Modern principles for the treatment of open fractures include stabilisation of the bone and management of the soft tissues. Wound debridement and irrigation is thought to be the mainstay in reducing the incidence of infection. Although numerous studies on animals and humans have focused on the type of irrigation performed, little is known of the factors which influence irrigation. This paper evaluates the evidence, particularly with regard to additives and the mode of delivery of irrigation fluid.

Normal saline should be used and although many antiseptics and antibiotics have been employed, no consensus has been reached as to the ideal additive. Despite the advocates of high-pressure methods highlighting the improved dilutional ability of such techniques, the results are inconclusive and these irrigation systems are not without complications.

New systems for debridement are currently being investigated, and an ideal method has yet to be determined.

Additives

Most surgeons use sterile saline for the irrigation of wounds. Other solutions have been added to a saline medium with the aim of improving wound healing and preventing infection. The most popular additives are antiseptics, antibiotics, and soap (Table I).16,19-27

Antiseptics. A number of studies have been carried out on animals and humans into the use of antiseptics.19-23,25 The most commonly used are povidone-iodine (Betadine; Seton Scholl Healthcare Pty Ltd, Terrey Hills, United Kingdom) and chlorhexidine gluconate (Hibitane; (Bioglan) Bradley Pharmaceuticals Inc., West Fairfield, New Jersey).21-23,25 These antiseptics are active against a broad spectrum of bacteria, fungi and viruses, and they help eliminate wound pathogens. Advocates of antiseptics believe that by reducing the bacterial load, their use will lead to less pressure on the host defence system.19,20,23 The disadvantages are their toxicity towards host cells and to cell function, which may cause delayed wound healing.19

In high concentrations povidone-iodine, sodium hypochloride and hydrogen peroxide killed 100% of human fibroblasts tested in vitro.21 A level of dilution that caused no damage to fibroblasts while maintaining bactericidal activity was also determined in this investigation (1/1000 for povidone iodine and 1/100 for sodium hydrochloride). Kaysinger et al25 had similar findings in their study on chick tibiae in vitro, even at high levels of dilution.

Brennen and Leaper,22 in rabbit studies, showed that all antiseptics have a negative effect on microvascular flow and endothelial...
IRRIGATION OF THE WOUNDS IN OPEN FRACTURES

integrity. Only povidone-iodine has been studied in humans. In 1975, Gilmore and Sanderson showed a statistically significant reduction in wound infection with the prophylactic use of povidone-iodine. However, no difference was found in the infection rates between operative wounds treated with normal saline or with povidone-iodine in the large series of Rogers et al.

In 1980, Vilijanto showed that a 5% povidone-iodine solution was too strong from the standpoint of wound healing, and that a 1% solution was safer. It was efficient in reducing the numbers of wound infections in children with appendicitis.

Antibiotics. Not all antibiotics are suitable for instillation in wounds because of their pharmacokinetic and pharmacodynamic properties. The most commonly studied antibiotics have been neomycin, whose mode of action is unknown, bacitracin, which interferes with cell wall synthesis, and polymyxin, which directly alters the permeability of the cell membrane.

Conroy et al used a rat model to show that infections in complex contaminated orthopaedic wounds could be reduced with the use of bacitracin. Rosenstein et al compared bacitracin with saline in a canine model and demonstrated a reduction in positive wound cultures and wound infections.

Evidence is sparse as to the topical use of antibiotics in orthopaedic surgery. However, animal models have shown that irrigation with antibiotic reduces the rate of infection compared with the use of saline solution. The lack of well designed and controlled clinical studies focused on the intra-operative local use of antibiotic irrigation has been identified. In a randomised controlled trial it was found that there was no benefit in the use of flucloxacillin for the irrigation of open fractures of the distal phalanx. Moreover, the use of antibiotics in irrigation is not without risk. There are two case reports of bacitracin causing an anaphylactic reaction after irrigation in surgical procedures. The use of antibiotics is costly, and the promotion of antibiotic resistance will always be a concern.

