



Review Article

Advances in treating exposed fractures[☆]



Pedro Nogueira Giglio*, Alexandre Fogaça Cristante, José Ricardo Pécora,
Camilo Partezani Helito, Ana Lucia Lei Munhoz Lima, Jorge dos Santos Silva

Department of Orthopedics and Traumatology, Hospital das Clínicas, School of Medicine, Universidade de São Paulo, São Paulo, SP, Brazil

ARTICLE INFO

Article history:

Received 11 April 2014

Accepted 1 May 2014

Available online 26 February 2015

Keywords:

Exposed fractures/diagnosis

Exposed fractures/classification

Wounds and injuries

Palavras-chave:

Fraturas expostas/diagnóstico

Fraturas expostas/classificação

Ferimentos e lesões

ABSTRACT

The management of exposed fractures has been discussed since ancient times and remains of great interest to present-day orthopedics and traumatology. These injuries are still a challenge. Infection and nonunion are feared complications. Aspects of the diagnosis, classification and initial management are discussed here. Early administration of antibiotics, surgical cleaning and meticulous debridement are essential. The systemic conditions of patients with multiple trauma and the local conditions of the limb affected need to be taken into consideration. Early skeletal stabilization is necessary. Definitive fixation should be considered when possible and provisional fixation methods should be used when necessary. Early closure should be the aim, and flaps can be used for this purpose.

© 2015 Sociedade Brasileira de Ortopedia e Traumatologia. Published by Elsevier Editora Ltda. All rights reserved.

Avanços no tratamento das fraturas expostas

RESUMO

O manejo das fraturas expostas é discutido desde a antiguidade e permanece de grande interesse da ortopedia e da traumatologia modernas. São lesões ainda desafiadoras. Infecção e não união são complicações temidas. Aspectos no diagnóstico, classificação e manejo inicial são discutidos. São essenciais a administração precoce de antibióticos, a limpeza cirúrgica e o debridamento meticuloso. Devem ser levadas em consideração as condições sistêmicas do paciente politraumatizado e as condições locais do membro acometido. A estabilização esquelética precoce é necessária. A fixação definitiva deve ser considerada quando possível e métodos de fixação provisória devem ser usados quando necessário. O fechamento precoce deve ser almejado e pode-se fazer uso de retalhos para esse fim.

© 2015 Sociedade Brasileira de Ortopedia e Traumatologia. Publicado por Elsevier Editora Ltda. Todos os direitos reservados.

[☆] Work developed at the Institute of Orthopedics and Traumatology, Hospital das Clínicas, School of Medicine, Universidade de São Paulo, São Paulo, SP, Brazil.

* Corresponding author.

E-mails: pedrongiglio@gmail.com, gigliopedro@gmail.com (P.N. Giglio).

<http://dx.doi.org/10.1016/j.rboe.2015.02.009>

2255-4971/© 2015 Sociedade Brasileira de Ortopedia e Traumatologia. Published by Elsevier Editora Ltda. All rights reserved.

Introduction

According to the historian Castiglione,¹ orthopedics originated “from the need for immediate assistance, even if using coarse empirical instruments”.

Although the term “orthopedics” was only created by Andry (1741) *apud* Maia,² evidence of orthopedic procedures can be seen in the ancient archeological records from our civilizations. It is likely that many of them not only had therapeutic objectives but also involved some type of magic, such as trepanation performed to release the demons that caused the diseases and malaises of that era.¹

There is a consensus among historians that times of war have been fundamental for the development and improvement of orthopedics.³

Definition

Exposed fractures are those that present communication with the external environment through a soft-tissue lesion.⁴ These situations are considered to be orthopedic emergencies⁵ and the aim of the treatment in such cases is to enable consolidation without occurrences of infection.

A large proportion of exposed fractures show evident exposure at the time of their initial presentation. However, in some of these cases, it may be unclear whether there is contiguity between the focus of the fracture and the external environment. Thus, it is recommended that it should be assumed that the fracture is exposed, whenever soft-tissue lesions are present, adjacent to the focus of the fracture.⁶

History

The first discussions regarding treatments for exposed fractures date back to Hippocrates, who advocated that the treatment should comprise occlusive dressings after improvement of the edema and debridement of the purulent material coming from the exposure.⁷ Galeno, *apud* Wangenstein,⁸ believed that the purulence was involved in the healing process and therefore should be stimulated. In the sixteenth century, Brunschwig and Botello, *apud* Trueta,⁹ were the first to observe the benefits of removal of the devitalized tissue.

