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Determination of optimum voltage for tibia fracture across limb in patients treated using DC electric stimulation

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ABSTRACT

Diagnosis of fracture and treatment always pose a challenge to medical practitioners. A DC voltage in the range of 0.1 to 0.7V was applied across tibia fracture site stabilized with Teflon coated carbon rings and the data was recorded at various patient follow-up periods. Using the concept proposed in one of our earlier work, a regular pattern of variation of capacitance is observed across the tibia fracture site exhibiting capacitance. In this work we determine the optimum voltage required for the following of the fracture treatment. The electrical data was recorded across radiographs different tibia fracture patients classified into 4 group's namely fresh presentation, presentation after a medium delay, presentation after a long delay and fracture with gap. The variation of capacitance for the range of applied input voltage 0.1 to 0.7V was calibrated. The data was subjected to Analysis of Variance (ANOVA). An ANOVA analysis of the four groups indicated a significant level F ratio and P value which suggested that results are at confident interval. From the results the best optimum value for applying input voltage for the tibia fracture case is 0.1volt.

Keywords: DC voltage, capacitance, optimum value, applying input, tibia fracture

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INTRODUCTION

The treatment of the long bone fractures has come through stages of initial plastering technique to the modern internal fixation techniques. In complicated fractures when the fracture is open we have modern Ilizarov rings .Estimation of patient dose and associated radiological risk from limb lengthening [1] and fracture healing assessment comparing stiffness measurement using radiographs [2] were already discussed. There is lack of consensus in the radiographic assessment of fracture- healing Concepts of fracture union, on-union and delayed union among orthopedic surgeons[3, 4]. There are different types of fracture healing rate that the concept of duration after fracture is controversial. [5] At present radiographs are used to diagnose fracture healing which cause many side-effects on frequent exposure [6-8] Researchers have identified that electric voltage applied to a fractured limb speeds up fracture healing especially in the un-united long bone fractures. [9- 11] Recently fracture healing assessment using Direct Current stimulation and with monitoring of fractures using online has gained attraction. Fracture Healing diagnosis by DC Electric Stimulation were studied by earlier works [12- 14]. A first order system model of fracture healing was explained for animals by another author .[15] We have also applied artificial intelligence techniques to predict the fracture healing [16]. A FOPDTZ model for tibia fracture site tissue for monitoring fracture was explained in a previous work healing by us [17]. We also made a comparative analysis of fracture healing predicted using mathematical model and soft computing techniques. [18] The effect of capacitance for a particular voltage during fracture healing was also analyzed statistically[19]. Tibia fracture site acting as capacitance was supported by dielectric properties [20, 21].

In the present work we determine the optimum voltage required for diagnostic DC application. This is done by calibrating the capacitance using the electrical data recorded during various follow-up periods is explained using the electrical data recorded across radiographs different tibia fracture patients.

METHODOLOGY

If the electric current is passed from one end of the unbroken bone by an electrode, it reaches the electrode at the other end by the conduction property of an intact bone. When an intact bone is broken into two pieces there will be two pieces as in Figure 1. The gap between the two fracture fragments pieces will be filled with blood clot. If one applies the same electric current through a fractured bone as in Figure 1, the current from the electrode passes through the first fragment A, then the blood clot and then the second fragment B, and reaches the other electrode. The blood clot in the fracture site is considered as a dissimilar material between the two fractured fragments of bone. When a current is applied this is considered as dissimilarity in electrical conduction of a blood clot supported by the studies (di-electric) [20,21]. This was also realized in our previous study by mathematical and empirical methods. Thus 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.

