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Tibia Fracture Healing Diagnosis: A Review.

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ABSTRACT

This paper reviews the available literature on effect of direct current on fracture healing; from a diagnostic view point. It also reviews various fracture treatments in practice, diagnostic tools, computational modeling and fracture healing prediction using Engineering techniques. We attempt to predict the complicated process fracture healing treated using DC electrical stimulation by computational methods. An exciting young area of research is being acquired to realize better the fracture healing mechanism under DC electric stimulation. One of the main goals of this work is to demonstrate, after a review of basics of bone growth, role of DC current and computational models, the main similarities and differences between different methods of prediction of fracture healing using Engineering and artificial intelligent technique. We also underline the importance of mathematical modeling, computational simulations in aiding diagnosis of fracture healing due to the difficulty of obtaining experimental or clinical results under certain ideal conditions.
Keywords: Tibia, fracture, DC electric stimulation, fracture healing, prediction, model.

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INTRODUCTION

Ever since electricity was discovered, functioning of various body systems was associated with the electricity. For example the conduction along nerve is compared with conduction of electric current in wires. In a more micro sense the cellular and inter cellular signaling is compared with the conduction inside an integrated circuit.

It is also worthwhile to know that to know about a material an external energy is directed on it and the resultant energy from it is collected and analyzed. This is also analyzed with known materials. Same is true about geological analysis of the earth. Also in crystallography the crystal in question is put in the way of a light ray and the distracted output is studied. So also when electric current is put in the tissue and an output is generated, it can be of use to study its property.

This can be of use not only in fracture assessment but also assessing mineral content of the person's bone. The first part of this review article we review structure of bone, different methods of assessing fracture, using Direct Current (DC), Alternating Current (AC) or Pulsed Electro Magnetic Field (PEMF).

Properties of bone

In general bone is a living tissue that repairs and regenerates itself. Fracture healing being a complicated process takes lengthy days or months at times. Few Authors have demonstrated the role of callus in tissue formation and healing is demonstrated by measurement of callus [1].

A variety of thermal, chemical, and mechanical stimuli were being identified that could produce bone callus[2]. Biomechanics of bone healing was discussed [3]. Up to 10 % of fracture patients go for non union. Some of the patients may undergo prematurely ,unnecessary procedures like bone grafting , if based on an arbitrary time limit of 9 months is taken as benchmark [4].

The beginning of modern bioelectrical research involving bone is generally traced to Iwao Yasuda, a Japanese orthopedic surgeon. He was primarily concerned with the factor responsible for initiating callus formation. He found that 1-100 µA of direct current (DC) produced callus in the medullary canal of rabbits [5]. Later DC current was found to speed up fracture healing by formation of more callus [6].The bone tissue in direct contact with metal wire cathodes further caused faster remodeling and improved clinical outcome.

The upper limit of current to be applied and also the criteria of selection ununited fractures for electric stimulation were delineated[7,8,9].The main similarities and differences between regular engineering materials and bone tissue from a structural point of view are explained [10]. Both the structural arrangement of the trabeculae tissue and large amount of bound water makes DC conductivity dominate the overall dielectric response of the bone tissue. The DC current flow across the fracture site occurs in two phases namely irregular and asymptotic. In the irregular current the jumping of electrons is in an erratic fashion. In an asymptotic current, electrons jump in a fashion that the charge passage is channelized and hence there is equilibrium. Thus the jumping of electron should be there even in an asymptotic output.

Lord Nataraja's cosmic dance posture itself has the semblance to sub atomic dance of particles even in a fracture callus when studied with electric current [11,12,13].Computational algorithms for predicting the structure of cancellous bone provide a simple, but powerful, method for identifying alterations in bone structure[14].

Ineffectiveness of Radiographs

X-rays, ultrasound are used in practice to diagnose fracture healing. Repeated exposure to radiations causes health side effects in patients [15,16].In practice, the ultrasound beam achieved is not perfect. Degradation of ultrasound and its variability from patient to patient limits its diagnostic use[17].There is no foolproof evidence of union radiologically as seen by many workers [18-20].

From the experimental findings in a rabbit osteotomy model showed that radiograph did not give sufficient information to accurately predict fracture healing [21].Radiographic appearances of fracture healing lag behind the mechanical properties of healing bone[22].Plain radiography provides poor parameters for monitoring the fracture healing process [23].In non unions the use of electrical stimulation modalities has been tried with more interest [24].

About 95 per cent are positive reports despite an extraordinarily wide selection of experimental techniques and models. Fourteen research groups report that electrical currents stimulated fracture healing with few if any complications in a total of 595 patients.

An exact mechanism of action and technique for its application is undecided [25].

Table 1 shows the various safety and healing induction parameters of current fracture healing assessment techniques.

Table 1: Comparison of fracture healing assessment techniques in practice

Method	Safety	Healing induction	Cost effective	Constant monitoring
X-Ray	Unsafe	Nil	Recurring	Not advisable
Ultrasound	Not 100% safe	May or May not	Cheap	Not advisable
DC Electric Stimulation	Safe	Yes	Yes	Possible

Electric Stimulation

Electric and electromagnetic devices have been shown to affect the healing process positively in delayed unions, nonunion, and osteotomies [26]. Electrical stimulation promotes sensory neuron regeneration and growth-associated gene expression[27].

Pulsed Electric Stimulation

The histological evaluations in cats , with the light and electron microscopic examination of cortical tissue subjected to charge-balanced, biphasic, constant-current pulses delivered through subdural implanted electrodes indicated a positive correlation of neural damage with both charge density and total charge [28,29].Nearly twenty eight tibia fractures were treated with external fixation by means of a Hoffmann apparatus. Through two electrode-screws in the Hoffmann apparatus a slowly pulsating, asymmetrical direct current was applied to the fracture site in each patient. In the stimulated patients there was 30 per cent acceleration in healing as found by mechanically stressing the Hoffmann apparatus used for immobilization of the fracture [30].

