ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

# Classification of Tibia Fracture Across Limb in Patients Treated Using DC Electric Stimulation Based on Observed Healing Pattern.

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## ABSTRACT

Nowadays, DC electric stimulation is used as an alternate diagnostic tool to predict fracture healing ;by orthopedic surgeons to minimize the number of radiographs . A DC voltage of 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. A regular pattern of conduction characteristics was observed across the tibia fracture site, in this work we classify the fracture into 3 broad categories namely stable, unstable and irregular based on the fracture pattern. The electrical data was recorded across 20 different tibia fracture patients whose fracture type were Grade III Open fracture, Grade I open comminuted fracture, displaced fracture, oblique, transverse,irregular and irregular fracture with gap non unions needing corticotomy. The variation of current for the range of applied input voltage 0.7V was calibrated. The data exhibited common conductance characteristics across patients who had similar type of fracture, clinical manifestation fall history of the injury and reporting time irrespective of variation in bodily status of the individual. From the results the fracture type such as transverse grade III open fracture, were classified into broad category namely stable fractures.;fracture types such as oblique, wedge and Comminuted were classified as unstable; while corticotomy, displaced were classified as irregular. A unique pattern of variation of current in initial period its steep fall at the time of healing and later becoming constant was observed in all cases irrespective of fracture types. Individual fracture types fitting into broad category of fracture classification is also inferred in this work. Various parameters like process gain, time constant are calculated.

**Keywords:** tibia, electric stimulation, limb

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ISSN: 0975-8585

## INTRODUCTION

Bone is complex materials with multiphase, heterogeneous, anisotropic microstructure .There are several methods of testing the bone fracture in various loading conditions. But as opposed to the inert materials, bone being a living tissue and it can repair itself. [1, 2]. This process called the fracture healing is a complicated process taking months to complete the process. The formation of the bridging bone called the callus is the foundation of the above fracture healing process. Various stimuli like thermal, chemical and mechanical stimuli have been linked to stimulate callus formation experimentally like even in the absence of fracture .The pioneer of electric phenomenon of bone is Iwao Yasuda, whose research was centered on the factors that initiated fracture healing.[3] His assumption was that electricity was a common pathway of signaling for callus. In rabbit medulla professor yasuda produced new bone by stimulating with 1-100 micro amp of DC. When DC is applied in the cathodic side there was production of certain factors like hydrogen peroxide and hydroxyl ions. These are implicated in accelerating remodeling of the fractures.[4]

The theory of conduction of the electric charge across an intact and fractured bone depends on its basic molecular structure of calcium hydroxyl apatite crystals linked with collagen. It also follows the stages of changes in conduction as fracture site blood becomes unmineralized matrix and later calcified bone. 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. [5]

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 and need of empirical model to analyze the flow of current is emphasized.[6] Computational algorithms for predicting the structure of cancellous bone provide a simple, but powerful, method for identifying alterations in bone structure [7].A first order system model of fracture healing was explained for animals [8]. A FOPDTZ model for tibia fracture site tissue for monitoring fracture healing was explained in our previous work [9]. The effect of capacitance for a particular voltage was analyzed statistically [10]. In the 20 cases studied with DC electric stimulation, there were different types of fractures which united with both anatomic and non-anatomic bridging when current flow stabilized[11]. We have already analyzed the association between current recorded across the fractured limb and fracture configuration and types of the graphs differed with shape of the fracture and stage of healing.[12]

In the present work we classify the fracture types into stable, unstable and irregular and develop empirical model First Order plus Dead Time with Zero (FOPDTZ) and analyze the model parameter effect on classified fracture types. The regular pattern inferred using the electrical data recorded during various follow-up periods of the fracture is explained for 20 different tibia fracture patients.

## METHODOLOGY

### Fracture Classification

Fractures are classified in to three types for the purpose of experimental study and analysis. Type 1-Stable fracture is one which resists slipping when aligned for healing and also has negligible gap. These fractures can be further sub classified based on angle of fracture as

(i) Transverse/Horizontal fracture with bone loss at edges as shown in figure 1 a.

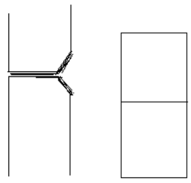


**Figure 1a. Stable horizontal fracture**

(ii) Inclined fracture [short oblique fracture] with angle less than 30 degree and almost no gap.

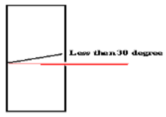



**Figure 1b. Stable inclined fracture**

Type 2-Unstable fracture: There are further sub classified as (i) wedge fracture as in figure 2a (ii) oblique fracture as shown in figure 2b. (iii) Comminuted fracture

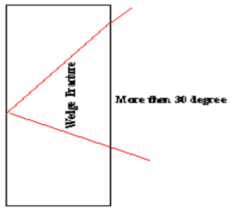



**Figure 2a. Wedge fracture with obliquity**

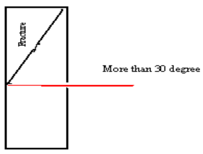



**Figure 2b. Oblique fracture**

Type 3-Irregular fracture with gap is shown in figure 3 and with gaps ranging from 5mm to 5cm

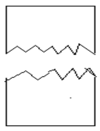


**Figure 3. Irregular fractures with gap**

**Participants involved and Fracture type**

In this study 20 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 detailed description of fracture type is shown in table 1.