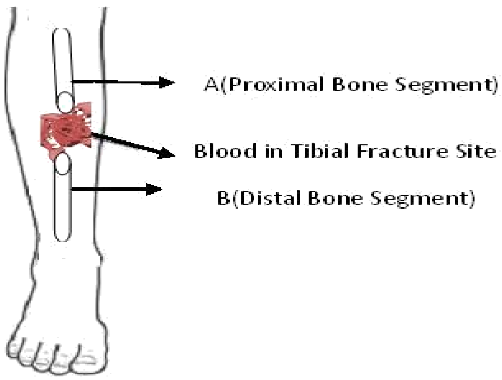


Figure 1: Broken bone

The experimental set-up for fracture healing model analysis is shown in Figure 2. Data from the prospective study that was conducted where open fractures of tibia were treated was used in this study [15-

16].The open fractures were cleaned of debris and contaminants and were stabilized with four Teflon coated carbon ring -Ilizarov external fixator on the fracture patient. Using 5mm diameter threaded rods and .1.8mm (316L stainless steel) K-wires were used to fix the bone to the carbon rings by wire-fixation bolts. As allowed by the patient's pain tolerance, this assembly with the limb was used to mobilize the patient with partial to full weight bearing in the immediate postoperative period. The upper wire of the fracture was given a DC voltage 0.1 to 1.0 V and the output was recorded across the fracture in the lower wire. The wire that passes only through the tibia was taken for the study.

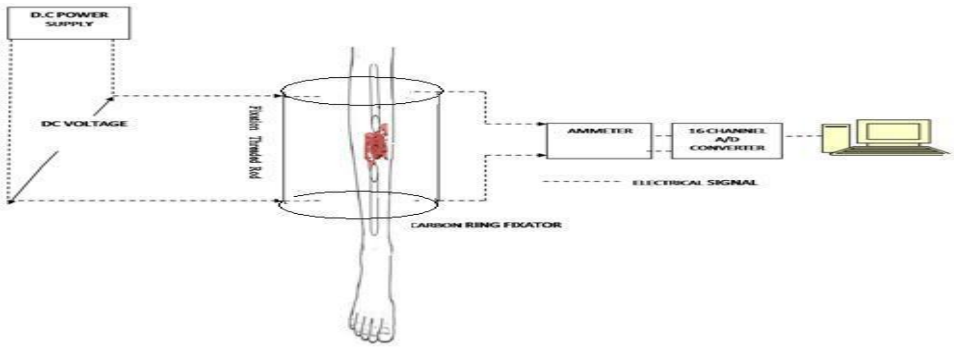


Figure 2: Experimental set-up for fracture healing model analysis

In these cases the healing was followed with clinical assessment and periodical radiographs till the endpoint of fracture union and then the rings were removed. Additionally, all the patients also had application of electrical voltage in the range of 0.1-1.0 V DC in 0.1 V increments, across the two wires on either side of fracture. The output current was recorded by an ammeter connected in series. Ammeter measures the current flow across the fracture .Using the ammeter reading as reference the online data recording of voltage calibration in terms of current is done. The schematic representation alone is shown in the experimental set up. The Ammeter output was connected to M/S AD Instrumentation 16 channel data acquisition card via signal conditioning unit. The card was connected to the USB port of the Pentium processor with an in-built anti aliasing filter. The card supports 16 ADC and DAC channels in the range of ±15V .Program was developed in 'C' language to read and display the patient's current rating in terms of mA. The graph was compared with the appearance of new bone formation in radiographs. The above methodology was carried upon 32 different patients at Thanjavur Government Medical College to predict the exact instance at which a fracture has united completely. For all the radiographs different patients same fracture healing pattern was obtained. The real time experimental data for four tibia fracture patients is shown in Figure 3.

Statistical Analysis

The radiographs patients were classified into 4 groups. During DC electric stimulation treatment for every patient in the follow-up period, the capacitance was calibrated. Using ANOVA analysis F value and P value was determined. The results were evaluated and found matching at confidence intervals.

Participants involved

In this study radiographs of tibia fracture patients subjected to fracture healing by diagnostic DC simulation were studied. As a regular pattern of current i.e. initial irregularity in the current flow and its stabilization in later stage were observed in all the cases. The patients were classified into 4 groups namely fresh presentation (patient was presented to practitioner within 2 weeks) , presentation after a medium delay (patient was presented to practitioner within a period more than 2 week but within 2 months) and presentation after a long delay (presented to practitioner after 2 months) and Fourth group were facture with gap. For all the four different groups (case) of patients same fracture healing pattern was obtained. The real time experimental data was shown in figure 3. In figure3 Case-1 shows the output response recorded during fracture treatment using DC electric simulation for one of the fresh presentation patient to the clinician. Case2 corresponds to response of a medium delay patient while Case3 corresponds to long delay more than 2 months. Case 4 shows the response of a patient presented with a fracture gap and was presented after 2 months delay to clinician.