A physician in the French army named Paré (1517-90), *apud* Castiglione,¹ rejected the practice of treating wounds and exposed fractures with boiling oil, which had been one of the precepts put forward by Hippocrates. Instead, he observed that the evolution was more satisfactory in cases in which the wound was simply cleaned and closed. Paré, *apud* Trueta,⁹ also observed that there was a need to expand the wounds in the fractured limbs, in order to allow free drainage of the material coming from the injury.

In the eighteenth century, Desault also recommended, along with Botello and Brunschwig *apud* Trueta,⁹ that the necrotic tissue in wounds should be cleaned out and removed. This procedure became known as debridement. Desault, *apud* Trueta,⁹ also observed that the time at which debridement was performed was fundamentally important for the prognosis of the lesion.

The Second World War greatly contributed toward advances in treatments for exposed fractures. Widespread use of antibiotics dates from this period.¹⁰ During the Korean and Vietnam wars, methods for temporary immobilization were developed, along with sterile dressings, broad-spectrum antibiotics, debridement techniques, irrigation with saline solution and sequential approaches toward lesions. These served as the foundation for the methods used today.¹⁰

Over the last few years, the role of the American College of Surgeons can be highlighted. This body established the principles of the attendance sequence known as advanced trauma life support (ATLS), which provide rules for pre-hospital and hospital care for multiple-trauma patients, often presenting exposed fractures.¹¹

Diagnosis

Diagnosing exposed fractures is not always an obvious matter. Therefore, if skin lesions are observed on a fractured limb, the first principles for treating such fractures need to be followed.¹²

Clinically, the diagnosis can be made through observing the fractured segment via the wound. However, in cases of doubtful diagnoses, such as in punctiform or contused lesions, droplets of fat that are present in the blood coming out of the wound may suggest this diagnosis. Radiographically, subcutaneous emphysema seen on simple radiographs or images suggestive of the present of gas at the focus of the fracture may contribute toward the diagnosis.¹³

An accurate physical examination, including inspection and palpation of bone protuberances, is fundamental for the initial management of these patients. The musculature involved should be assessed; the existence of pulse and perfusion alterations should be investigated from the coloring and temperature of the extremities; and a neurological examination should be performed in order to assess sensitivity, motricity and reflexes. These steps will help in classifying the lesions and in making an early diagnosis of possible complications, such as compartmental syndrome.¹⁴

Measurement of the compartment pressure may be useful in cases in which there is some doubt regarding the occurrence of compartment syndrome.¹⁵ Ultrasonography with color Doppler may be useful in making diagnostic evaluations on suspected vascular lesions and can be complemented with arteriography.¹⁶

Radiographs covering the entire fractured segment, including the joints proximal and distal to the fracture, are fundamental for characterizing the fracture and for estimating the level of energy that was involved in the initial trauma.^{17,18} Computed tomography may be requested in cases of fractures in which the joint surfaces are compromised, in order to plan the surgery more adequately,¹⁹ after emergency treatment measures have been implemented.

Classification

A variety of systems have been proposed for classifying exposed fractures.

Table 1 – Gustilo classification for exposed fractures.

I – Low energy, exposure less than 1 cm, low degrees of contamination and comminution.
II – Exposure of between 1 cm and 10 cm, contamination, soft-tissue injury and moderate comminution.
III – Exposure greater than 10 cm, high degree of soft-tissue injury and contamination.
IIIA – Primary coverage is possible.
IIIB – Primary coverage is not possible.
IIIC – Arterial injury requiring repair.

The Gustilo classification, which is the one most used nowadays, takes into consideration the energy of the trauma, the degree of soft-tissue injury and the degree of contamination, which all have prognostic implications and define the treatment^{20,21} (Table 1).

The AO group (Arbeitsgemeinschaft für Osteosynthesefragen)²² has also developed a classification system (Table 2) for exposed fractures. This system, along with that of Tscherné and Ouster²³ (Table 3), also emphasizes the importance of soft-tissue injuries, even in the absence of contiguity solution with the environment.

