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Management of osteoarticular and dental injuries in electrocuted patients

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ABSTRACT

Electrical accidents can usually lead to severe skin burns and soft tissues damages, but also to uncommon, but often neglected various osteoarticular and dental injuries, such as fractures, dislocations, osteonecrosis, dentition injuries and heterotopic ossification of soft tissues. This review highlights the complete spectrum of osteoarticular and dental injuries previously described in literature in relation to electrocution accidents, with their pattern, diagnosis, clinical and imaging assessment, treatment guidelines, severity and possible risk factors, accordingly to localization and pathophysiology. Fractures and dislocations usually occur after a traumatic event related to electrical injuries, but they can be rarely produced by violent tetanic muscle contractions, due to electrical current passage. The practitioners involved in the management of the electrocuted patients need to bear in mind the possibility of skeletal injuries. All electrocuted patients with suggestive symptoms and signs such as pain, swelling, bone tenderness, and functional impairment, should be examined carefully and in detail, both clinically and by imaging studies. The early recognition, the confirmation by imaging studies and the prompt orthopedic or dental treatment ensure a favorable result and remove the deleterious possible complications.

Key words: osteoarticular injuries; electrocution; fractures; dislocations.

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INTRODUCTION

Electrocutions can determine not only apparent deep electrical burns of the contact areas, but particularly deep and progressive injuries of the soft tissues, as well as infrequently, but neglected skeletal injuries. The spectrum of electrical injuries is very wide, ranging from minimal injury, to extensive burns, severe multiorgan failures and even death.

The electrical injuries are not very usual trauma, but they require a special attention and expertise in the emergency departments, due to specific pathophysiology and to high morbidity and mortality, not encountered in other types of thermal injury. Acute and chronic manifestations and complications, length of hospital stay, human and material resources and therapeutic measures are much extensive than those expected, based only on cutaneous burn size [1, 2].

Although electrical burns are only 3-4% of all burn injuries, they require huge material and human resources and also a carefully planned team approach [2]. Besides extensive and progressive tissue damage, needing aggressive debridement and even amputation, these injuries can lead to other harmful complications, such as: renal, septic, cardiovascular, neurological, osteoarticular and ocular manifestations [2, 3]. Comprehensive knowledge of pathophysiology, of complete manifestations, of laboratory and imaging studies and of adequate treatment guidelines improves patient care, final outcome and quality of life [1].

Table 1: The range of tissues, from the most conductive (least resistant) to the least conductive (most resistant).

Resistance	Tissue
Least	Nerves Blood Mucous membranes Muscle
Intermediate	Dry skin Tendon Fat
Most	Bone

MATERIAL AND METHODS

This work material, regarding the skeletal injuries following electrical discharges, contains considerable analyses and synthesis on available data from literature, like Medline and other databases, journals collections such as Annals of Burns and Fire Disasters, search engines, publications, being selected the most representative and reliable studies. The wide range of osteoarticular complications was highlighted and analyzed, accordingly to localization and pathophysiology. Diagnosis, clinical and imaging assessment, therapeutic management and prognosis of these injuries were carefully investigated.

RESULTS AND DISCUSSIONS

The extent and the severity of electrical injuries are together determined and estimated by the electric current parameters: magnitude of energy delivered, resistance encountered, conductance, current pathway, and duration of contact. All tissue damages and systemic effects are directly proportional to the magnitude of electrical energy delivered to the human body.

Current strength (intensity) is directly proportional to voltage and inversely proportional to tissue resistance, according to Ohm's law [1, 4]. Frequently, only voltage can be established in current practice and is used to predict the potential magnitude of current flow and, therefore, the magnitude of injury [1]. While the patient or witnesses often knows the voltage involved, the intensity of current remains practically unknown [2].

Consequently, tissues that are less conductive and more resistant are likely to heat up more, due to electrical current passage. The order of tissues, ranging from the most conductive (i.e., least resistant) to the least conductive (i.e., most resistant) is shown in Table 1 [4].