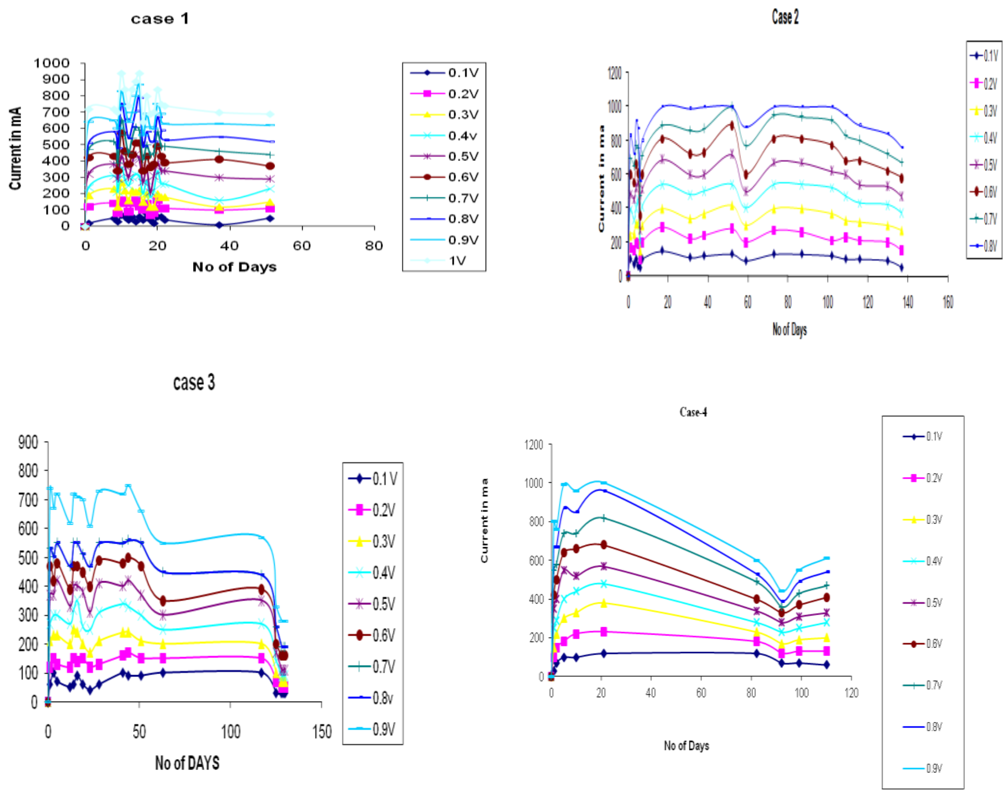


Figure 3: Experimental data collected from open loop response of a four tibia fracture patient cases.

Calibration of Capacitance

Based upon the mathematical correlation of the tibia fracture model as explained in an earlier work [17], the calibration of capacitance was done at various follow-up period .Tables 1 to 4 show the capacitance calculated for four groups of patients for varying input voltage in the range of 0.1 to 0.7 V. Figure 4 shows the variation of capacitance for a voltage of range 0.1 to 0.7V. The variation of capacitance for all the groups exhibit a similar pattern i.e. the capacitance initially increases to attain a peak maximum value, then decreases and reaches a minimum value finally. Radiographs taken on the day of capacitance dropping down to minimal value confirmed the fracture union.

From this figure when the voltage is continually applied to the patients until the bone heals it was confirmed with radiographs in this case initial stages it will behavior like a transient response.

