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Prevention of Infection in the Treatment of One Thousand and Twenty-five Open Fractures of Long Bones

RETROSPECTIVE AND PROSPECTIVE ANALYSES

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ABSTRACT: In 673 open fractures of long bones (tibia and fibula, femur, radius and ulna, and humerus) treated from 1955 to 1968 at Hennepin County Medical Center, Minneapolis, Minnesota, and analyzed retrospectively, the infection rate was 12 per cent from 1955 to 1960 and 5 per cent from 1961 to 1968. In a prospective study from 1969 to 1973, 352 patients were managed as follows: débridement and copious irrigation, primary closure for Type I and II fractures and secondary closure for Type III fractures, no primary internal fixation except in the presence of associated vascular injuries, cultures of all wounds, and oxacillin-ampicillin before surgery and for three days postoperatively. In 158 of the patients in the prospective study the initial wound cultures revealed bacterial growth in 70.3 per cent and the infection rate was 2.5 per cent. Sensitivity studies suggested that cephalosporin is currently the prophylactic antibiotic of choice. For the Type III open fractures (severe soft-tissue injury, segmental fracture, or traumatic amputation), the infection rates were 44 per cent in the retrospective study and 9 per cent in the prospective study.

Prevention of wound sepsis remains the prime objective in the management of open fractures. The reported infection rates in these fractures, which range from 3 to 25 per cent, are a challenge to every surgeon who treats them^{6-8,10,14,15,21,22,26}.

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There is universal agreement that open fractures require emergency treatment, including adequate débridement and irrigation of the wound. Beyond these two basic tenets, opinions differ as to the following:

1. Primary or secondary closure. If the wound is left open and secondary direct skin closure is not possible, when does one do skin-grafting, or create a cross-leg pedicle flap or a rotational flap?
2. Use of primary internal fixation. What are the indications for primary internal fixation and if internal fixation is delayed, when is the proper time for open reduction and internal fixation?
3. Use of antibiotics. Should they be used routinely? What antibiotics should be used and for how long?

In an attempt to answer these questions we carried out retrospective and prospective analyses of a total of 1,025 open fractures of all the long bones treated at Hennepin County Medical Center, Minneapolis, Minnesota, from 1955 to 1973.

Retrospective Study, 1955 to 1968

As previously reported^{14,15}, 673 open fractures of long bones in 602 patients were treated at Hennepin County Medical Center from 1955 to 1968. The data on these fractures were collected by review of the charts, follow-up letters, and telephone calls. Of the 673 fractures, 583 (86.6 per cent) were followed for at least one month until soft-tissue healing had occurred. The remaining ninety patients failed to return for any follow-up.

All patients were cared for by the general surgical or orthopaedic resident assigned to the Trauma Service with a

member of the attending staff consulting. The management of these fractures was essentially the same throughout the period of this study, except for the antibiotics used. Treatment during this period included:

1. Adequate débridement and copious irrigation of the wound.
2. Primary closure whenever possible, regardless of the severity of the fracture and the soft-tissue injury.
3. Internal fixation used at the discretion of the surgeon and not in accordance with any rigid criteria. Some fractures treated by internal fixation could have been treated in a plaster cast alone or with pins above and below the fracture incorporated in a plaster cast.
4. Routine antibiotics. During the first five years (1955 to 1960), penicillin, 40,000 to 60,000 units, was given intravenously every four to six hours in combination with streptomycin, 0.5 to 1.0 gram twice daily, starting postoperatively and continuing for seven to ten days. From 1961 to 1966, penicillin, 600,000 to 1.0 million units, and Chloromycetin (chloramphenicol), 0.5 to 1.0 gram, were given intravenously every six hours starting one to three hours preoperatively and continuing for seven to ten days. From 1967 to 1968, penicillin, 1.0 million units every six hours, and oxacillin, 1.0 gram every four hours intravenously, were started one to three hours before operation and continued for seven to ten days. Occasionally, when the wound was severely contaminated, kanamycin, 0.5 gram twice a day, was also given.