**Table 1.Various fracture Types for 20 different patients**

| S.No of cases | Fracture type description |
|---|---|
| 1 | Grade III Open fracture Right Tibia upper third |
| 2 | Wedge comminution with an ununited fracture of left Tibia-with an inter locking nail inside. |
| 3 | Oblique un-united fracture of upper tibia |
| 4 | Open fracture corticotomy |
| 5 | Open fracture corticotomy |
| 6 | Irregular Grade III Open fracture Right Tibia distal third |
| 7 | Irregular Grade III Open fracture left Tibia distal third. |
| 8 | Open fracture oblique fracture of tibia |
| 9 | Open fracture of tibial shaft at middle third |
| 10 | Open fracture displaced upper tibial fracture |

| | |
|---|---|
| 11 | Displaced open fracture of right leg both bones middle third lower third junction with medial side bone loss with infection |
| 12 | Open fracture of right leg both bones middle third lower third junction with infection. His examination revealed a sutured wound over the right lower leg with external fixation. |
| 13 | Grade III Open fracture of upper third of both bones of left leg |
| 14 | Irregular fracture Grade III Open fracture left Tibia upper third of leg |
| 15 | Irregular fracture Grade III Open fracture of left Tibia upper third of leg |
| 16 | Irregular fracture Grade III Open fracture of right tibia lower third |
| 17 | Irregular fracture irregular with comminution<br>Grade III Open fracture of right tibia middle third |
| 18 | Grade I open comminuted fracture of right leg tibia with severe soft tissue contusion. |
| 19 | Displaced fracture of left leg in the middle third and distal third junction |
| 20 | Comminuted fracture of right tibia and fracture of his 5$^{th}$ toe proximal phalanx. |

**Materials Involved**

A Teflon coated carbon Ilizarov external fixator ring fixator is fixed across the tibia fractures in consenting medically fit patients. Carbon ring fixators are stronger, lighter and radiolucent. 5mm diameter threaded rods were used to connect the carbon rings.1.8mm (316L stainless steel) K-wires were used to fix the bone to the carbon rings by wire-fixation bolts. Teflon coated carbon Ilizarov external fixator ring fixator were chosen in this study of electric conduction as there are no conducting material across and the current is recorded across the fracture. These patients were mobilized with partial to full weight bearing in the immediate postoperative period as allowed by their pain tolerance. The wire above the fracture was given a DC voltage up to 1 V and the output was recorded across the fracture in the lower wire. The wires that passes only through the tibia were taken into consideration and those wires that have purchase in fibula were avoided.

**Experimental Setup**

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 fixators.

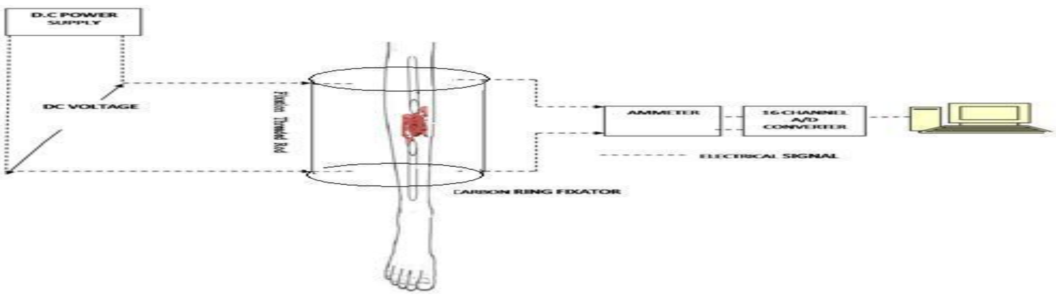
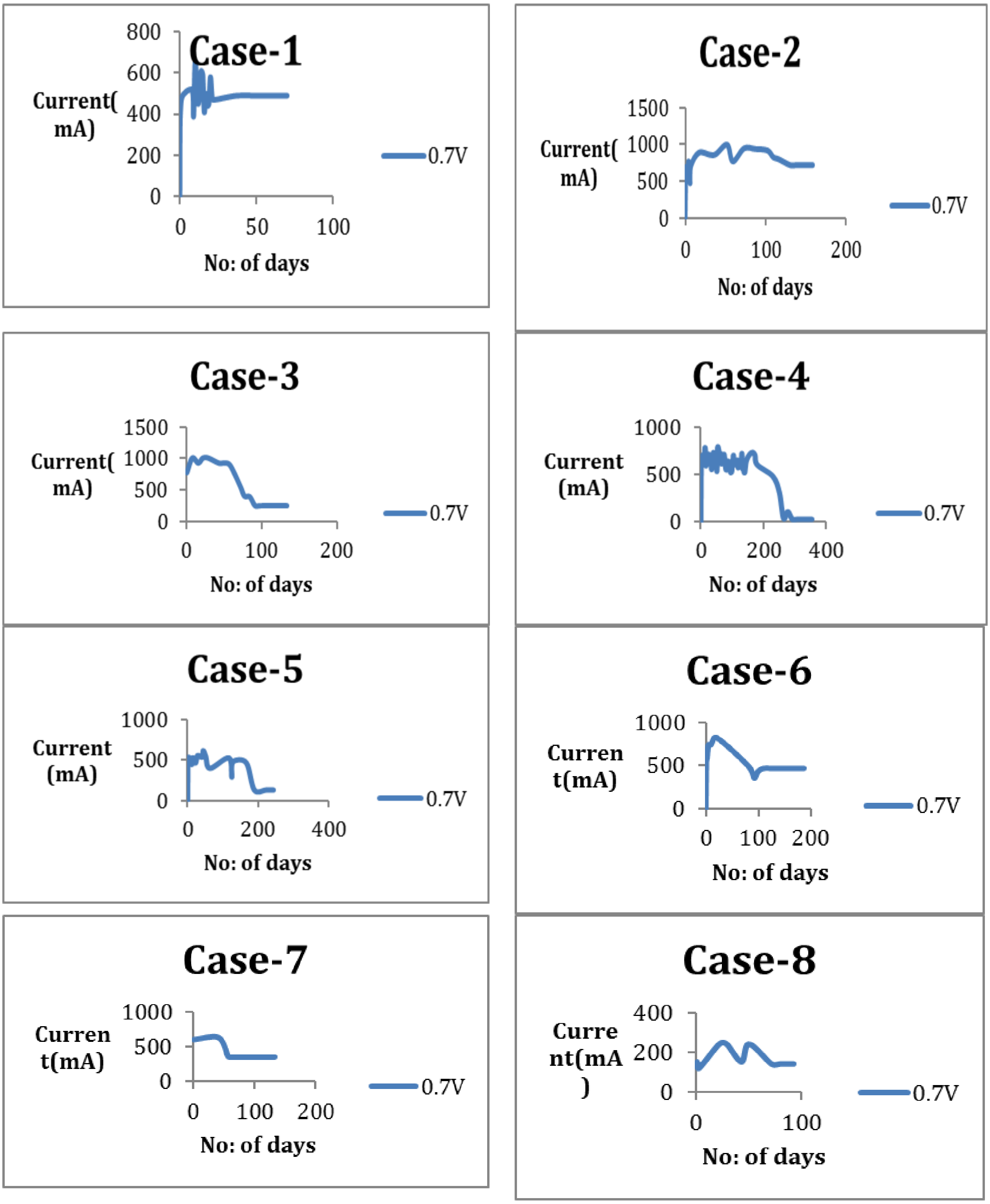