Surfactants. Before the widespread use of antibiotics, Koch recommended the use of soap solutions to cleanse open wounds. Surfactants work by disrupting the hydrophobic or electrostatic forces that drive the initial stages of bacterial surface adhesion. The purpose of the soap is to lower the bacterial load in the wound by removing the bacteria, rather than killing them.

Conroy et al found in an animal study that soap appeared to be at least as effective as many antisepsics and antibiotics. A prospective randomised clinical study comparing soap and antibiotic solutions for the irrigation of wounds in open fractures of the lower limb showed that neither method had a particular advantage.

The effect of pressure

Low-pressure methods. Traditionally, irrigation fluid has been delivered either via a bulb syringe or with an elevated pressure.
fluid bag and a giving set, aided by the use of a scrubbing brush and suction. The benefit of using non-pulsatile methods is that more debris may be removed from a wound than when using pulsed devices.33 There is no evidence to suggest that bulb syringe and suction cause soft-tissue damage or inhibit fracture healing if used at the fracture site.33 Brown et al34 compared the use of pulsed lavage with a bulb syringe in vivo and found that the former was more effective in bacterial clearance. Bhattacharjya et al35 also found that pulsed lavage was three times more effective than a bulb syringe in wound irrigation.

**High-pressure methods.** Many pulsed lavage systems exist, such as the Interpulse (Stryker Orthopaedics, Mahwah, New Jersey),6 Powerpulse (Smith & Nephew Orthopaedics Ltd, Warwick, United Kingdom)9 and the MicroAire (MicroAire Europe, Meerbusch, Germany).7 These systems work optimally at pressures of 50 psi to 80 psi.6,8 Advocates of the pulsed lavage system claim that it works more effectively to remove contaminants from wounds than the bulb syringe.18,34,35 However, it has been noted to cause damage to the structure of bone, interfere with fracture healing and to damage soft tissue.11,36-41

### Table II. Studies on bone damage by pulsed lavage

<table>
<thead>
<tr>
<th>Author/s</th>
<th>Model</th>
<th>Systems</th>
<th>Bacterial studies</th>
<th>Debris studies</th>
<th>Bone damage/fracture healing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dirschl et al37</td>
<td>Rabbit</td>
<td>Pulsed lavage vs bulb syringe</td>
<td>N/A*</td>
<td>N/A</td>
<td>Macroscopic damage and decreased new bone formation</td>
</tr>
<tr>
<td>Bhandari et al32</td>
<td>Human tibiae</td>
<td>Pulsed lavage vs no irrigation</td>
<td>Intramedullary bacterial seeding observed</td>
<td>N/A</td>
<td>Macroscopic damage</td>
</tr>
<tr>
<td>Bhandari et al30</td>
<td>Human tibiae</td>
<td>70 psi pulsed lavage vs 14 psi pulsed lavage</td>
<td>Equal reduction up to 6 hours</td>
<td>N/A</td>
<td>High pressure caused significant microscopic damage</td>
</tr>
<tr>
<td>Lee et al38</td>
<td>Rabbit</td>
<td>Pulsed lavage vs bulb syringe</td>
<td>N/A</td>
<td>Equal reduction of debris with no intramuscular seeding</td>
<td>Microscopic damage</td>
</tr>
<tr>
<td>Draegar and Dahners33</td>
<td>Rabbit</td>
<td>High-pressure pulse lavage vs low-pressure lavage</td>
<td>N/A</td>
<td>N/A</td>
<td>New bone inhibited at 50 psi and above</td>
</tr>
</tbody>
</table>