Results

Infection Rate

The infections were usually evident during the first month after surgery, the majority being recognized during the first seven days. Drainage developed in thirty-eight (6.5 per cent) of the wounds, of which thirty-one had positive and five had negative cultures, and two were not cultured. All thirty-eight wounds were considered infected because of the purulent drainage and characteristic appearance of the wounds. Sensitivity studies were done on all pathogenic bacteria recovered and the antibiotic programs were changed as indicated. The common pathogenic organisms isolated were *Staphylococcus aureus* coagulase positive in twenty-six patients, *Escherichia coli* in three, *Proteus* in two, and *Pseudomonas* and a gram-negative rod in one each.

The over-all incidence of wound infections from 1955 to 1960 was 11.85 per cent and from 1961 to 1968, 5.24 per cent. These rates were considered low and appeared to justify the methods of treatment, considering the high incidence of infection reported in previous series of open fractures^{6-8,10,14,15,20,21,26}.

Primary Internal Fixation

The incidence of infection in open fractures of the femur and tibia treated by primary internal fixation was compared with that in fractures treated without internal fixation. The fractures were not matched or selected at

random, a problem in all retrospective studies. However, we believe that the fractures treated with primary internal fixation could have been treated by plaster alone or by pins inserted above and below the fracture site and incorporated in a plaster cast. Fifty-two open fractures (thirty-four tibiae and eighteen femora) treated by primary nailing or plating had a 19 per cent infection rate, and 238 open fractures (194 tibiae and forty-four femora) were treated without internal fixation and had an infection rate of 5 per cent.

Primary Versus Secondary Wound Closure

In a retrospective study it is not possible to make statistically valid comparisons. Obviously some of the wounds that were left open were the most contaminated or had the most tissue loss. Of forty-four open fractures treated by initial débridement and secondary closure, 20 per cent became infected, while only 6 per cent of the 495 fractures treated by primary closure became infected. Because of these excellent results with primary closure, in 1966 we advocated primary closure for all open fractures except when the surgeon thought that the débridement and irrigation had not been entirely satisfactory. From 1955 to 1960, 18 per cent of the open fractures were left open; from 1961 to 1966, 4 per cent; and from 1967 to 1968, only 1 per cent.

These over-all results might suggest that primary closure is indicated for all types of open fractures. However, we observed that in the majority of the thirty-eight infected cases the injuries were segmental fractures, extensive soft-tissue lacerations, or traumatic amputations treated by primary closure. Furthermore, of the twenty-one patients with open segmental tibial fractures and associated extensive soft-tissue injuries treated from 1961 to 1968, the sixteen treated by primary closure (three of them by primary internal fixation as well) had an infection rate that was a staggering 44 per cent, while only one of the five treated by delayed closure had an infection.

The conclusions from this retrospective study, therefore, were that primary internal fixation increases the incidence of infection; that primary closure after segmental open fracture, open fracture with extensive laceration and avulsion of the soft tissues, or traumatic amputation results in a high infection rate; and that prophylactic antibiotic therapy is essential in the treatment of open fractures.

Prospective Study of 352 Open Fractures, 1969 to 1973

From 1969 to 1973, all open fractures were classified into three categories:

Type I — An open fracture with a wound less than one centimeter long and clean.

Type II — An open fracture with a laceration more than one centimeter long without extensive soft-tissue damage, flaps, or avulsions.

Type III — Either an open segmental fracture, an open fracture with extensive soft-tissue damage, or a traumatic amputation. Special categories in Type III were

gunshot injuries, any open fracture caused by a farm injury, and any open fracture with accompanying vascular injury requiring repair.