Advances in treating exposed fractures

Treatment of exposed fractures constitutes an orthopedic emergency and this should be included in the sequential attendance for multiple-trauma cases that is recognized within ATLS.²⁴ Initially, efforts should be directed toward ensuring the patient's survival and the so-called ABCDE of the trauma should be performed²⁵ (Table 4).

Table 2 – AO classification for soft-tissue injury in exposed fracture cases.

<i>Skin injury</i>
IO 1 – Punctiform skin injury from inside to outside.
IO 2 – Skin injury with contused edges from outside to inside, smaller than 5 cm.
IO 3 – Skin injury larger than 5 cm, with devitalized edge.
IO 4 – Injury encompassing the full thickness, with severe contusion, loss of skin or extensive degloving.
<i>Muscle injury</i>
MT 1 – No muscle injury.
MT 2 – Circumscribed muscle injury, in one compartment only.
MT 3 – Considerable muscle injury, in two compartments.
MT 4 – Muscle defect, tendon laceration and extensive contusion.
MT 5 – Compartmental syndrome, crushing syndrome and broad injury zone.
<i>Neurovascular injury</i>
NV 1 – No neurovascular injury.
NV 2 – Isolate neurological injury.
NV 3 – Localized vascular injury.
NV 4 – Extensive segmental vascular injury.
NV 5 – Combined neurovascular injury, including subtotal or total amputation.

Table 3 – Tscherné classification for soft-tissue injuries associated with exposed fractures.

Fr. 1 – Skin lacerated by bone from inside to outside, little or no skin contusion and simple fractures resulting from indirect trauma.
Fr. 2 – Skin laceration or circumferential contusion and moderate contamination, including all cases exposed due to direct trauma.
Fr. 3 – Extensive soft-tissue injuries, generally associated with vascular or neurological injury. Includes fractures relating to ischemia, severe bone comminution, compartment syndrome, injuries in rural settings and high-velocity gunshot wounds.
Fr. 4 – Partial or total amputations (separation of important anatomical structures, especially vessels, with total ischemia).

Table 4 – Sequence of initial attendance for multiple trauma victims according to the ATLS.

A – Keep the airways open and protect the cervical spine.
B – Maintain adequate ventilation.
C – Ensure circulation and perfusion.
D – Evaluate neurological injuries.
E – With wider exposure, assess other injuries and protect against hypothermia.

All individuals who have injuries to more than one systemic organ, such that at least one of them is life-threatening or has a score of more than 16 in the injury severity score (ISS), should be considered to be multiple-trauma cases.^{26,27}

For multiple-trauma patients, because of the significant immunological response, the treatment should be sequenced into four parts²⁵ (Table 5).

The treatment for exposed fractures is started at the emergency service. After the patient has been brought to the emergency room, and as soon as the clinical stabilization phase has been finished, an orthopedic examination should be conducted. All the findings should be documented in the medical file, with photos if possible, and the area of exposure should be protected with a sterile dressing. Multiple reevaluations of the wound are not recommended, given that this has been correlated with greater risk of infection.²⁸ Anti-tetanus prophylaxis should be administered, depending on the patient's vaccination status and the degree of contamination of the wound²⁹ (Table 6).

As soon as venous access can be achieved, antibiotic prophylaxis should be started.³⁰ For Gustilo type I fractures, first-generation cephalosporin should be prescribed, while for type II or III fractures, gentamicin and clindamycin should be prescribed, for an initial period of 14 days. This length of

Table 5 – Phases of sequential attendance for multiple trauma victims.

1st phase – Resuscitation (first hours)
2nd phase – Stabilization (one to 48 h). Control over damage in order to avoid hypotension, acidosis and coagulopathy.
3rd phase – Regeneration (after the second day).
4th phase – Reconstruction and rehabilitation (weeks).