Clinical manifestations following electrocutions range from a tingling sensation, to extensive tissue damage and even to sudden death. Electrical injuries can exhibit a wide range of presentations, including cardiac or respiratory arrest, cardiac arrhythmias, seizures, coma, blunt trauma, deep and severe burns [5].

For the successful management of the electrical injuries, it should be established from the beginning: type of electrical exposure (AC or DC; high or low voltage), pathway through the human organism, duration of contact and additional trauma.

Electrical discharges can cause a series of acute musculoskeletal injuries, such as:

- fractures and dislocations as a result of falls or of powerful muscle contractions, more frequently encountered in upper limb and in vertebrae
- rhabdomyolisis leading to renal failure, as an effect of massive muscle damage
- compartment syndrome, especially resulted from circumferential burns of the chest and extremities. Palpation of extremity and distal neurologic, vascular, and motor examinations should be performed, in case of presumption of a compartment syndrome. Compartment pressure can also be measured and early fasciotomy with aggressive debridement can prevent unfavorable evolution and subsequent limb amputation [1, 5].

Taking account of pathophysiology, clinical and therapeutic approach, the osteoarticular lesions are a particular and rather uncommon category of electrical injuries, which is often overlooked, with harmful consequences and subsequent deleterious complaints.

The pathophysiology of osteoarticular lesions implies indirectly injury through additional mechanic energy, in contrast to direct damage of the soft tissues through electrical energy. In electrocutions, the usual cause of skeletal injury is a fall due to the electrical shock.

Also, fractures following electroconvulsive therapy (ECT) for psychiatric patients are a well-known complication, but skeletal injuries as a result of accidental electrical flow are very unusual [6-8]. Thus, fractures or dislocations can result from tetanic muscular contractions [8]. The most frequently affected level after electro-convulsive therapy (ECT) was a vertebra, in 40% of all fractures [9]. ECT therapy represents the major cause of most bilateral femoral neck fractures [8] and the fractures of the lower limbs represent 28% of all fractures due to ECT, all of them being femoral neck fractures [9].

In electrical injured patients, skeletal injuries can appear as a result of two distinct pathophysiologic mechanisms:
- secondary falls associated with electrical shock
- forceful muscle contractions, as a result of direct muscle electrical stimulation or of seizures caused by electrical shock [10].

These skeletal injuries are mostly encountered in the shoulder, wrists, femurs and the spine, and may require aggressive surgical treatment through open reduction and internal fixation [3, 11-14]. Currently, fractures after electrocution occur in places with significant and bulky muscular bodies, such as spine, hip and shoulder. These fractures occur as a result of musculoskeletal contractions, which may appear even at low-voltage exposures [14-16]. The threshold for tetanic muscle contractions from direct current is approximately 50 V. Muscular contractions can result from contact with a direct current of at least 20 mA or with an alternating current of 10 mA [7].

In electrocuted patients, the real diagnostic of fractures can delay for days, weeks or even months after injury [10], taking into account lack of direct trauma to the musculoskeletal system. Local signs and symptoms such as swelling and pain can be initially attributed to deep muscle contractions and to the damage to the soft tissues. Therefore, a detailed and complete physical examination of the musculoskeletal system should be practiced in electrocuted patients in the emergency unit, especially when they complain of musculoskeletal disorders. X-ray films are often unnecessary in awake and cooperative patients, with no significant pain and tenderness, full active range of motion of the joints, and good function. However, in the unconscious or uncooperative patient, X-ray films of the shoulders, spine, and pelvis are recommended, especially if such structures were in the pathway of the electric current [7].

In general, the delay in diagnosis and subsequent treatment of fractures after electrocution may be related to:
- delay in presentation of the patient
- evaluation and treatment of apparently greater comorbidities (cardiac disturbance, dermal burns, myonecrosis leading to renal failure)
- difficulty in obtaining a clear history and physical examination on a recently and confused electrocuted patient [6].