Guidelines for the treatment of these fractures were established prospectively and followed with only minor alterations. These guidelines were as follows:

1. All open fractures were treated as emergencies.
2. Cultures were obtained routinely on admission and before wound closure or application of the postoperative dressing after 1971.
3. Oxacillin, 1.0 gram every four hours, and ampicillin, 1.0 gram every six hours, were given intravenously before, during, and for three days after surgery. Occasionally, when the wounds were severely contaminated, gentamicin, three to five milligrams per kilogram of body weight, was given instead of ampicillin to "cover" gram-negative bacteria. If the wound was left open, antibiotics were continued for more than three days in ac-

the delayed infections, was possible for 326 of these fractures, of which seventy-eight were Type I; 181, Type II; and sixty-seven, Type III. Therefore, there was no follow-up at all on twenty-six of the 352 fractures.

Results

Bacterial Flora and Sensitivities

Bacteriological studies were complete in the 158 consecutive patients seen after 1971. Of these, eighty (50.7 per cent) showed a positive wound culture on admission, and thirty-one (20 per cent) had a negative culture initially, but a positive culture at wound closure following irrigation and débridement. Therefore, a total of 111 patients (70.3 per cent) had a contaminated wound as shown by a positive culture either on admission or at wound closure.

As shown in Table I, approximately fifteen organisms were isolated on 143 occasions. Eighty-six of the isolates

TABLE I

Organism	No. of Isolates	Sensitivities*							
		Cephalothin	Penicillin	Oxacillin	Cleocin	Ampicillin	Gentamicin	Carbenicillin	Chloramphenicol
Gram positive									
Staphylococcus coag. pos.	12	100	20	100	100	—	—	—	—
Staphylococcus coag. neg.	41	100	57	85	95	—	—	—	—
Diphtheroids	14	—	—	—	—	—	—	—	—
Alpha Streptococcus, group D	1	100	100	—	—	—	—	—	—
<i>Bacillus subtilis</i>	11	—	—	—	—	—	—	—	—
Alpha Streptococcus	7	50	50	0	0	—	—	—	—
Gram negative									
<i>Escherichia coli</i>	4	86	—	—	—	50	100	—	100
<i>Klebsiella enterobacter</i>	20	83	—	—	—	6	100	—	100
<i>Klebsiella</i> species	1	0	—	—	—	100	100	—	100
<i>Enterobacter</i> species	6	0	—	—	—	17	100	—	100
<i>Pseudomonas</i> species	17	0	—	—	—	0	100	100	100
<i>Proteus</i> species	3	100	—	—	—	100	100	—	100
<i>Herellea</i>	3	0	—	—	—	66	100	—	100
<i>Achromobacter</i> species	2	—	—	—	—	—	—	—	100
Other gram-neg. rods	1	100	—	—	—	—	100	—	100

* The sensitivity studies were done by the Kirby-Bauer method. A dash indicates that no studies were done.

cordance with the finding by wound culture or the appearance of the wound. Usually, antibiotics were continued for three days after secondary wound closure in the Type III fractures.

4. Thorough débridement and copious irrigation were emphasized, and for the more recently treated Type III injuries jet lavage was used^{13,16}.

5. No primary internal fixation was employed except in rare cases in which vascular injury required repair. External skeletal fixation or traction was the preferred method of immobilization.

6. Primary closure was performed in Type I and II fractures and delayed closure, in Type III lesions.

From 1969 to 1973, 352 open fractures were treated at Hennepin County Medical Center according to the protocol described. Of these fractures, 81 per cent were Types I and II and 19 per cent, Type III. Follow-up for at least six weeks, sufficient to determine the incidence of all but

were gram positive and fifty-seven were gram-negative organisms. Thirty-two of the 158 wounds yielded mixed bacterial growth.

Based on the sensitivity studies of these organisms, the cephalosporins (cephalothin and cefalozin) appeared to be the most effective antibiotics for prophylaxis after open fractures. These agents are effective against all gram-positive organisms including *Staphylococcus* coagulase positive and negative, and the majority of *Escherichia coli*, *Klebsiella*, and *Proteus*, excluding *Pseudomonas*. We did not find that anaerobes were particularly significant in these studies, presumably because the anaerobic culture technique at our institution was not satisfactory prior to 1974.