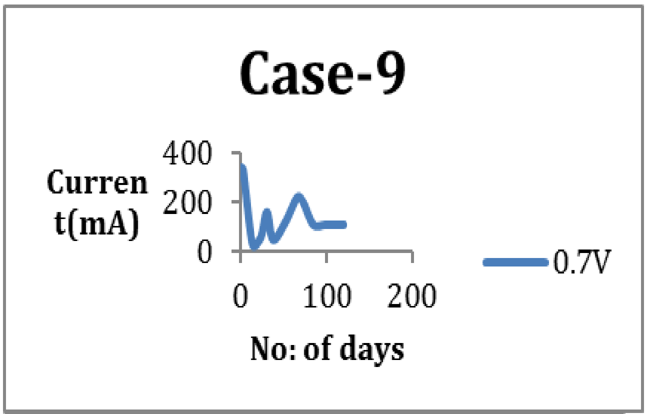

**Figure 2. Experimental set-up for fracture healing model analysis**

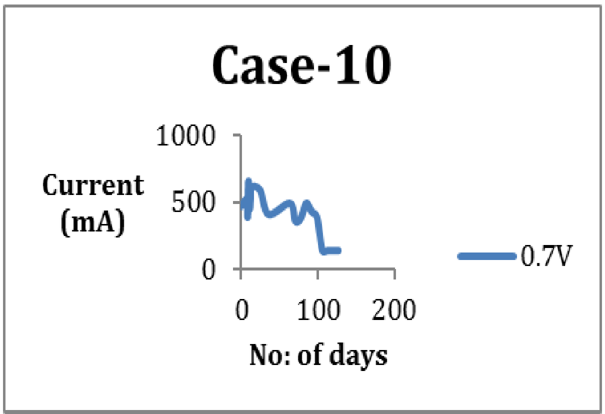
In these cases the healing was followed with clinical assessment and periodical radiographs till the endpoint of fracture union and then the rings were removed. Additionally, all the patients also had application of electrical voltage in the range of 0.1-1.0 V DC in 0.1 V increments, across the two wires 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 wired diagram is published by one of the authors in references [13-16].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