In electrical injured patients, the therapeutic management of fractures and dislocations closely follows the principles of orthopedic surgery, also taking into account the other patient comorbidities and electrical concomitant determinations.

Osteoarticular injuries of vertebral column can appear at different levels, as result of tetanic contractions of important muscle coverage, following electrical passage. Vertebral fractures are more commonly encountered after low-voltage and alternating current, as compared to direct current, and should be suspected in electrocuted patients with the following signs and symptoms: back pain, neurologic deficits, and continuous loss of consciousness [10].

Multiple spine fractures after electrical injuries are extremely rare. Cervical and thoracic fractures can be produced by tetanic muscle contractions leading to powerful flexion or extension of the neck and trunk. They can be suspected by the occurring of severe neck pain, even in the absence of other signs and symptoms, such as: chest or extremity pain, palpitations, dyspnea, weakness, numbness and paresthesia. These fractures are highlighted on spinal films, CT scanning and MRI imaging and can be successfully treated by minimally invasive procedures (kyphoplasty or vertebroplasty) or conservatively with pain medication and external orthopedic stabilization [10, 18, 19].

Lumbar fractures after low-voltage injuries can be suspected by the occurring of incessant low back pain and tenderness, with or without neurologic deficits. The diagnosis is established by X-rays and CT scan. They can be treated by external stabilization, with subsequent clinical and radiographic follow-up to assess consolidation [10, 14].

Lesions of the skull after electrical shock are unusual and occur especially after highvoltage exposures, often associated with very deep burns and serious brain injuries [10]. Their treatment requires surgical approach for skull covering through complex reconstructive interventions, such as locoregional flaps or free flaps, sometimes associated with neurosurgical reconstruction. The use of skin grafts is not recommended, since they are fragile and unstable in the long term; skin grafts can be applied in small defects and only if the periosteum is intact or over the granulation tissue developed after perforation or removal of the outer table [20].

Osteoarticular injuries of the shoulder (fractures and dislocations) appear to be most frequently involved in electrocuted patients, as result of a series of factors:
- great shoulder mobility
- significant and powerful surrounding muscle and tendons, prone to violent contractures
- frequent location in electrical flow path, having the hand as contact point
- shoulder can be surprised by the electric shock in unfavorable positions.

Scapular fractures are uncommon injuries, usually caused by direct high-energy trauma. There have also been reported following cardiopulmonary resuscitation, seizures and electroconvulsive therapy. Scapular fractures following electrical exposures usually occur when the patient falls after the accident, but as a direct result of electrical shock they are very rare, with only few cases reported in literature [21].
The scapula has multiple muscle attachments, both origins and insertions, prone to violent electric contractions. However, dislocation of the shoulder is a more frequent form of injury seen after upper limb electrocution. Significant disability has been found in patients with displaced scapular, spine and neck fractures, especially pain at rest in 50–100% and in passive or active motions. The emergency physician of a patient suffering low voltage electrical injury should have a high degree of clinical suspicion towards these injuries. These fractures can be suspected by some suggestive signs and symptoms, such as painful shoulder, bony or soft tissue tenderness and limited range of mobility [22]. The diagnosis is made by X-rays and CT scan, to assess the extent of the fracture and to rule out extension into the glenoid. Scapular fractures can be conservatively treated, with a broad arm sling and physiotherapy including passive and active exercises to mobilize the shoulder as pain allowed [21, 23]. Bilateral scapular fractures can be treated non-operatively through shoulder immobilization, analgesia, and progressive physiotherapy, with restoration of the normal shoulder function [24, 25].

Literature studies highlight some indications for surgical treatment of scapular fracture, such as glenoid fractures with dislocation or displacement of the fragments, and coracoid fracture with acromioclavicular separation or associated neuromuscular injury [15].