* N/A, not applicable

### Table III. Studies on soft-tissue effects of pulsed lavage

<table>
<thead>
<tr>
<th>Author/s</th>
<th>Model</th>
<th>Specimens</th>
<th>Irrigation system</th>
<th>Bacterial clearance*</th>
<th>Debris removal</th>
<th>Tissue damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhattacharjya et al35</td>
<td>Rats</td>
<td>1095</td>
<td>Pulsed lavage vs bulb syringe</td>
<td>N/A</td>
<td>PL &gt; BS</td>
<td>N/A</td>
</tr>
<tr>
<td>Rodeheaver et al44</td>
<td>Guinea pigs</td>
<td>72</td>
<td>Pulsed lavage vs bulb syringe</td>
<td>N/A</td>
<td>PL &gt; BS</td>
<td>N/A</td>
</tr>
<tr>
<td>Madden et al33</td>
<td>Rats</td>
<td>100</td>
<td>Pulsed lavage vs gravity flow vs bulb syringe</td>
<td>PL 7 x more effective than BS</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Wheeler et al40</td>
<td>Pigs</td>
<td>15</td>
<td>Pulsed lavage vs bulb syringe</td>
<td>Greater infection rate in PL group</td>
<td>N/A</td>
<td>PL: deeper damage</td>
</tr>
<tr>
<td>Brown et al34</td>
<td>Rats</td>
<td>234</td>
<td>50 psi pulsed lavage vs bulb syringe</td>
<td>PL SS p &lt; 0.5</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Tabor et al45</td>
<td>Canines</td>
<td>20</td>
<td>Pulsed lavage vs bulb syringe</td>
<td>26% better with PL</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Boyd and Wongworawat31</td>
<td>Ovine muscle</td>
<td>65</td>
<td>Pulsed lavage vs gravity flow</td>
<td>N/A</td>
<td>N/A</td>
<td>PL &gt; GF†</td>
</tr>
<tr>
<td>Hassinger et al46</td>
<td>Ovine muscle</td>
<td>50</td>
<td>Pulsed lavage vs gravity flow</td>
<td>Gravity &gt; PL</td>
<td>N/A</td>
<td>Bacterial penetration with PL</td>
</tr>
<tr>
<td>Draegar and Dahners33</td>
<td>Beef steaks</td>
<td>8</td>
<td>Pulsed lavage vs bulb syringe</td>
<td>N/A</td>
<td>BS &gt; PL</td>
<td>PL &gt; BS</td>
</tr>
</tbody>
</table>

* N/A, not available; PL, pulsed lavage; BS, bulb syringe; SS, statistically significant
† GF, gravity flow
Concerns over bone damage with the use of pulsed lavage were first noted by Dirschl et al in 1998. An in vivo osteotomy model was used to prove detrimental effects on early new bone formation after pulsed lavage. An in vitro study of contaminated fractures of the human tibia confirmed that pulsed lavage causes macroscopic damage to the architecture of the bone and allows seeding of bacteria into the medullary canal. In a follow-up study, Bhandari et al demonstrated the microscopic damage to bony architecture caused by pulsed lavage. More animal studies followed to show that pulsed lavage caused damage to bone and was no better than a bulb syringe for removing debris from a wound. A pressure threshold of 50 psi was identified, beyond which new bone formation was inhibited. The studies focusing on bone damage are summarised in Table II.

An earlier study on pigs investigated irrigating a wound and then inoculating it with a normally sub-infective dose of staphylococci. This investigation raised concerns about increased fluid penetration within tissues, reduced wound resistance to infection, and probable transient bacteremia, although this has never been shown to be clinically significant.

A recent study on fresh ovine muscle showed that high pressure pulsed lavage penetrates and disrupts soft tissue to a deeper level than low-pressure lavage, causing considerable gross and microscopic tissue disruption. Table III summarises the available studies focusing on soft tissue damage.

**Bacterial clearance**

The best method of irrigation to promote better bacterial clearance has not been established.

Advocates of the high pressure pulsed lavage system believe that it allows quicker and more efficient delivery of irrigant to the wound and has superior dilutional effects which promote greater bacterial clearance. This opinion has been supported in studies using rat, canine and human models. An early study also demonstrated that pulsatile flow was less effective than continuous flow in bacterial clearance. It was suggested that 15 psi is the minimum level required to achieve sufficient tissue debridement. Tabor et al showed that bacterial levels were reduced by a mean of 70% (SD 10%) by high pressure pulsed lavage and 44% (SD 50%) by bulb irrigation.