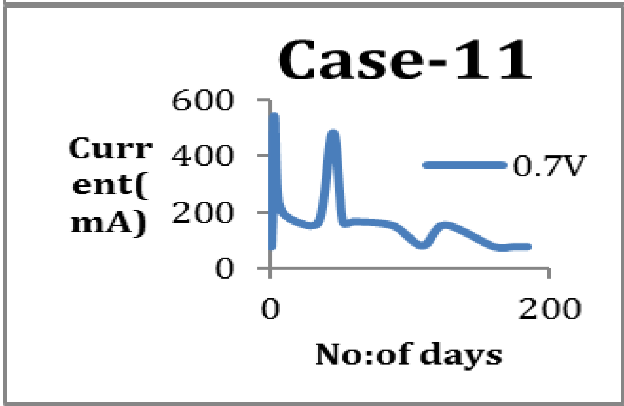
ISSN: 0975-8585

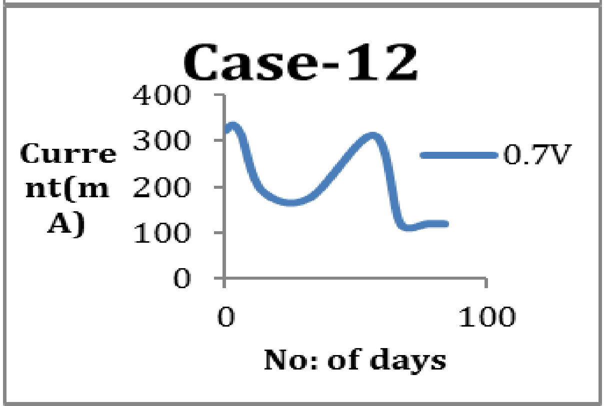
the patient's current rating in terms of mA. The graph was compared with the appearance of new bone formation in X –rays. The above methodology was carried upon twelve different patients at Thanjavur Government Medical College to predict the exact instance at which a fracture has united completely. For all the twelve different patients same fracture healing pattern was obtained. The real time experimental data for four tibia fracture patients is shown in Figure 4.