Wound Closure

Of the sixty-seven Type III fractures, 19 per cent were treated by delayed secondary closure, either direct

skin closure, skin-grafting, or allowing the wound to heal by granulation tissue. Early (at five days to three weeks) pedicle flaps were used in five cases.

Primary Internal Fixation

In the last five years, only two open fractures were treated by primary internal fixation. Both were comminuted supracondylar fractures, complicated by injuries to the popliteal artery requiring repair. Both wounds became infected. In seventeen femoral-shaft fractures (thirteen Type I and II and four Type III) treated by intramedullary nailing ten days or more after fracture, there were no infections.

Infection Rate

Eight (2.4 per cent) of the 326 fractures in the prospective study became infected compared with twenty-four (5.2 per cent) of the 458 fractures in the series from 1961 to 1968 and fourteen (11.8 per cent) of 135 fractures in the series from 1955 to 1960 ($p < 0.02$). Of the eight infections in the prospective series, six involved fractures of the tibial shaft and two, supracondylar fractures of the femur. Six were Type III and two, Type II. Three of the eight fractures were associated with vascular injuries, two of the popliteal (in one patient) and one of the posterior tibial artery. Five of these eight infections appeared to be secondary, developing when the wound cultures became positive after the wounds had been open for two weeks or more because we had failed to close them secondarily by repeated skin grafts. For the Type III fractures the infection rate in this series was 9.9 per cent in contrast to the 44 per cent rate in the group studied retrospectively ($p < 0.01$).

The three open fractures associated with vascular injury and extensive soft-tissue damage were treated by débridement (considered adequate at the time), copious irrigation, primary internal fixation, vascular repair, and packing the wound open. In the patient with bilateral supracondylar open fractures and bilateral lacerated popliteal arteries, the operative time was eight hours, while in the other patient with a comminuted open fracture in the proximal part of the tibia and laceration of the posterior tibial artery, the time was three and one-half hours. To our dismay, forty-eight to seventy-two hours later we found more soft-tissue necrosis in all three wounds, which required further débridement. Infection was evident several days later in each instance.

In the uninfected Type III wounds, delayed primary closure by either direct suture or split-thickness skin-grafting was done five to seven days after the primary procedure in all but five cases in which rotational or cross-leg pedicle flaps were created. Split-thickness skin-grafting was successful over exposed bone when the periosteum was intact; otherwise, we resorted to some type of flap coverage. To date we have tried delayed (five days to three weeks after injury) primary cross-leg pedicle grafts to cover large exposed areas of bone five times, all successful. This procedure appears to prevent delayed infection

and provides better coverage of the bone.

Bacterial culture and sensitivities of the eight infected open fractures from 1969 through 1973 revealed that three had infections with gram-positive and gram-negative bacteria. The predominant organisms were *Staphylococcus coagulase positive*, *Klebsiella enterobacter*, *Escherichia coli*, *Proteus*, and *Staphylococcus coagulase negative*.

Fracture Healing

Of the 352 fractures in the prospective study, 197 were followed with roentgenographic and clinical evaluations for at least six months after injury. The other 155 had not been followed for six months, had been transferred to private care, or were lost to follow-up at the time of writing. Of the 197 fractures which were followed, 170 (86.4 per cent) united uneventfully and twenty-seven (13.6 per cent) failed to unite and required bone-grafting.

Discussion

Adequate Débridement and Copious Irrigation

Scully and co-workers described criteria for muscle viability called the four C's: (1) color, (2) capacity to bleed, (3) contractility, and (4) consistency. In our experience color was a reliable guide and the other three C's correlated well with muscle viability. However, adequate débridement remains a difficult technical problem. *If there is the slightest doubt in the surgeon's mind as to whether there has been adequate débridement of the wound after an open fracture, the wound should not be closed regardless of the type of open fracture. For the surgeon who manages only an occasional open fracture, the safe rule is not to close the wound.*

Copious irrigation implies that the wound is irrigated with normal saline solution in large amounts in conjunction with débridement in order to remove all dirt and foreign material as well as all devitalized tissue. In our institution, the residents use an average of ten to fourteen liters of normal saline solution for open fractures of long bones. Recently use of jet lavage, particularly in Type III fractures, accomplished this task more effectively in a shorter time and with about half as much irrigating solution.