Table 6 – Recommendations for prophylaxis against tetanus in high-risk wounds.^a

History of immunization	Vaccine	Anti-tetanus immunoglobulin
Less than 3 doses or unknown	Yes	Yes
Last dose less than 5 years ago	No	No
Last dose 5 to 10 years ago	Yes	No
Last dose more than 10 years ago	Yes	No

^a High-risk wounds include exposed fractures, wounds due to firearms or cold weapons, wounds with retention of a foreign body and punctiform wounds caused by sharp objects.

time may be extended, depending on the patient's clinical evolution.²⁹ Collection of culturing material from the initial debridement has been questioned because of the low correlation between the microorganisms isolated from this and the real causative agents of possible infections.³¹

After the initial clinical stabilization, the patient is taken to the surgical center for local treatment of the fracture. The wound is firstly covered and a sepsis and antisepsis are performed on the entire limb. After this, the wound is uncovered and, if necessary, extended in order to view the deep tissues better. Irrigation with simple physiological serum is implemented, usually with a volume of around 10L. This can be increased if necessary, until no more debris and dirt can be seen. This process aims to diminish the absolute number of contaminating bacteria and remove dirt that cannot be removed manually.³² After this irrigation has been completed, the surgical scrubs are changed and new antisepsis is implemented. Debridement of the devitalized tissues is then performed. The muscles are evaluated with regard to color, consistency, contractility and capacity for bleeding.³³ Muscles that do not present these criteria have a higher chance of being unrecoverable. Tendons should be preserved whenever possible, except in cases in which there is total loss of their function or gross contamination.^{34,35}

Some fractures, because of their high degree of initial contamination, require another debridement procedure within 48 h after the first surgical cleaning, which is known as a "second look" at the lesion.³⁶

After completing the surgical cleaning and debridement of the tissues, stabilization of the fracture is performed. The aims of this stage are to restore the length and alignment of the limb, reconstruct the joint surface involved and protect the soft tissues.³⁷ The different fixation methods should enable easy access to the surgical wound and early mobilization. Immobilization in a plaster cast does not serve these objectives, especially because this makes it difficult to access the wound. Therefore, plaster casts should not be used for this purpose.

Immediate definitive fixation of the fracture may be performed at the emergency service if the local and systemic conditions allow this, i.e. in situations of absence of soft-tissue lesions, major contamination and clinical instability.¹² This approach is known as early total care. Classically, immediate internal fixation was only an option if done within the first 6 h after the trauma.³⁸ However, reviews of the literature conducted more recently have shown that debridement followed by definitive fixation at the emergency service can be

done after this 6-h period, without any increase in the incidence of infection.³⁹

In cases in which definitive fixation is not possible, external fixation has been shown to be the fixation method that is most suitable for stabilizing exposed fractures in long bones, including within the contact of so-called "damage control". This is a rapid and minimally invasive means of providing stability and restoring the alignment and length of the limb. It contributes toward diminishing the inflammatory response relating to the trauma, avoids subsequent damage to the soft tissues and enables easy access to the wound, both for dressings and for surgical procedures for subsequent skin coverage.^{4,12,40}

One important consideration in using external fixators concerns their conversion to an internal fixation method (plate or intramedullary nail). In the literature, it has been shown that a window of opportunity exists between the seventh and fourteenth days after installation of the external fixation, for conversion to be implemented.³⁷ After this period, the risk of infection with internal osteosynthesis becomes greater, such that it is recommended that decontamination of the path of the external fixation pins should be performed through exchanging them, before performing the definitive internal fixation.

The skin coverage in cases of exposed fractures is another topic with a diversity of opinions. One option is to perform immediate primary closure. Alternatively, this could be delayed for 48–72 h. The first option can be implemented in cases of small wounds with little contamination, provided that there is no tension on the edges of the wound (which would lead to a risk of contamination through anaerobic bacteria), and that administration of antibiotics is started within the first 12 h after the fracturing.⁴¹ Second-intent closure is only rarely performed but has recently presented better results, thanks to the advent of vacuum dressings.⁴²

Closure by means of grafts or flaps can also be used. The development of local flap rotation techniques and the dissemination of microsurgical flap techniques have had a major impact on the prognosis for cases of exposed fractures, given that they have enabled stable good-quality skin coverage and thus have decreased the infection rates and increased the fracture consolidation rates.⁴³

Presence of exposed fractures also gives rise to discussion about whether severely injured limbs should be preserved or not. So far, there are no universally accepted criteria for guiding decisions on whether or not to amputate a severely injured limb.⁴⁴ For this decision, the risk to the patient's life and the expected degree of functioning at the end of the multiple procedures required to saving the limb need to be assessed. In 1985, Lange et al.⁴⁵ proposed that amputation should be indicated in cases of injury due to crushing, with hot ischemia lasting for more than 6 h, irreparable vascular injuries, complete amputation of the lower limbs and irreparable injury to the sciatic nerve or tibial nerve, in patients with Gustilo type IIIC fractures. Since then, there have been efforts toward creating scoring systems that might predict whether limb amputation is needed. One of the best known and most used systems is MESS (Mangled Extremity Severity Scoring System)^{46,47} (Table 7). This scale takes into account the degrees of bone and soft tissue, the duration of ischemia, the patient's age and whether or not clinical instability is present. A score

Table 7 – Severity score for mutilation of extremity.