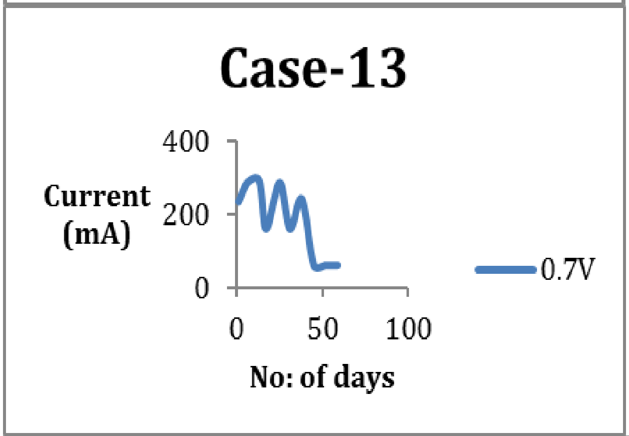


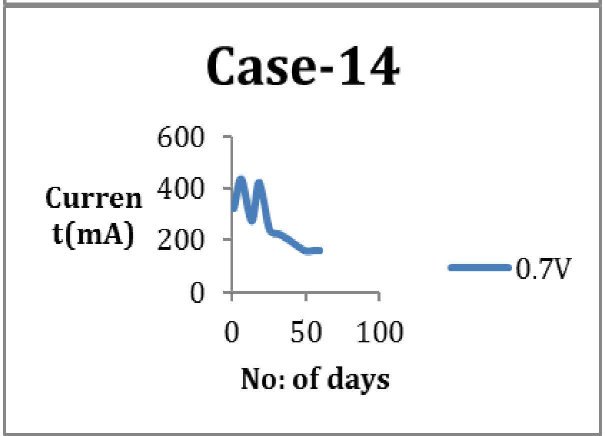

Case-9
Curren t(mA)
400
200
0
0
100
200
No: of days
0.7V

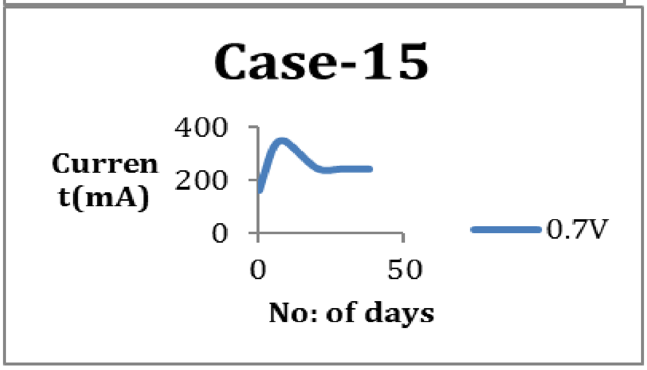

Case-10
Current (mA)
1000
500
0
0
100
200
No: of days
0.7V

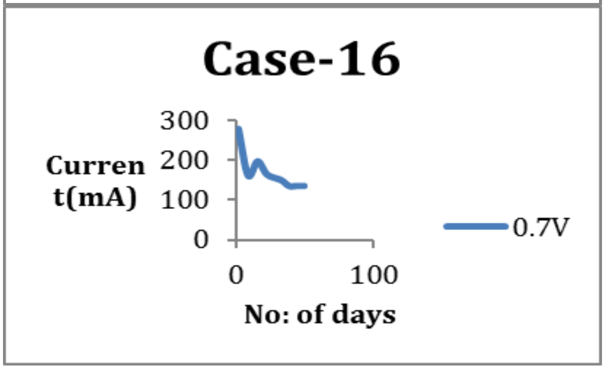

Case-11
Curr ent( mA)
600
400
200
0
0
200
No:of days
0.7V


Case-12
Curre nt(m A)
400
300
200
100
0
0
100
No: of days
0.7V


Case-13
Current (mA)
400
200
0
0
50
100
No: of days
0.7V


Case-14
Curren t(mA)
600
400
200
0
0
50
100
No: of days
0.7V


Case-15
Curren t(mA)
400
200
0
0
50
No: of days
0.7V


Case-16
Curren t(mA)
300
200
100
0
0
100
No: of days
0.7V

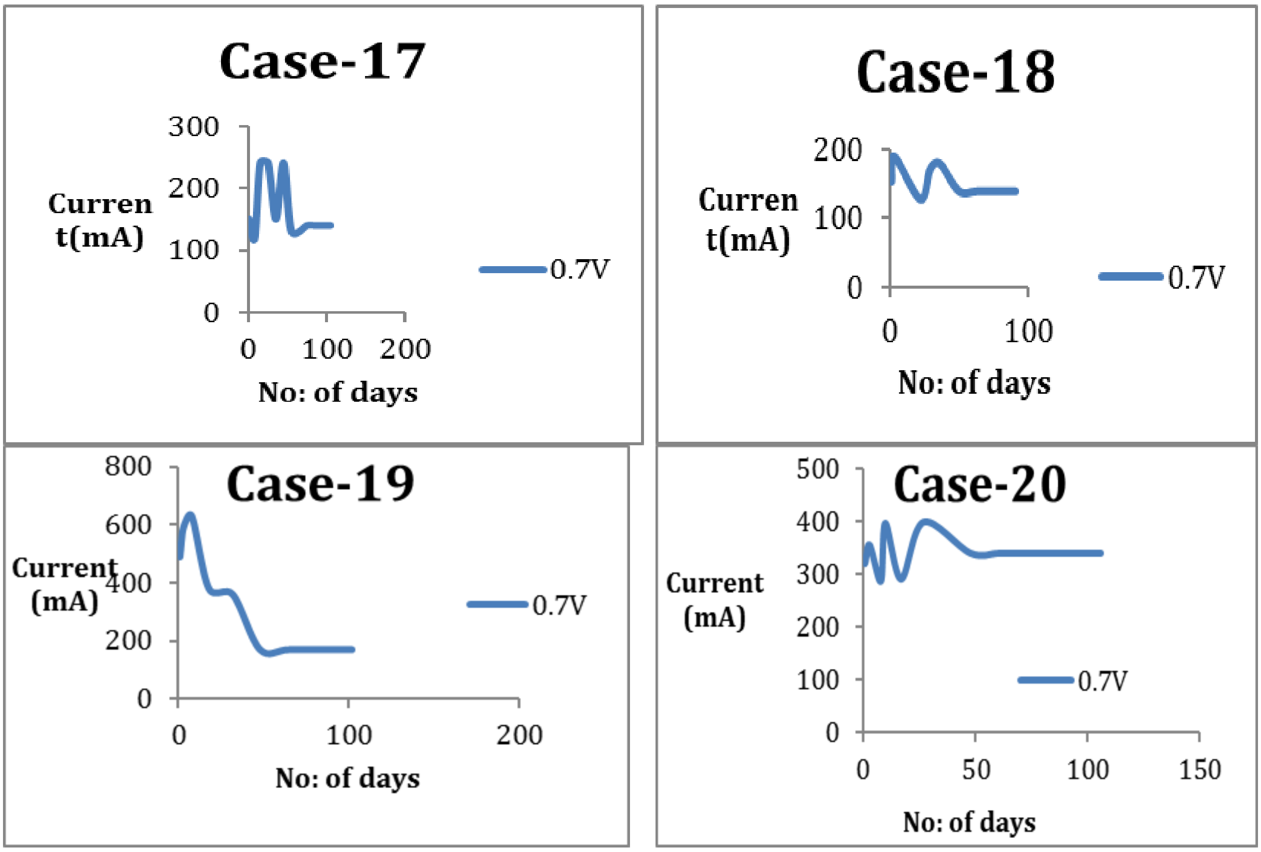
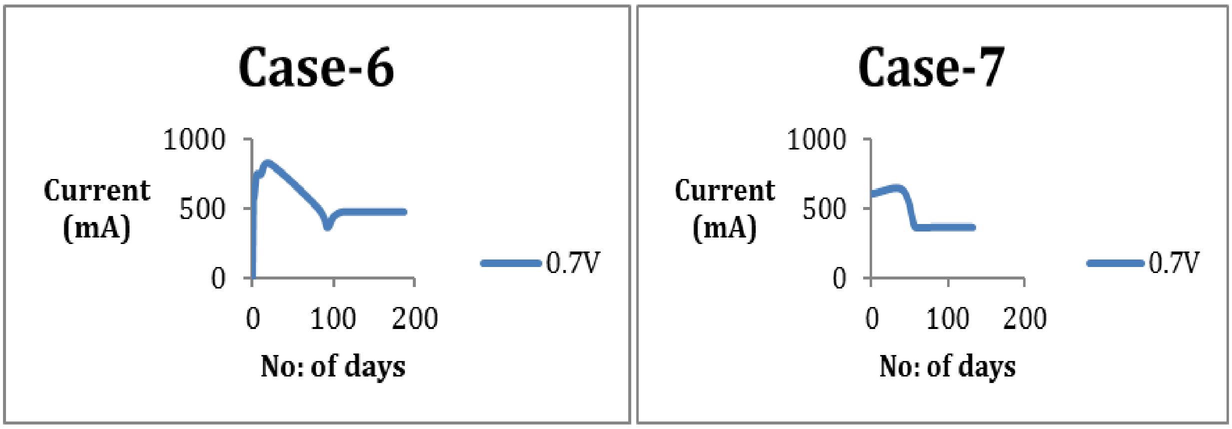