Rationale for Routine Use of Antibiotics

In our institution, every open fracture is now considered a severely contaminated wound and, therefore, more likely to become infected than a wound made in a clean, elective surgical procedure. Studies by Patzakis and associates and our own study (Table I) showed that open fractures are contaminated. In our series, 70.3 per cent of the open wounds yielded positive cultures. Therefore, we consider the routine use of antibiotics in open fractures as therapeutic rather than prophylactic, and we think that subsequent changes in antibiotic coverage should be guided by the sensitivity of the organisms isolated from the infected open fractures. Use of Chloromycetin was dis-

continued in the early phase of the study because of the rare complication of agranulocytopenia.

Since our culture and sensitivity studies of the bacterial flora in open fractures and of the bacteria isolated from the infected wounds suggested that the best single antibiotic for prophylaxis is a cephalosporin (cephalothin or cefalozin), in 1974 we began using cephalosporins exclusively as the antibiotics for open fractures.

The dosage and duration of antibiotic administration remain unsettled questions. Antibiotics were given most commonly for seven to ten days in all previous studies, including our own. We could find no evidence to support this practice. The rationale appears to be that the wound heals in seven to ten days. On the other hand, recent clinical reports^{2,22} have shown that prophylactic antibiotics given for a shorter time, such as three to five days, are probably just as effective in preventing wound infection and have the advantage that if infection develops, it will be manifest while the patient is still in the hospital. In our present regimen prophylactic antibiotics for open fractures are given one to three hours before surgery, during surgery, and for three days thereafter. They are then stopped whether the patient is febrile or not. If the wound becomes infected, gram stain and culture are obtained, and surgical débridement and irrigation are done immediately. The appropriate antibiotic is administered as soon as the sensitivities of the bacteria are known.

If the wound is left open initially, antibiotics are continued depending on the appearance of the wound and the results of its culture. It is difficult to keep a large open wound sterile for a long period of time, and it should be closed secondarily with either a skin graft or a cross-leg pedicle flap as soon as possible. If a wound is not closed, secondary contaminants such as *Pseudomonas* and other gram-negative bacteria, for which the antibiotics used are not effective, appear and become pathogenic.

The aminoglycosides (kanamycin and gentamicin) may be used occasionally in severely contaminated open fractures, primarily for gram-negative bacteria, but the patient must be watched carefully for nephrotoxic effects. The serum creatinine and blood urea nitrogen values should be determined daily. In patients who have had multiple trauma with severe open fractures, the aminoglycosides predispose to acute renal shutdown. These drugs should be used only if the anticipated beneficial effects are deemed essential after careful weighing of the potential benefits and dangers.

Unresolved Problems

During the last five years we have focused our attention on Type III fractures characterized by extensive soft-tissue loss, instability, and large areas of exposed bone requiring soft-tissue coverage. In these cases thorough débridement of the devitalized tissue is absolutely essential, and during the process large areas of bone are exposed. Use of the jet lavage apparatus certainly helps in cleaning these wounds, reducing the amount of irrigating

solution and also shortening the operating time. At the end of the procedure the wound is packed open, and five to six days later split-thickness skin grafts are applied, followed if need be by repeated skin grafts as a good base of granulation tissue develops.