Table 1: Calibration of Capacitance for Case-1 Tibia fracture patient

S.No	Capacitance calibrated for Applied Input Voltage(Volts)						
	0.1V	0.2V	0.3V	0.4V	0.5	0.6V	0.7V
1.	200	600	633	600	640	700	671
2.	4000	5600	6133	6200	6080	5733	5942
3.	2700	3600	3600	4725	5220	5100	5014
4.	7000	8000	9000	9000	8600	9500	9285
5.	6600	7700	8066.667	7975	8140	8433	8800
6.	4800	5400	6400	7500	7200	7600	7714
7.	7800	9100	9533	9750	10140	9533	10028
8.	4200	11200	9800	11200	12radiographs0	11900	12200
9.	9000	9000	11000	11625	12300	12750	12642.86

Table 2: Calibration of Capacitance for Case-2 Tibia fracture patient

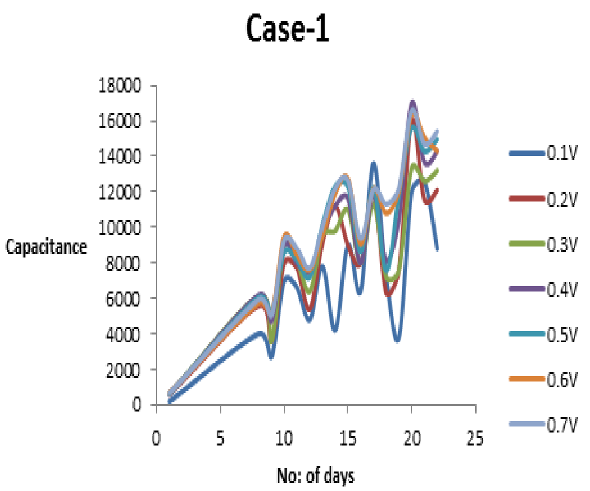
S.No	Capacitance calibrated for Applied Input Voltage(Volts)						
	0.1V	0.2V	0.3V	0.4V	0.5	0.6V	0.7V
1.	1000	1000	1066	1050	1080	1100	1100
2.	10400	10800	11200	11200	11200	11333	11428
3.	17600	16800	20266	20000	19840	20800	21028
4.	30800	28600	29333	29700	30360	30433	31428
5.	40600	40600	40600	42050	41180	41566	41428
6.	35200	40000	40533	40800	42880	42133	42057
7.	42900	50700	49400	49725	50700	52000	51257
8.	49200	49200	51933	52275	53300	53983	52714
9.	48000	52800	51200	51600	51840	52000	51428

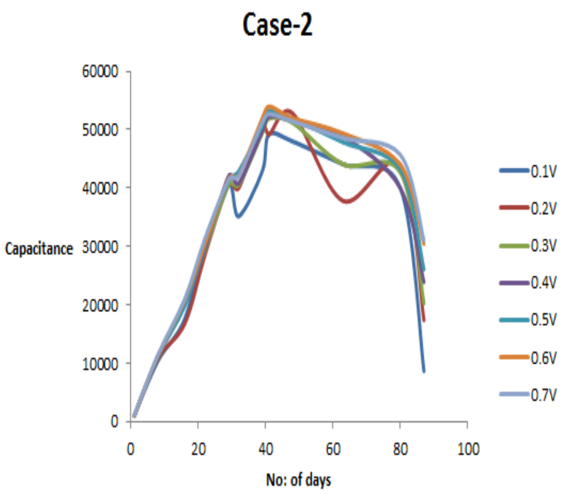
Table 3: Calibration of Capacitance for Case-3 Tibia fracture patient

S.No	Capacitance calibrated for Applied Input Voltage(Volts)						
	0.1V	0.2V	0.3V	0.4V	0.5	0.6V	0.7V
1.	300	500	500	625	700	700	785.7142857
2.	1400	1500	1466.666667	1450	1600	1666.666667	1657.142857
3.	5000	4500	5000	5000	5500	5333.333333	5285.714286
4.	10000	11000	11000	11000	10400	11000	10571.42857
5.	25200	24150	26600	25200	23940	23800	24600
6.	98400	73800	62866.66667	57400	55760	54666.66667	57400
7.	64400	55200	52133.33333	52900	51520	50600	47314.28571