**Figure 4. Experimental data collected from open loop response of a 20 tibia fracture patient cases.**

## FRACTURE CATEGORIZATION

For 20 patients during DC electric stimulation was applied during the follow up period and the current was calibrated. The variation of current for the step change in input voltage for various recording intervals was plotted and conduction behavior was studied. The 20 patients were classified into 3 major fracture types based on the observed pattern of conduction. The conduction responses classification based on types namely type 1, type 2 and type 3 are shown in the figure 5, 6 and 7 respectively. The healing indication in days for various fracture type is indicated in the table 2.



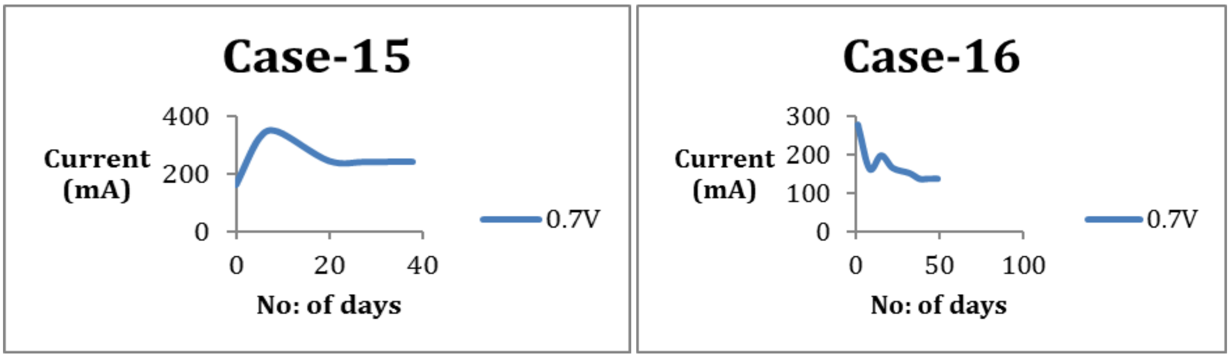



Figure 5. Conduction responses of Type1 stable fracture.