Nevertheless, a number of concerns exist over the use of pulsed lavage in open fractures, and its use is by no means universal. In addition to the ample evidence suggesting that bone healing and soft tissue are damaged, Hassinger et al have shown that high pressure pulsed lavage causes deeper penetration of bacteria and results in greater bacterial retention in soft tissue than low-pressure lavage.

As noted, Bhandari et al identified increased bacterial seeding into the medullary canal in the human tibia, and they also showed that pulsed lavage was more effective in reducing bacterial counts only when irrigation was delayed for six hours after contamination.

**Latest developments**

The surgical knife remains the standard of care to which all other forms of tool for debridement have to be compared. Other alternatives have been designed, such as enzymatic and laser debridement, with the potential advantages of haemostasis, surgical precision and control of the depth of excision.

Klasen described a study dating back to the Second World War using enzymes of plant origin, such as the proteolytic enzymes derived from filtrates of *Clostridium histolyticum* and *Bacillus subtilis*, for debridement. Although this is an interesting idea, the results have been far too variable for this method to be recommended.

Levine et al compared the use of a carbon dioxide laser with the standard technique for debridement of burns using a scalpel, and found that there was considerably less blood loss. However, the results were of little clinical consequence. Despite the efficacy of laser treatment in reducing the amount of bleeding from the wound bed, it has failed to gain general acceptance.

The Versajet system has recently been specifically designed and introduced for controlled surgical debridement. Initially this instrument became popular in neurosurgery and was developed to aid debridement of the nucleus pulposus during laminectomy. This system used the Venturi effect and fluid-jet technology. The Venturi effect creates a local vacuum on the surface of the debridement area directly facing the operating window. Recent studies have suggested that it produces a lower bacterial load in burns.

The Versajet has been shown to be more selective and less aggressive than the scalpel, and allows superior sparing of healthy tissue. It also prevents the diffusion of microbial contamination deeper into the wound. The system is gaining favour in the debridement of vascular ulcers, and patients have found that the system is more comfortable than high-pressure pulsed lavage when used at the bedside without anaesthetic.

**Discussion**

Irrigation has always been, and will remain, a key step in the initial management of open fractures. The object is to reduce necrotic debris and foreign material, and minimise the bacterial load. No study has doubted the need for irrigation, but many have differed as to the ideal method.

The first issue we have examined is which additive, if any, should be used for irrigation. Many studies in animals using antiseptics such as betadine and hydrogen peroxide have shown that in the undiluted form both solutions have toxic effects on tissues. Human studies have shown a reduction in wound infections when using betadine.

The use of antibiotics as additives has also been investigated, but the results are inconclusive. Human studies...
using antibiotics are sparse and tend to be confined to general surgery. The use of antibiotics is not without risk, with instances of anaphylaxis following irrigation with bacitracin.29-31 Soap has been shown to be as effective as antibiotics in the irrigation of open wounds, and at least as effective as bacitracin in the irrigation of open fractures.16

When pulsed lavage was introduced in the early 1970s, the studies were then supportive of the high-pressure system. Several in vivo studies34,35,44,45 found that the bacterial burden could be reduced following irrigation with high-pressure lavage. More recently, however, concerns have been raised as to the macroscopic and microscopic damage to the bone and surrounding soft tissues caused by pulsed lavage.13,37-39,41,46 These studies also identified concerns over a delay in fracture healing, but there is no clinical evidence to support this.

The Versajet system is one of the latest advancements in debridement of open fractures. Based on current evidence we can make the following recommendations:

1. Normal saline should be used routinely for the irrigation of fractures.
2. The use of antibiotics and antiseptics as additives should be limited because of inconclusive evidence and potential risks.
3. Low-pressure irrigation methods should be used routinely.
4. Surgeons who continue to use high-pressure pulsed lavage systems should limit the pressure to 50 psi.

References


