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Designing of a Simulated Fracture Supporting Device and Studying Electric Conduction across it.

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ABSTRACT

To analyse fracture healing repeated X-rays are needed increasing the problem of radiation. Though already Electric Current is used widely in therapeutic aspect to accelerate fracture healing, only recently it has been tried as a diagnostic tool in assessing fracture healing. To study conduction across a fracture the first step is to devise a suitable simulated structural support for fracture in fractured limb. For this, two Ilizarov rings of stainless steel are connected by wooden rulers. The distance between these rings are adjusted to be 4 cm and 6 cm. The Direct Current voltage is applied between the K-wires fixed to each of these circular rings and current output measured in different solutions like tap water, de-mineralized water and Sodium chloride solutions of different concentrations, glycerol and heparinised domestic goat's blood. It was found that the relationship between voltage applied and current recorded across two wires of an Ilizarov ring kept in electrolyte solutions and goat's blood up to 1 volt was linear. This method will be of use in measuring such electric conduction between wires passed across a fracture during its healing period. Such models being inexpensive can also use to teach electric conduction to students.
Keywords: Electric Conduction, Goat's blood, NaCl solution, Ilizarov ring, non-conducting, Fracture.

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INTRODUCTION

It is common that fracture healing is followed with X-rays**.** This method has not only the problem of radiation but also is dependent on the doctor's familiarity with X-rays [1,2]. This questions its usefulness. There is no established description of bone union in X-ray. [3,4] Electric stimulation has been tried therapeutically to heal fractures [5,8]. Recently there is an interest in using electric stimulation for monitoring fracture healing. In these papers the authors had used Ilizarov ring as the support apparatus in immobilizing the fracture and also had used DC voltage. There was also difficulty in insulating the wires across the limb and the separate bone conduction from conduction by other tissues and hence the studies are empirical [9-13]. In an intact bone, no one is sure as to how electric conduction occurs. It can be due to bone tissue or due to the fluids present in live bone and fresh harvested bone. The support for the role played by the bone fluid is strengthened by the observations in animal experiments. These experiments showed an increase in the bone's electric resistance after the death of the experimental animal and *in vitro* bone samples. Thus, reduction in body fluids which naturally occur once an animal dies would have changed the electro conductivity of bone [14]. The exact mechanism or path of the conduction between such bone electrodes is not known. In another experiment, two platinum electrodes was embedded in the femur medullary area *in vivo*. Interestingly when current-voltage relationship in the between them were studied only below one volt, there was good Ohmic dependence and above one volt, electrolysis occured and the readings became non-linear. Thus studies suggested that suche experiments which adjust the current through bone tissue, assumed an ohmic dependence are logical and deserve more analysis [15].

We theorized that fresh fracture haematoma is chemically different from mature fracture callus. This means that electrical behavior across the fracture bone will progressively change as the fracture heals [13].

Any experimental study needs to be carefully evaluated in lab in simulated models before any in vivo experiments are considered. Thus there is a need to evolve a model to measure electric conduction across a fracture, when treated with an external fracture supporting device. It was felt that such a study will also be useful to possibly arrive at an appropriate volt current characteristic to be adopted in real fractured limbs. In this context to study the feasibility of such electric conduction, Ilizarov ring fixator has been selected. Ilizarov is a method of treatment for open fractures where the fracture is fixed with rings and K-wires above and below. An example of an Ilizarov fixator on a patient and the X-rays of the limb may be seen in the figures 1 and 2. In a real set up there will be no conductive material like plate or nail between the two wires if the rings are connected with a non conducting material.

The purpose of this paper is to evolve a device which will simulate an Ilizarov ring apparatus used on a patient as shown in the figure so that it can be kept in electrolyte solutions to test electrical conduction. If successful such a device may be applied on live animal bones (for e.g. new Zealand rabbits) and electric conduction may be tested in the bone before a fracture in an intact bone and immediately after an induced fracture and at different stages of healing of the fracture.