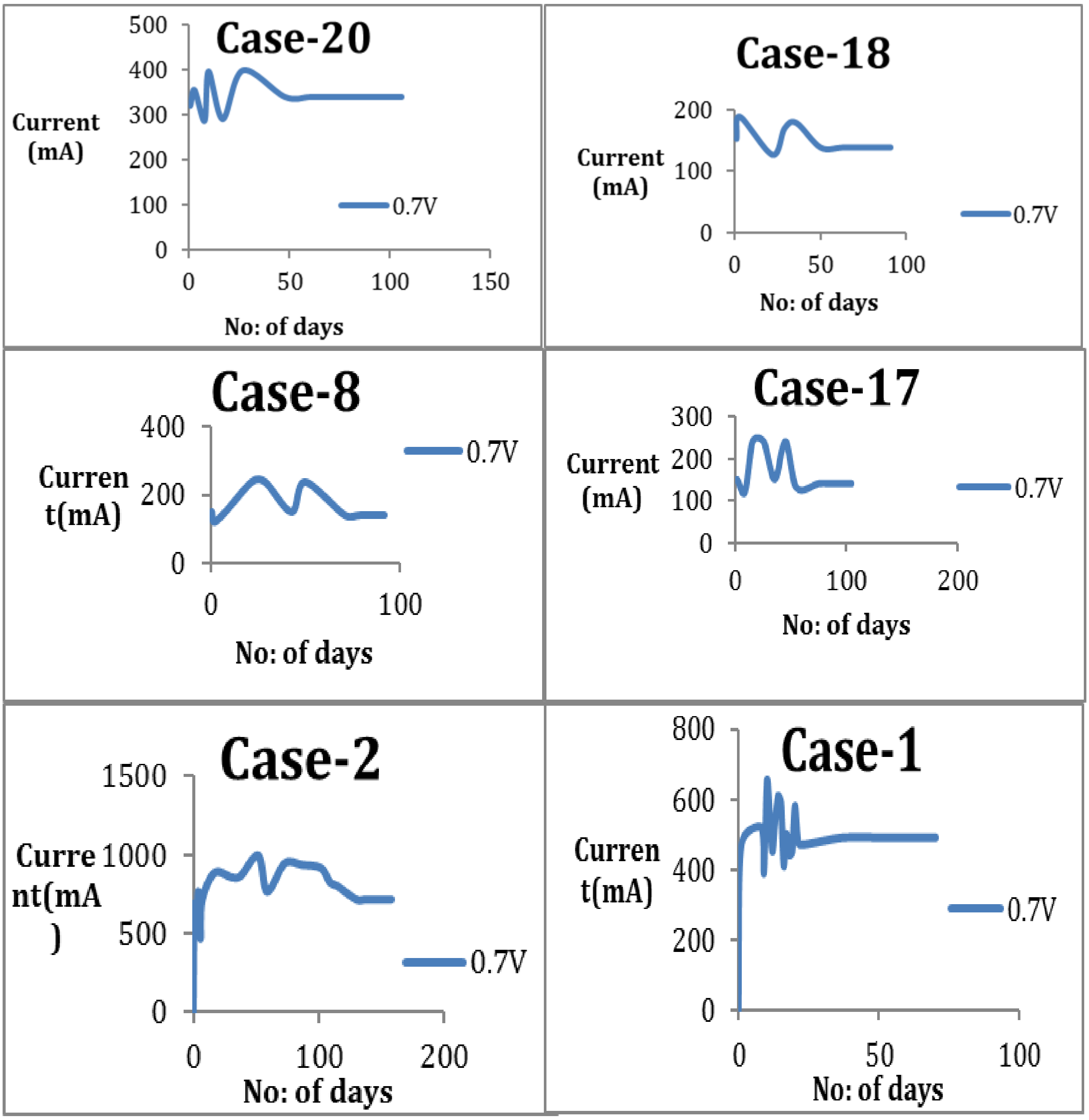
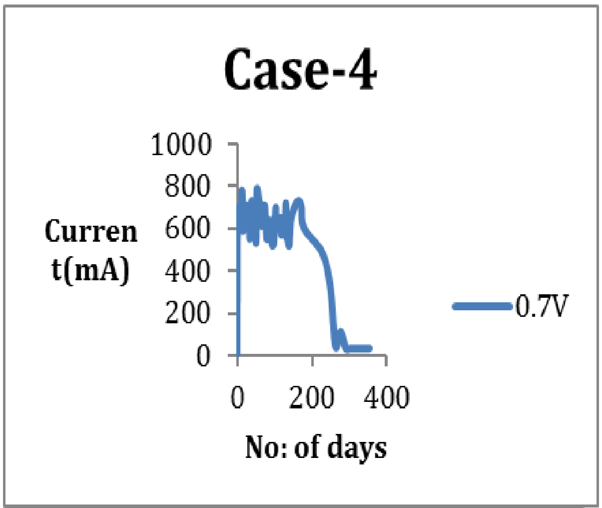
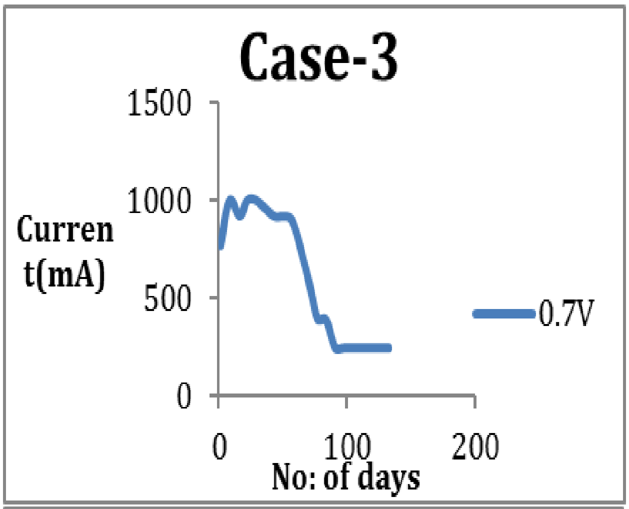
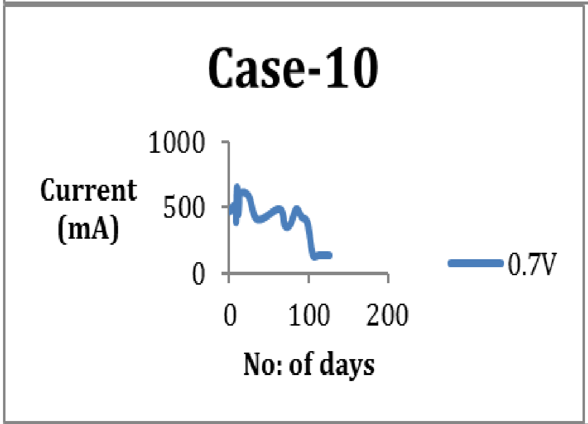
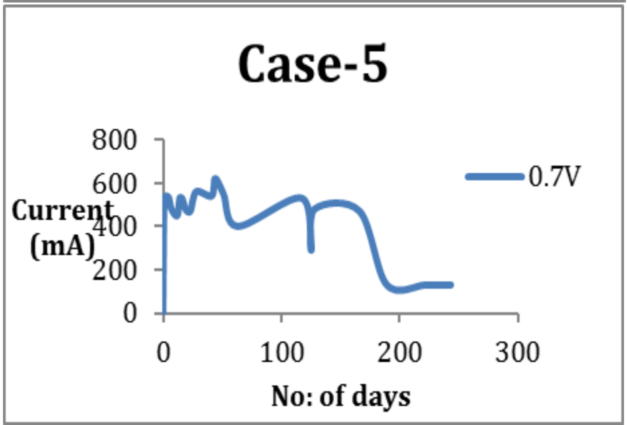


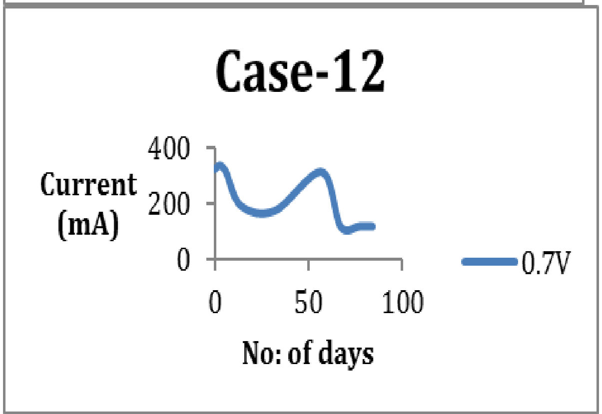

Figure 6. Conduction responses of Type2 unstable fracture.