Posterior fracture-dislocation of the shoulder is one of the most common osteoarticular injury detected after electrocution, as result of massive contraction of the infraspinatus and teres minor, with deltoid, latissimus dorsi and teres major forcing the humeral head superiorly and posteriorly against the acromion, and medially against the glenoid fossa, causing the humeral head to lodge behind the glenoid rim [21]. This type of electrical injury can appear where there are no direct traumas and can be caused by violent muscular contractions. Once the patient is hemodynamically stabilized, treatment of osteoarticular injury should follow the normal principles of orthopedic surgery, aiming to achieve articular congruency through the reduction of fragments, stable osteosynthesis and normal functioning of the shoulder, and rehabilitation should begin at an early stage [26, 27].

The reduction of shoulder dislocation should be performed as soon as possible, to minimize vascular lesion of humeral head that can lead to osteonecrosis and subsequent colaps[27, 28]. However, although perfusion of the head fragment is an essential element, it is not unique factor to consider for operative decision. Even in the presence of ischemic humeral head, the conservative treatment is an option when revascularization is expected or when a management protocol of two stages is required: first stage osteosynthesis; second stage, hemiarthroplasty if avascular necrosis is not tolerated. In case of acute displaced fractures in young patients, gentle closed reduction is attempted; however, open reduction and internal fixation are the best option. If good result cannot be obtained or when more than 50% of the articular surface of the head is involved, hemiarthroplasty is another therapeutic alternative. Some authors suggest that hemiarthroplasty is the treatment of choice in elderly patients (> 65 years) with comminuted fractures of the humeral head (three or four fragments), who are at high risk of avascular necrosis. However, others think that there is insufficient evidence to establish that hemiarthroplasty is a better therapeutic option than plate fixation [15, 27, 29-32].

Bilateral posterior shoulder dislocation represents a special and unusual situation, which has different etiologies and represents less than 5% of all posterior dislocations. The "triple E syndrome" (epilepsy or any convulsive seizure, extreme trauma and electric shock) assigns the three most frequent causes of bilateral posterior shoulder dislocation. Almost 50% of bilateral posterior dislocations appear as a result of a convulsive seizure, rising to 90% if the dislocations are associated with fractures, and less than 5% of them are caused by electric shocks. The diagnosis of bilateral posterior shoulder dislocation is often delayed, and up to 50% of them are not correctly identified on emergency. Possible associated nerve and vascular injuries should be checked. CT scan ensures a complete description of the lesion and can be useful for planning surgery. When the fracture is minimally displaced and the viability of the humeral head is not in doubt, closed reduction, and if necessary pin fixation, should be done, but at three weeks after trauma, closed reduction is almost impossible and surgical treatment is required. For displaced acute fractures in young patients, if an attempt of gentle closed reduction is not successful, open reduction and internal fixation is required. If open reduction cannot be obtained or in patients in which more than 50% of the joint surface of the humeral head is involved, then hemiarthroplasty is recommended. In older patients (>65 years) with three or four-part acute fractures, there is a high risk of avascular necrosis, therefore the indication is hemiarthroplasty. A total shoulder arthroplasty may be required, in case of both involvement of humeral head and glenoid damage [15, 31-39].

Besides, a Cochrane systematic review, published in 2015, established that surgery does not result in a better outcome for the majority of patients with displaced proximal humeral fractures and is likely to result in a greater need for subsequent surgery. Otherwise, there is not enough evidence to determine the best non-surgical or, when selected, surgical treatment for these fractures [40].

Humeral head osteonecrosis is a noteworthy but unusual complication of electric shock, as a result of excessive heat and bone “melting”. Since bone has the highest electrical resistance among all body tissues, it also accumulates the greatest heat while conducting an electric current.Therefore, an osteonecrotic lesion may develop in a distant joint towards the entry point, even after a low voltage electric shock (alternating household current), and this should always be considered in diagnosis and treatment of electrocuted patients [36, 41].

Forearm fractures due to electrically-induced tetanic muscle contractions are uncommon and have been reported in literature only in pediatric patients, suggesting children vulnerability to this type of fracture [19], which could be attributed to factors such as:

- initial electrical flow path through hand and forearm
- more fragile paediatric bone structure
- less developed musculature of pectoral girdle in children, avoiding shoulder fractures as a result of strong muscle contractions.