Table 4: Calibration of Capacitance for Case-4 Tibia fracture patient

S.No	Capacitance calibrated for Applied Input Voltage(Volts)						
	0.1V	0.2V	0.3V	0.4V	0.5	0.6V	0.7V
1.	1000	850	800	975	960	1000	985.7142857
2.	2100	2250	2500	2475	2700	2750	2785.714286
3.	4000	4000	4133.333333	4000	4160	4400	4400
4.	3000	4750	5166.666667	5625	5500	5083.333333	5357.142857
5.	3000	3000	3000	3000	radiographs40	3600	4028.571429
6.	7000	7000	7000	7175	7140	7000	7100
7.	25500	24650	22666.66667	22950	23460	22950	21614.28571
8.	34100	34100	35133.33333	37200	37200	37200	38085.71429
9.	45600	45600	46866.66667	47500	45600	46233.33333	47228.57143





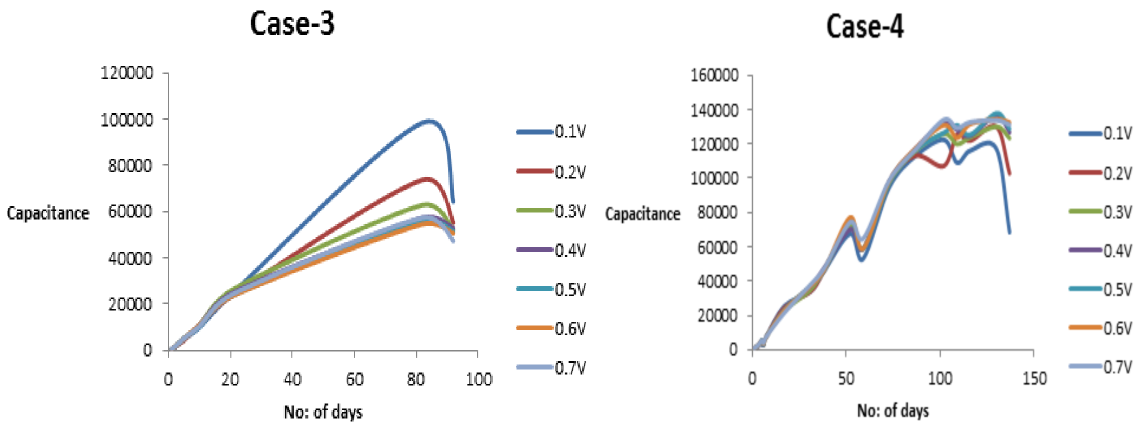


Figure 4:Variation of Capacitance from open loop response of a four tibia fracture patient cases for 0.1 to 0.7V

ANOVA analysis

Hypothesis: All groups of tibia fracture patients under dc electric stimulation exhibit a regular Pattern of Conductance and Capacitance. When ANOVA F factor was obtained whose significance level was within the critical region and 95% confidence level was obtained for Resistance and Capacitance.

Table 4 ANOVA	Single factor for c					
Groups	Count	Sum	Average	Variance		
Group 1	46	12.85939	0.279552	0.0477		
Group 2	46	5.809407	0.126291	0.008263		
Group 3	46	5.866097	0.127524	0.005597		
Group 4	46	1.949425	0.042379	0.000359		
Table5. ANOVA						
Source of Variation	SS	df	MS	Fcritic	P-value	F
Between Groups	1.347167	3	0.449056	29.00943	2.38E-15	2.654792
Within Groups	2.786337	180	0.01548			
Total	4.133504	183				

RESULTS AND DISCUSSION

For case 1 the peak value is reached on the 50th day, then after wards capacitance values deceased. This indicates that the bones united .Afterwards around 65th day capacitance values starts increasing and maintains a constant value. The same trend is repeated for all cases but for want of space we have presented 4 sample cases only. The same aspect was analyzed for all the voltages from 0.1 v to 0.7 Volts and trend projection response is shown in figure 6.It is inferred from the figure 7 that except case 1 all the other case behaved in the same manner. The case 1 is varying in nature due to it presented very early to us and he had debridement and direct application of the ring. The other three cases illustrated presented to us after a time span of at least three months after initial treatment of rod type external fixator. This may be the reason for the different pattern in the fourth case..

CONCLUSION

The variation of capacitance for the range of applied input voltage 0.1 to 0.7V was measured and the data was subjected to ANOVA analysis. From this it is inferred that once the fracture heals the capacitance will decrease. Based on the above work the best optimum value for following the tibia fracture case is 0.1Volt.

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