Figure 1: A patient is seen with an Ilizarov fixator on his limb

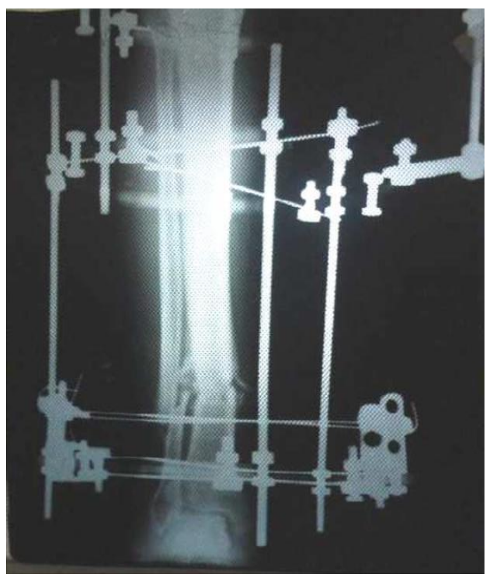

Figure 2: X-rays of the patient seen in Figure 1

AIM

We aimed to **design a simulated fracture support device and** measure and analyze the electric conduction across the two stainless steel K-wires of two Ilizarov rings when placed in a conduction cell.

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EXPERIMENTAL SET UP AND METHODOLOGY

Firstly a simulated fracture support device SFSD is devised as described in section 3 a. this was followed by the measurement of electric conduction when above support device is placed in different electrolyte solutions and substances as described in 3 b

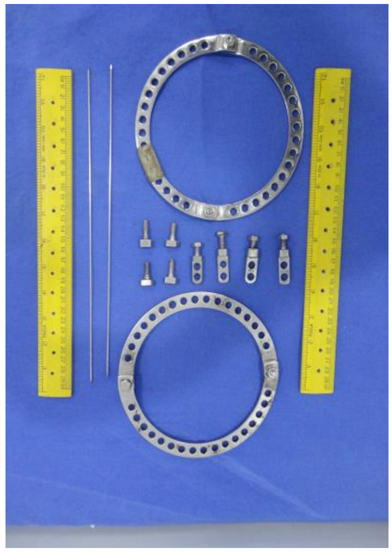

Figure 3 a: The constituent parts of simulated fracture support device. Wooden rulers, Stainless steel K wires,Stainless steel Ilizarov Rings, , male posts , nuts and bolts

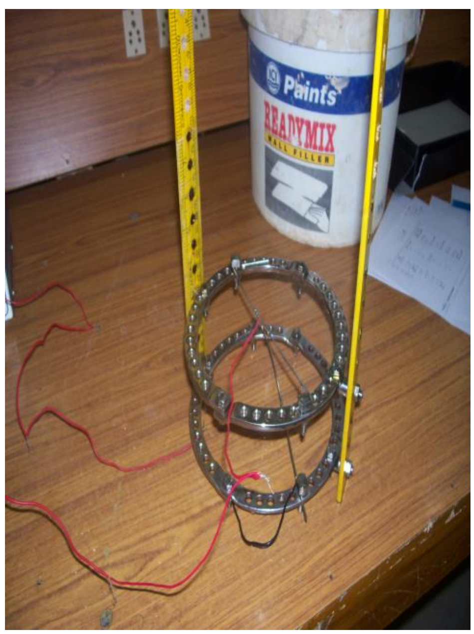

Figure 3b: Assembling of the compaonents shown in figure 3a.

Figure 3c: Ring-power supply set up with an Ammeter and DC generator for preliminary studies on different solutions

Designing of the simulated fracture support device SFSD

To simulate structural support for fracture in fractured limb we assembled Ilizarov rings as shown in the figure 3a and 3b.