Musculoskeletal injury	
Low energy	1
Medium energy	2
High energy	3
Extremely high energy	4
Limb ischemia	
Pulse low or absent, perfusion normal	1
Pulse absent, perfusion low	2
Cold limb, paralyzed, insensitive	3
Shock	
Systolic arterial pressure always > 90 mmHg	0
Transitory hypotension	1
Persistent hypotension	2
Age	
<30 years	0
Between 30 and 50 years	1
>50 years	2

of seven points or more on this scale signifies a prediction of amputation of 100%.²⁵

Expectations

Treatments for exposed fractures are continuing to advance. The advances that can be expected include development of the use of mesenchymal cells, which would increase the consolidation success rates; dissemination of the use of grafts coming from tissue banks; and development of replacement bones⁴⁸ and growth factors,^{49,50} which would reduce the obstacles and the time needed for treating patients with exposed fractures, thereby restoring their social and occupational functions within a shorter time. In parallel, continual improvement of prostheses may serve as encouragement for patients who suffered severe trauma that resulted in amputation, such that these individuals might become functional and productive again.⁵¹

Final remarks

As presented above, many advances in treatments for exposed fractures have been attained. The main points regarding this progress are as follows:

1. Attendance for multiple trauma victims has become systematized, with the creation of well-defined management protocols going from the pre-hospital phase to the hospital phase. This has made it possible for patients to be brought more rapidly to referral centers for trauma care, in a better stabilized condition.
2. More hospital centers have become equipped to provide care for such patients.
3. Awareness that exposed fractures constitute a medical emergency has become greater among the physicians responsible for the initial management of multiple trauma victims.
4. Antibiotics have undergone development.

5. Fracture fixation techniques have developed, with the use of external fixation for controlling damage and definitive fixation when the patient's systemic conditions and the location of the fracture on the limb allow this.
6. Surgical techniques for constructing local flaps and microsurgical techniques have developed and physicians with the capacity to perform these procedures have been trained, thereby assuring stable skin coverage for patients with exposed fractures.
7. There have been advances in the techniques for dressings, among which the development of vacuum dressings can be highlighted, thus enabling better local control over wounds.

Nonetheless, these injuries continue to pose a challenge, with the possibility of feared complications, such as infection and non-consolidation, along with the inherent difficulty of dealing with high-energy injuries with significant bone and soft-tissue impairment.

Conflicts of interest

The authors declare no conflicts of interest.

REFERENCES

1. Castiglione A. *A história da medicina*. São Paulo: Companhia Editora Nacional; 1947.
2. Maia ABS. *Bibliografia brasileira de ortopedia e traumatologia 1797–1977*. Recife: Editora da Universidade de Pernambuco; 1967.
3. Napoli M, Blanc C. *Ortopedia brasileira – Momentos, crônicas e fatos*. São Paulo: Sociedade Brasileira de Ortopedia e Traumatologia; 2000.
4. Cross WW 3rd, Swiontkowski MF. Treatment principles in the management of open fractures. *Indian J Orthop*. 2008;42(4):377–86.
5. Jorge-Mora A, Rodriguez-Martin J, Pretell-Mazzini J. Timing issue in open fractures debridement: a review article. *Eur J Orthop Surg Traumatol*. 2013;23(2):125–9.
6. Keese GR, Boody AR, Wongworawat MD, Jobe CM. The accuracy of the saline load test in the diagnosis of traumatic knee arthrotomies. *J Orthop Trauma*. 2007;21(7):442–3.
7. Pape HC, Webb LX. History of open wound and fracture treatment. *J Orthop Trauma*. 2008;22(Suppl 10):S133–4.
8. Wangenstein OH, Wangenstein SD. *The rise of surgery from empiric craft to scientific discipline*. Minneapolis: University of Minnesota Press; 1978.
9. Trueta J. "Closed" treatment of war fractures. *Lancet*. 1939;1(6043):1452–5.
10. Hauser CJ, Adams CA Jr, Eachempati SR. Surgical infection society guideline: prophylactic antibiotic use in open fractures: an evidence-based guideline. *Surg Infect (Larchmt)*. 2006;7(4):379–405.
11. Frink M, Zeckey C, Mommsen P, Haasper C, Krettek C, Hildebrand F. Polytrauma management – a single centre experience. *Injury*. 2009;40(Suppl 4):S5–11.
12. Dunbar RP, Gardner MJ. Initial management of open fractures. In: Bucholz RW, Heckman JD, Court-Brown CM, Tornetta P, editors. *Rockwood and Green's fractures in adults*. 7th ed. Philadelphia: Lippincott: Williams & Wilkins; 2010. p. 285.
13. Aufranc OE, Jones WN, Bierbaum BE. Gas gangrene complicating fracture of the tibia. *JAMA*. 1969;209(13):2045–7.

