argued that the hypotonicity of distilled water may have the potential for cellular damage and possibly delayed wound healing or impaired cellular function which could ultimately result in increased infection rates [8, 11, 25]. This study demonstrated that distilled water is as effective as isotonic saline in irrigating open fractures of the lower extremities.

### Conclusion and recommendations

Distilled water and isotonic saline are both effective irrigation solutions. There is no significant difference in wound infection rates or wound healing rates using either distilled water or isotonic saline for wound irrigation in open fractures of the lower extremities.

We concluded from this study that distilled water should be used as an alternative to isotonic saline for wound irrigation in open fractures of the lower extremities.

### Conflict of interest

OOT and AAI certify that they have no financial conflict of interest (e.g., consultancies, stock ownership, equity interest,
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