Figure 3 a shows the constituent parts of the Ilizarov ring apparatus. Two Ilizarov rings made of stainless steel with holes along the circumference (Advanced OrthoTech Chennai) are selected. To prevent electrical short circuit, these two rings were connected using two vertically placed wooden rulers (those rulers used in the schools). Holes were drilled in the rulers such that the vertical distance between the two Ilizarov rings could be adjusted (either four centimeters or six centimeters). Through these holes Ilizarov male posts (Advanced OrthoTech Chennai) were inserted and these posts were used to connect the above two rings. A K-wire was fixed to each of these circular rings with special wire fixation bolts. (Advanced OrthoTech Chennai). As shown in figures 3b and 3c. Electric wires were soldered to these K-wires and the soldered junction was sealed all around using an epoxy resin Araldite® (Araldite®- epoxy adhesive kit manufactured by Petro Araldite Pvt Ltd.Manali Express Highway, Manali, Chennai-6000068) to prevent short circuiting. The arrangement is seen in figure 3 b.The electric wires were connected to a Direct current [DC] voltage source (Automatic Electric Ltd®. Mumbai) by which voltage range can be adjusted with a potentiometer arrangement. With this arrangement the resulting current output, could be measured with an ammeter (Automatic Electric Ltd®. Mumbai). The ring-power supply set up and accessories for preliminary studies on different solutions to arrive at proper voltage current range also can be seen in figure 3c.

Measurement of electric conduction, when the simulated fracture support device is placed in different electrolyte solutions and substances.

A container was selected so that the above apparatus (SFSS) when kept in the container, is fully immersed in the solution kept in it. Figure 4 shows the SFSS immersed in a conduction cell. Figure 5 shows a line diagram of the same SFSS in a conduction cell. The above ring apparatus with the K-wire at six centimeters [cms] gap was immersed in tap water and various DC voltages of 1.0 to 2.0 volts from a DC voltage source were applied and the current output was measured. The distance was then reduced to four cms and measured the current output. First the conduction was tested in 5 litres of demineralised water and then 5 gm ,10gm, 15gm Sodium chloride were serially added to it and conduction tested each time for two distances 4 and 6 cms. Thus current- output was recorded for various voltages and distances as mentioned above. For measuring electric conduction in a viscous substance, five litres of Glycerol was used. To measure conduction in animal connective tissue, five liters of goat's blood was collected and heparinized from a licensed -slaughterhouse and was used (figure 6).

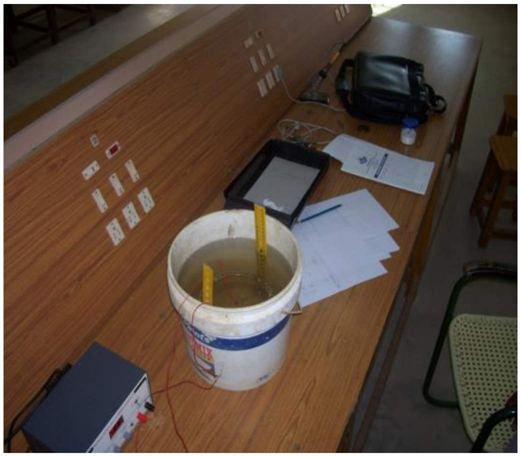

Figure 4: SFSS immersed in a conduction cell.

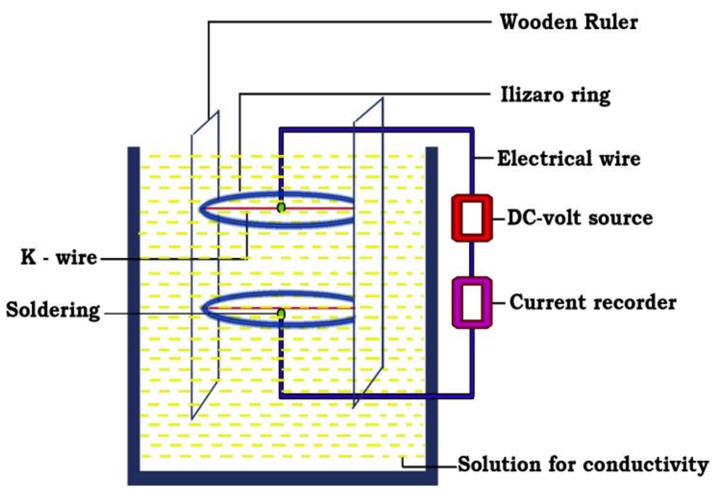

Figure 5: Line diagram of the SFSS in a conduction cell.