According to literature data, forearm fracture can appear after low-voltage electric shocks at different levels:
- radius, in a 14-year-old boy who suffered also a minor burn [42]
- distal radius, unilateral in a 6 year-old girl [19] or bilateral, in a 12 year-old boy [6]
- wrist fracture, in a 6-year-old girl [16]
- Galeazzi fracture dislocation of the wrist (distal radius fracture with radioulnar joint disruption), in an 11-year old child [44].

These pediatric cases are original due to the uncommon localization of the fracture following low-voltage electrical discharge, associated with falling or significant muscular contractures [43].

Femoral neck fractures can be attributed to violent muscle contractions of powerful pelvitrochanteric muscles, following electrical current passage, in patients without falling or loss of consciousness. Patients exhibit signs and symptoms, such as pain, inability to stand or walk. Diagnosis is established through imaging studies (X-rays and CT scan), and treatment is surgical, through open reduction and internal fixation (e.g., with a dynamic hip screw) or hip arthroplasty. Subsequent follow-ups are necessary, to assess range of hip movement and to detect unfavorable signs of malunion or avascular necrosis [7].

Bilateral femoral neck fractures are extremely rare and were associated with [8, 45, 46]: high energy trauma, repetitive minor trauma, abnormal anatomy, irradiation for malignancy, seizure, electrical injury, electroconvulsive therapy, primary or secondary bone diseases: osteomalacia, hyperparathyroidism, chronic renal disease or severe osteoporosis, especially after corticotherapy. Literature data show that simultaneous bilateral hip fractures occur more commonly after electroconvulsive therapy rather than seizures, and with a male predominance. This could be explained by better development of the muscular structures surrounding the hip in the male. During convulsions, the powerful muscular contractions could lead to hip (including acetabular) fractures or dislocations [47].

Following electrical shock, bilateral femoral neck fractures are very infrequent and can occur even in the absence of primary and secondary bone disease [8-10, 48]. The emergency physicians, orthopedic surgeons and general practitioners should be particularly vigilant to the possibility of bilateral femoral neck fractures in electric injury patient, even in absence of high impact injury, primary or secondary bone disease, especially if the patients are confused and unable to standing, walk or localize pain. A delay in diagnosis is usual, and undiagnosed femoral neck fractures have deleterious long-term results and complications, which are common in young patient [7, 8]: pain, risk of non-union and osteonecrosis of femoral head with functional disability, degenerative joint disease, progression of an undisplaced femoral neck fracture to a displaced fracture, due to delayed diagnosis, which complicates situation further.
Different procedures have been reported in literature for treatment of bilateral femoral neck fracture, single or combined, such as [45, 46, 49]:

- in situ fixation
- open reduction and internal fixation, the most used option
- open fixation with valgus intertrochanteric osteotomy
- pedicle bone grafting
- hemi or total hip arthroplasty in one or two-staged operations.

The postoperative complications comprise: non-union, delayed union and shortening. Femoral head osteonecrosis and coxavara can be avoided with correct treatment [45]. A long term systematic follow-up is recommended in all patients, with frequent clinical and X-ray check-ups, to evaluate their evolution and to avoid possible complications [8].

Osteonecrosis of the femoral head was also reported in literature after electrical shock. This is a disabling and devastating injury, which is not a specific entity, but the final common pathway of various conditions that impair the blood supply to the femoral head. Its pathogenesis is considered multifactorial and is associated in some cases with both, a genetic predilection and exposure to certain risk factors, such as: corticosteroid use, alcohol intake, smoking, different chronic diseases (renal, hematological, inflammatory bowel disease, hypertension, gout), inherited coagulation disorders, thrombophilic and hypofibrinolytic coagulation abnormalities. These subclinical coagulation defects could result in a clinical disease when overlapped by environmental factors, the so called “second hit” (e.g., trauma, alcoholism, steroids). Osteonecrosis detected at a site distant to the entry or exit point is most likely attributed to injury to the vascular wall which in turn will cause thrombosis and ischemia. The effects of electrical injuries to bone may appear immediately or after a delay of months to years; in addition, the bony injuries may occur near the entry point or in the distance from contact points. The patients complain of hobbling and increasing chronic pain in the hip, and physical examination shows restricted and painful range of hip motion. X-ray of the affected hip can highlight advanced degenerative changes of the hip joint with narrowing of the joint space, thus establishing the diagnosis of osteonecrosis of the femoral head. These patients can be surgically treated by total hip replacement [50, 51].