14. Turen CH, Burgess AR, Vanco B. Skeletal stabilization for tibial fractures associated with acute compartment syndrome. *Clin Orthop Relat Res.* 1995;(315):163-8.
15. McQueen MM, Court-Brown CM. Compartment monitoring in tibial fractures. The pressure threshold for decompression. *J Bone Joint Surg Br.* 1996;78(1):99-104.
16. Halvorson JJ, Anz A, Langfitt M, Deonanan JK, Scott A, Teasdale RD, et al. Vascular injury associated with extremity trauma: initial diagnosis and management. *J Am Acad Orthop Surg.* 2011;19(8):495-504.
17. Garbuz DS, Masri BA, Esdaile J, Duncan CP. Classification systems in orthopaedics. *J Am Acad Orthop Surg.* 2002;10(4):290-7.
18. Martin JS, Marsh JL. Current classification of fractures. Rationale and utility. *Radiol Clin North Am.* 1997;35(3):491-506.
19. Wuerz TH, Gurd DP. Pediatric physeal ankle fracture. *J Am Acad Orthop Surg.* 2013;21(4):234-44.
20. Gustilo RN, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. *J Trauma.* 1984;24(8):742-6.
21. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. *J Bone Joint Surg Am.* 1976;58(4):453-8.
22. Rüedi TP, Buckley RE, Moran CG. *AO principles of fracture management.* 2nd ed. Stuttgart/New York: Georg Thieme Verlag; 2007.
23. Tscherner H, Ouster HJ. A new classification of soft-tissue damage in open and closed fractures. *Unfallheilkunde.* 1982;85(3):111-5.
24. Giannoudis PV, Pape HC. Management of the multiply injured patient. In: Bucholz RW, Heckman JD, Court-Brown CM, Tornetta P, editors. *Rockwood and Green's fractures in adults.* 7th ed. Philadelphia: Lippincott: Williams & Wilkins; 2010. p. 261-7.
25. The American College of Surgeons. *Advanced Trauma Life Support (ATLS) students manual.* 6th ed. Chicago: American College of Surgeons; 1997.
26. American College of Surgeons/Committee of Trauma. *National Trauma Data Bank annual report 2005, dataset version 5.0.* Chicago: American College of Surgeons Committee on Trauma; 2005.
27. Baker SP, O'Neill B, Haddon W Jr, Long WB. The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. *J Trauma.* 1974;14(3):187-96.
28. Peterson N, Stevenson H, Sahni V. Size matters: how accurate is clinical estimation of traumatic wound size? *Injury.* 2014;45(1):232-6.
29. Subcomissão de controle de infecção hospitalar IOT. *Padronização do uso de antimicrobianos - 2012/2013.* São Paulo: Hospital das Clínicas da Faculdade de Medicina de Universidade de São Paulo; 2012.
30. Prokuski L. Prophylactic antibiotics in orthopaedic surgery. *J Am Acad Orthop Surg.* 2008;16(5):283-93.
31. Valenziano CP, Chattar-Cora D, O'Neill A, Hubli EH, Cudjoe EA. Efficacy of primary wound cultures in long bone open extremity fractures: are they of any value? *Arch Orthop Trauma Surg.* 2002;122(5):259-61.
32. Anglen JO. Wound irrigation in musculoskeletal injury. *J Am Acad Orthop Surg.* 2001;9(4):219-26.
33. Artz CP, Sako Y, Scully RE. An evaluation of the surgeon's criteria for determining the viability of muscle during débridement. *AMA Arch Surg.* 1956;73(6):1031-5.