 

Figure 6 a and 6b: Five liters of heparinized goat's blood collected from a licensed –slaughterhouse.

This heparinisation was in proportion of 5000 IU of heparin for 5000 ml of blood[16-17]. The heparinized blood was constantly stirred and the reading was taken within few minutes. This is to prevent sedimentation and the hence avoid difference in conductivity. In between the change of the solutions the entire SFSS was removed, washed well with demineralised water and dried with a domestic hair drier.

RESULTS

The relationship between the voltage applied and the current recorded across two wires of an Ilizaro ring kept in electrolyte solution and goat's blood were studied. Table 1 and table 2 show the results of the above experiment at 4 cm and 6 cm gap between the rings respectively across the different solutions and substances.

Table 1: The results of current recorded for given voltages at 4 cm gap between the rings across different solutions and substances.

Voltage	Tapwater	Demin	NaCl1g/l	NaCl2g/l	NaCl 3g/l	Glycerine	Heparinized goat's blood
0.2	0.42	0.02	0.76	1.204	1.282	0	0.722
0.4	0.84	0.04	1.52	2.409	2.564	0	1.444
0.6	1.26	0.06	2.281	3.614	3.846	0	2.166
0.8	1.68	0.08	3.041	4.819	5.128	0	2.88
1	2.1	0.1	3.8	6	6.4	0	3.6
1.2	8	0.2	6.4	8.8	9.4	0	7.4
1.4	10.4	0.3	10	11.6	12	0	12
1.6	12.2	0.4	13.4	15.4	16	0	20
1.8	14.2	0.5	19.4	20	20	0	20
2	16.5	0.6	20	20	20	0	20

Column 1= applied voltage in volts , Columns 2 to 8 = recorded current in milli amperes

Table 2: The results of current recoded for given voltages at 6 cm gap between the rings across different solutions and substances

Voltage	Tapwater	Demin	NaCl1g/l	NaCl2g/l	NaCl 3g/l	Glycerine	Heparinized goat's blood
0.2	0.36	0	0.63	0.961	1.242	0	0.4
0.4	0.72	0	1.261	1.923	2.484	0	0.8
0.6	1.081	0	1.892	2.884	3.726	0	1.2
0.8	1.441	0	2.523	3.846	4.968	0	1.6
1	1.8	0	3.15	4.8	6.2	0	2
1.2	6	0.1	5.8	5.6	9	0	5
1.4	8.4	0.2	8.2	10	11.5	0	10
1.6	10.2	0.25	10.4	12	15	0	20
1.8	12.2	0.35	14.8	20	20	0	20
2	14.5	0.4	20	20	20	0	20

Column 1= applied voltage in volts , Columns 2 to 8 = recorded current in milli amperes

The tabulations include the current readings measured for a fixed voltage, for various solutions and blood at fixed distances of four cms and six cms between the rings at room temperature. They are presented graphically in figures 7a and 7b.