DC Electric Stimulation

Experimental techniques involving the adjustment of current through bone tissue assuming an ohmic dependence with little or no associated polarization effects are valid and certainly warrant further investigation [31].DC current is effective in stimulating osteogenesis in nonunion was demonstrated with rabbits. This form of treatment is effective, simple and safe; it can be used after the failure of repeated operations for nonunion [32].

The human study involving an initial group of 4 tibia fracture cases treated with DC electric stimulation resulting in minimal of X-ray was demonstrated to be safe diagnosis[33].The final radiological appearances of cases treated with Ilizarov and followed by electric stimulation were compared and studied. The main outcome measurement was the shape of the callus and whether it is anatomical or not. If it was anatomical, how many cortices the bridging occurred and any affection of the return to daily pre-injury status or refractures [34].

Behavior of Electric Parameters

All electrical and dielectric properties were also transversely isotropic in nature, the values for the axial direction being different from the values obtained for the two transverse directions[35].A review of the available data on the electrical properties (resistance, capacitance, dielectric constant, dielectric loss factor, and dissipation factor, etc.) of whole as well as standardized bone specimens suggest that impedance was lowest in the longitudinal direction and highest in the radial direction.

This is further evidence of the anisotropic nature of bone. The electrical properties of fully hydrated bone were significantly different from those of dry and partially wet bone[36].In general, the specific capacitance depended more on density for all bone specimens, and only a weak relationship was found between the resistivity of human cortical bone and density[37].The biopotentials recorded decreased during the healing phase but were significantly higher in the vicinity of the tibia fracture in rats[38].The current varied irregularly and then decreased during the healing across humans [39].

AC or DC Electric Stimulation

One main concern is the safety of using AC and DC .The high electrical resistance of human skin makes it a dielectric with the sub-cutaneous tissue and metal plate on either side acting as plates of a capacitor.

In cases of electrocution by DC voltage source, this capacitative property is of little importance. But if electrocution is by AC voltage source, the natural resistance of the epidermis is reduced allowing the current to bypass that resistance of the part of the body in contact causing reduction in the total resistance.

The danger of the electrocution depends on the amount of current passing through the body .Thus when the resistance is reduced, the current passage is more. So AC is hazardous than DC [40].

Moreover, the chemical changes occur only when DC stimulus is continuous and applied over time. Muscle contraction occurs when current intensity rose to stimulus threshold. Based on the experimental data obtained from tibia fracture patients treated using electrical stimulation, the variation of DC current applied over number of days across tibia fracture site across humans is shown in Figure 1.

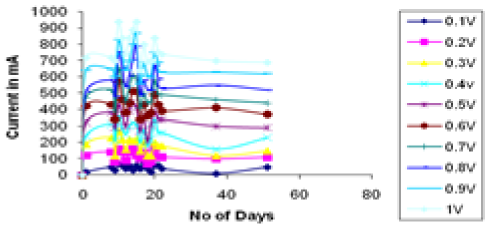

Figure 1: Real time experimental output showing variation of DC current applied over number of days.

From the figure 1 it is observed that the current varies irregulary during the initial healing period , drops down when healed and becomes constant.

NEED FOR MODELLING

To understand more about the process and provide greater insight about the parameters modeling of the system has to be performed. Studies in animals have clearly established that various forms of stimulation (electrical/mechanical) positively affect the growth, repair, and remodeling of hard and soft tissue.

Although the various electrical stimulation modalities (faradic, capacitive, and inductive) are different in their physics and biochemistry, each produces a variety of biological responses in a wide range of animal models[41].

A first order system model for simulating the influence of stress stimulation on fracture strength during fracture healing in 70 New Zealand rabbits was proposed [42].A finite element model of an osteochondral defect in the knee was created, and used to simulate the spontaneous repair process. The model predicts bone formation.

This result leads to the conclusion that repair tissue degradation is initiated in the fibrous tissue that forms at the articular surface[43,44]. The fracture stiffness allows the detection of patients at risk for nonunion. The healing time increased with increasing fracture gap size and was less in patients with younger age, less complex fractures, and lesser degrees of soft tissue damage [45].

The ability of bone to react to changing mechanical demands by adapting its internal microstructure through bone forming and resorbing cells was experimented with mice[46].

Bioelectric potentials after tibia fracture during the healing phase was recorded and analyzed in rats and [47].

ELECTRICAL BEHAVIOUR OF FRACTURE HEMATOMA.

The fracture hematoma favors healing; removal of the hematoma after some days is more harmful to healing than when the hematoma is removed in the initial phase was demonstrated with rat [48].

While analyzing fracture healing The fracture site blood clot is considered as a dissimilar material between the two fractured fragments of bone A and B. When a current is applied this is considered as a di-electric and electrical conduction of a blood clot supported by the studies [49,50]is also realized in our recent study by mathematical and empirical methods. Hence we consider the tibia fracture site as a capacitance.

Once the fracture site hematoma heals to become bone and becomes continuous with the two fragments A and B, the original conductivity and resistivity of an intact bone is restored to near normal.

Once it was observed that the ionic transfer did not occur as evident from the asymptotic graphs, at this healed stage, the gain of the process is constant, which we found out in our model FOPDTZ (First Order plus Dead Time Zero) with constant gain[51]. The modeling was performed based on the system identification principles applied in nonlinear process [52-54].

CONCLUSION

This paper reviews the available literature on effect of direct current on fracture healing; from a diagnostic view point, fracture treatments in practice, diagnostic tools, computational modeling and fracture healing prediction using Engineering techniques. The importance of mathematical modeling is also realized.

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