34. Olson SA, Schemitsch EH. Open fractures of the tibial shaft: an update. *Instr Course Lect.* 2003;52:623-31.
35. Tscherner H. The management of open fractures. In: Tscherner H, Gorzen L, editors. *Fractures with soft tissue injuries.* New York: Springer Verlag; 1984. p. 10-32.
36. Hierner R, Nast-Kolb D, Stoel AM, Lendemans S, Täger G, Waydhas C, et al. Degloving injuries of the lower limb. *Unfallchirurg.* 2009;112(1):55-62.
37. Gardner MJ, Mehta S, Barei DP, Nork SE. Treatment protocol for open AO/OTA type C3 pilon fractures with segmental bone loss. Report of 38 cases treated with a standard protocol. *J Bone Joint Surg Am.* 1984;66(9):1349-56.
38. Robson MC, Duke WF, Krizek TJ. Rapid bacterial screening in the treatment of civilian wounds. *J Surg Res.* 1973;14(5):426-30.
39. Schenker ML, Yannascoli S, Baldwin KD, Ahn J, Mehta S. Does timing to operative débridement affect infectious complications in open long-bone fractures? A systematic review. *J Bone Joint Surg Am.* 2012;94(12):1057-64.
40. Hildebrand F, Giannoudis P, Krettek C, Pape HC. Damage control: extremities. *Injury.* 2004;35(7):678-89.
41. Dunbar RP, Gardner MJ. Initial management of open fractures. In: Bucholz RW, Heckman JD, Court-Brown CM, Tornetta P, editors. *Rockwood and Green's fractures in adults.* 7th ed. Philadelphia: Lippincott: Williams & Wilkins; 2010. p. 295.
42. Herscovici D Jr, Sanders RW, Scaduto JM, Infante A, DiPasquale T. Vacuum-assisted wound closure (VAC Therapy) for the management of patients with high-energy soft tissue injuries. *J Orthop Trauma.* 2003;17(10):683-8.
43. Gopal S, Majumder S, Batchelor AG, Knight SL, De Boer P, Smith RM. Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia. *J Bone Joint Surg Br.* 2000;82(7):959-66.
44. Moghadamian ES, Bosse MJ, MacKenzie EJ. Principles of mangled extremity management. In: Bucholz RW, Heckman JD, Court-Brown CM, Tornetta P, editors. *Rockwood and Green's fractures in adults.* 7th ed. Philadelphia: Lippincott: Williams & Wilkins; 2010. p. 333.
45. Lange RH, Bach AW, Hansen S T, Johansen KH. Open tibial fractures with associated vascular injuries: prognosis for limb salvage. *J Trauma.* 1985;25(3):203-8.
46. Helfet DL, Howey T, Sanders R, Johansen K. Limb salvage versus amputation. Preliminary results of the Mangled Extremity Severity Score. *Clin Orthop Relat Res.* 1990;(256):80-6.
47. Kumar MK, Badole C, Patond K. Salvage versus amputation: utility of mangled extremity severity score in severely injured lower limbs. *Indian J Orthop.* 2007;41(3):183-7.
48. Kurien T, Pearson RG, Scammell BE. Bone graft substitutes currently available in orthopaedic practice: the evidence for their use. *Bone Joint J.* 2013;95-B(5):583-97.
49. Ronga M, Fagetti A, Canton G, Paiusco E, Surace MF, Cherubino P. Clinical applications of growth factors in bone injuries: experience with BMPs. *Injury.* 2013;44(Suppl 1):S34-9.
50. Blokhuis TJ, Lindner T. Allograft and bone morphogenetic proteins: an overview. *Injury.* 2008;39(Suppl 2):S33-6.
51. Harvey ZT, Potter BK, Vandersea J, Wolf E. Prosthetic advances. *J Surg Orthop Adv.* 2012;21(1):58-64.