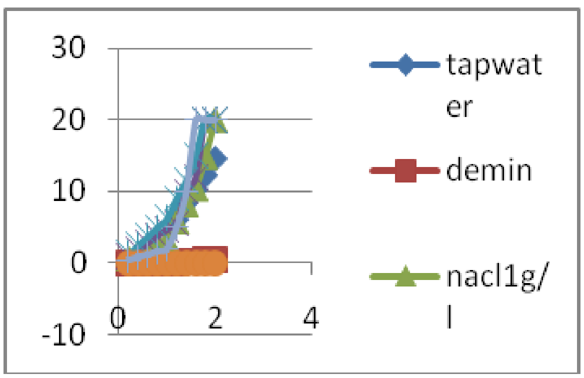

Figure 7 a

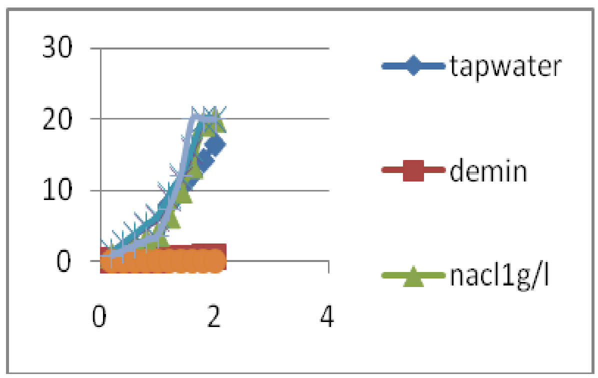

Figure 7b

Figure 7a: Conduction characteristics at room temperature through the different solutions , across the two rings in the SFSS at 4cm .
Figure 7b: Conduction characteristics at room temperature through the different solutions , across the two rings in the SFSS at 6cm

From the above graphs, it can be seen that there was no conduction in demineralised water and glycerine.In other solutions like tap water, Nacl soutions,heparinized goats blood, it was observed that there was linear increase in conduction as the voltage is increased. This trend was seen upto 1 volt ,then there was non linearity in the graphs for both four cms and 6 six cms distances.. It was also observed that, when the distance between these two rings was reduced or the concentration of NaCl solutions was increased, the conduction increased. The sensitivity was highest for heparinized goat's blood. Irrespective of the distance between the rings, i.e. in both the graphs it was observed that, any DC voltage applied above 1.0 volt caused non linearity in the graph.

DISCUSSION

A study using electrophoresis to estimate salt concentration in proteomics solutions, found that the solute concentration was directly proportional to the conduction.[18] The red blood cells do not conduct electricity. This property is exploited to find the relative percent of these cells in blood. i.e. anemic blood conducts more than normal blood.[19] With a similar idea an appropriate model was devised and its predictions were confirmed *in vitro* with a range of indicators and canine blood (with a small tetra polar conductivity cell).[20] In flowing blood, the electrical conductivity depends on its flow velocity.[21] This present experiment is done in static heparinized blood of domestic goat.

As already pointed out in the introduction of this paper there is disagreement with regard to electro conductivity of bone in vitro and in vivo.[14,15] There are few other works on conduction and resistivity of blood. [22,23]

In contrast to resistivity, conductivity is the ability of a substance to conduct electrical current. As the fundamental unit of resistance is Ohm, its reverse i.e. mho was first used to denote the unit of conductivity. mho is now replaced by the unit Siemens. In the industry, increasing conductivity of a solution means an increase in impurities. To find the quality of water, the test and control level conductivity are electronically measured.[24] Here the individual ions cannot be differentiated. Still the conductivity quantifies of total impurities so is practically useful. Also another disadvantage is that concentrated solutions show a slightly lower µS /cm conductivity for each ppm (parts per million), than do dilute solutions. The probes when used for long periods become coated affecting their accuracy. [24] Periodical cleaning of the probes and replacement with new ones are needed to avoid this. Obviously in our case, as we have used the equipment for only a shorter duration, we feel this may not be a problem to us. However if it was used in teaching conduction to students then the entire apparatus should be dismantled. The wooden rulers can be changed as they become weakened on long use. The wires and the rings can be periodically cleaned with water and soap to render them free from electrolyte coating.

In the studied set up, the question is where actually the conduction occurred and what are the components of this SFSS that actually formed the 'electrode'? Being soldered and covered with epoxy resin, the conduction occur through the stainless steel rings, the wire fixation bolts and the K-wire on both sides. Thus the composite of the stainless steel ring, the two wire fixation bolts and the K-wire composite, one on either side forms the electrode.

However in real patients it will be difficult to insulate the wires. Unlike in metals, ionic motion is the mechanism of electric conduction in aqueous solutions. This conduction constantly rises with increasing temperature. Temperature sensors have time lag depending on their position and mounting. With only such sensors most conductivity study readings are referenced to 25 ° C. If the conductivity of a solution is more, then the distance between the electrodes in the conductivity cell is increased .[24] Also as the temperatures will affect the conduction, there is a need to keep the temperatures constant.[25]

In literature there was no consensus as to how clotted blood will behave with regard to conduction. One author (Bayliss) had reported an 18 ½ times reduction in conduction on clotting probably due to disappearance of ions.[25] This was contested strongly by others who felt it could be only an error in observation. This is because in many studies, there is no change in conduction in clotted blood and if at all there was a slight decrease in conduction, it may be due to jellying of blood, slowing the movement of ions. Same was the observation when egg protein was coagulated by heat.[25]

The more time it takes to do the measurements , the erythrocyte sedimentation occurs and its changes the conductive behaviour of the blood. i.e. the part without erythrocytes conduct better.This is minimised by constantly stirring the blood and making the measurements rapidly.[25] In our experiments with blood constant stirring was done to prevent such sedimentation and hence to prevent any difference in conductivity.