During the long intervals that such wounds are open, secondary infections, usually with gram-negative organisms, may be a problem since these organisms are usually difficult to control by antibiotics alone. Prolonged aminoglycoside therapy, particularly for *Pseudomonas*, is dangerous and of questionable value. Daily soaks of the open wound with solutions such as 0.25 per cent silver nitrate, hydrogen peroxide, and acetic acid, or with plain normal saline, help to control these infections and enhance the formation of good granulation tissue. A cross-leg pedicle flap or rotational flap to cover any exposed bone or large soft-tissue defect, done early, may prevent secondary contamination and subsequent infection. We treated five patients with cross-leg pedicle flaps to cover extensive soft-tissue defects in the leg five days to three weeks after injury, while extraskletal fixation was used to immobilize the unstable open fractures. The results were satisfactory in all five patients.

Another major problem is the comminuted open fracture with vascular injury and extensive soft-tissue damage. This injury usually requires extensive débridement and primary repair of the damaged blood vessels. In the past it has been our policy to fix all fractures associated with arterial injury internally, in order to provide stability for the repaired vessel. To do this, however, increases the operating time as well as the amount of dissection around the fracture site, with consequent additional surgical trauma which predisposes to wound sepsis.

The danger of vascular disruption from unstable fracture fragments prompted many authors to advise internal fixation of the fracture prior to arterial repair in patients with combined bone and arterial injuries. However, experience with injuries treated during the Vietnam war raised questions about the necessity for internal fixation in severely traumatized limbs^{11,18,24}. A study of civilian femoral and tibial fractures by Connolly and co-workers⁴ also did not substantiate the need for internal fixation, since 4.5 to 6.8 kilograms of skeletal traction was shown to immobilize these fractures safely and effectively after arterial repair, especially when there was a severely contaminated wound or when the blood flow had to be restored as soon as possible. The method of managing the fracture, therefore, probably should not take precedence over treatment of the related serious soft-tissue injury⁵.

In open fractures with arterial injury it is difficult to determine the extent of avascular and devitalized tissue initially. In our experience, despite prompt arterial repair, non-viable and necrotic tissues not recognized at the initial procedure were found two to three days later. This oversight was obviously the result of inadequate circulation not evident initially.

Therefore, we now recommend in such cases that a complete débridement be carried out, as is done in all open fractures, the damaged blood vessels repaired, and the fracture immobilized in traction, leaving the wound open to be closed secondarily by direct closure, split-thickness skin-grafting, or a cross-leg pedicle flap.

The use of large metallic fixation devices such as plates and intramedullary nails may be indicated rarely to provide stability and to facilitate wound care so that the soft tissues around the fracture site may be preserved. In only one patient, treated in 1974, was a Lottes nail used for a Type III fracture of the tibia associated with an extensive, almost circumferential degloving soft-tissue wound of the thigh. By stabilizing the tibia, care of the thigh and leg wounds, which otherwise would have been very difficult, was made much easier. We do not close wounds primarily when large metallic devices are used in the initial care of fractures, and we advocate strongly that extraskelatal fixation devices, such as pins incorporated in plaster, a Roger Anderson device, or a Müller apparatus, be used whenever stability is needed to facilitate care of an open wound.

It is worthy of note that there have been no cases of gas gangrene in over 1,000 patients treated at Hennepin County Medical Center. The method of treatment adv-

cated is believed to have helped in the prevention of this complication.

Conclusions

1. Open fractures require emergency treatment, including adequate débridement and copious irrigation.
2. Primary closure is indicated for Type I and II open fractures, but delayed primary closure, including split-thickness skin grafts or appropriate flaps, should be used for Type III open fractures.
3. Internal fixation by plates or intramedullary nails should not be used. External skeletal fixation by skeletal traction, pins above and below the fracture site incorporated in a plaster cast, or such devices as the Roger Anderson or Müller apparatus is recommended.
4. Open fractures associated with arterial injury requiring repair should be treated in skeletal traction whenever possible instead of by primary internal fixation.
5. Antibiotics should be administered before and during surgery, the antibiotics of choice currently being the cephalosporins in therapeutic doses. If the wound is closed primarily, the antibiotics are stopped on the third postoperative day. If the wound is closed secondarily, the antibiotics are continued for another three days after this procedure.

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