Osteonecrosis and melting of bone tissue can develop after high voltage discharges, as a result of electrothermic effects. On the surface of injured bone may appear grayish white and hollow osseous pearls [10].

Periosteal burns, destruction of bone matrix, and osteonecrosis can appear in addition to extensive soft tissues injuries, requiring serial surgical debridements. In such cases, stripping of the devitalized periosteum and achieving early soft tissue coverage can restrict the size of bony injury [52].

Late sequelae of electrical injury similar to severe thermal burns include:
- major joint contractures
- limited function of the extremities [3].

Heterotopic calcification in periarticular tissues of large joints, especially elbows, is another common late skeletal complication of electrical injuries. Causative factors may include:
- forced passive mobilization
- secondary articular bleeding
- calcium precipitation and deposition in damaged or degenerating muscle and connective tissue [3].

Heterotopic bone formation is unique to the electrically injured patient and can appear at the cut ends of amputation stumps, in up to 80% of patients with long bone amputations, but not in patients with disarticulations or small bone amputations. Together with common formation of bone cysts in the amputation stump, these events may lead to secondary skin erosion, inflammation, and difficult adjustment of prosthesis. Thus, heterotopic ossification can be severe enough to require surgical revision of the bone end in 28% of cases. Adequate surgical therapy can be easily accomplished by opening the stump incision, excision of the soft heterotopic bone and wound closure [2, 3, 53].

Damage to developing dentition was also reported in younger children with mouth burn, which is the most common electrical injury seen in children less than 4 years of age and which occurs from biting, chewing or sucking on a household electrical extension. This situation is recommended to be managed by an oral surgeon familiar with electrical injuries [54, 55]. Due to the risk of damage to developing dentition and to the possibility of a poor aesthetic result, patients suffering orofacial electrical injuries require surgical and dental approach for oral splinting, postburn debridement, and possible reconstructive surgery [56, 57].

CONCLUSION

Besides skin and soft tissues damages, electrical exposures can also lead to unfrequently, but overlooked skeletal injuries. Following electrical aggressions, fractures and dislocations usually appear as a result of an associated traumatic event, but they can be also produced by violent tetanic muscle contractions. Although fractures due to low-voltage electric discharge are rare, symptoms and signs such as pain, swelling, bone tenderness, and impossibility or limitation of motion, suggest emergence of fractures and require confirmation by subsequent imaging studies, to avoid a possible delay in diagnosis. Thus, all electrocuted patients should be examined carefully and in detail [15].

Therefore, all practitioners involved in the management of the electrocuted patients need to be informed and to take account of the possibility of skeletal injuries. The early recognition, the confirmation by X-ray examination and the prompt orthopedic treatment ensure a favorable outcome and remove the harmful complications. The particular type of treatment for fractures and dislocations should be indicated and performed in each patient by the orthopedic surgeon. The main objectives are the reduction of dislocation-fractures, adequate stabilization, and the restoration of normal functionality [35]. The patients who underwent reconstructive surgery should be closely followed-up, by periodic clinical and radiologic assessments, to ensure a good anatomic and functional result, as well as to avoid possible deleterious complications [52].

Conflict of interest statement
The authors have no conflict of interest and no funding has been involved.
Both authors analyzed and interpreted the literature data regarding osteoarticular and dental injuries occurred in electrocuted patients, contributed in writing the article, read and approved the final manuscript.

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