In our studies, the linearity of current conduction seen upto 1 volt and non linearity later (more than 1.0 V)in the graphs, confirm the results of other studies that showed that the ohmic dependence is only under 1 volt irrespectuve of the concentrations or distance between the electrodes. We have conducted this experiment in lab setting in room temperature of 29 degree. There was no attempt to study the conditions in different temperatures as that was not the aim of the study. Such studies are already reported. However all the solutions were tested in similar conditions. This may not affect the conductivity testing qualitatively. However it should be accepted that individual solutions will behave differently in different temperatures which may quantitatively differ in conduction**.** In the industry, chemical water treatment involves measurement of conductivity of waters which consists ionic compounds dissolved in water as impurities.[24]

Obviously electrical conduction in electrolytes is familiar and this paper does not aim to study that aspect. The work only highlights the applicability of the fracture support system in the context of electrolyte conduction. There has been no study in this line, to date. In future the wire are planned to be inserted into live and dried bones with the same apparatus and electrical conduction will be studied. The main problem expected in real clinical setting will be a non-availability of a strong yet non conducting material which can be machined like real threaded stainless steel rods. Hence in real situations we can opt for a non conducting ring material like a Teflon coated carbon epoxy ring connected with real threaded rods. There is no such study using electric current flow across the Ilizarov wires.

The simulated fracture support device **(**experimental apparatus) found in the study thus offers an inexpensive equipment to study conduction across two wires placed in electrolyte solutions. From the voltage studies and available literature it was found that a range of 0.1 V- 1.0 V is well within the safety limits for humans.[26] In a real setting with such an apparatus in the patient's lower limb, the application is localized i.e. to the limb only. (Figures 9 a) and DC power flow through his heart does not occur as in figure 9b

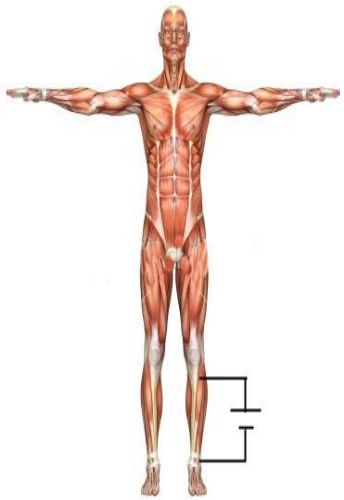

Figure 9a

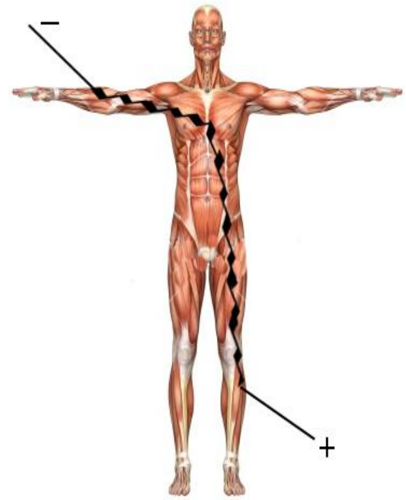

Figure 9b

Figure 9a showing localized application of current and figure 9 b showing current passing through the heart.

CONCLUSION

Thus a simulated fracture supporting device was built and conduction across the wires of this device was studied when it was placed in a conduction cell with different solutions. This is in-expensive and reproducible. This experiment not only gives an insight on using a similar device on a fractured limb but also can be used as a teaching aid to the students of medicine, bio technology, instrumentation engineering so that further new ideas will evolve.

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