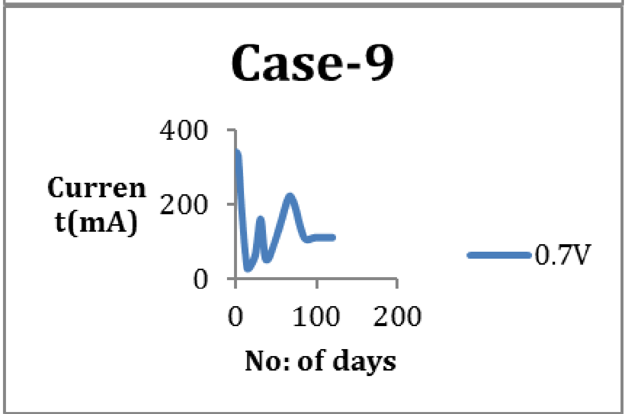

Case-4
Curren t(mA)
1000
800
600
400
200
0
0
200
400
No: of days
0.7V

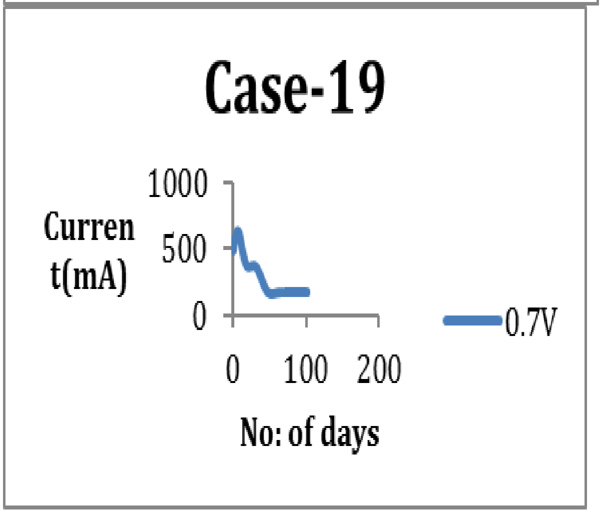

Case-3
Curren t(mA)
1500
1000
500
0
0
100
200
No: of days
0.7V

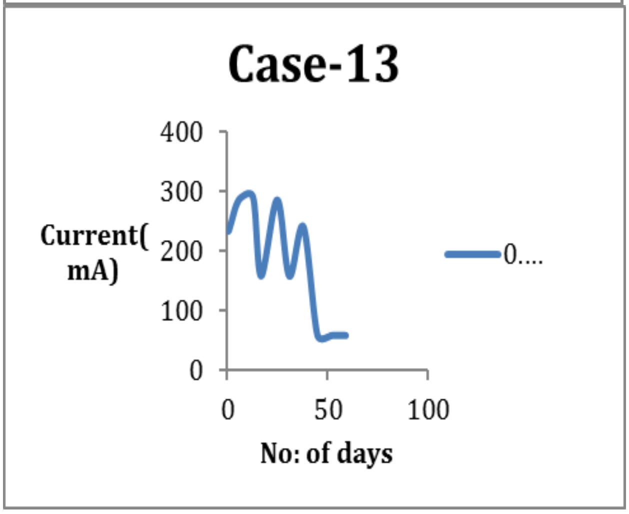

Case-10
Current (mA)
1000
500
0
0
100
200
No: of days
0.7V

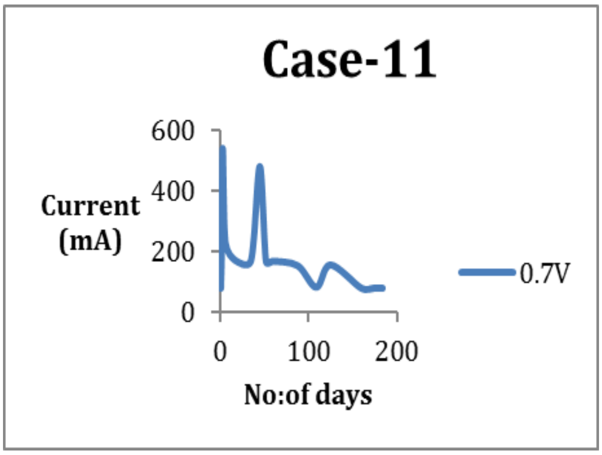

Case-5
Current (mA)
800
600
400
200
0
0
100
200
300
No: of days
0.7V


Case-12
Current (mA)
400
200
0
0
50
100
No: of days
0.7V


Case-9
Curren t(mA)
400
200
0
0
100
200
No: of days
0.7V


Case-19
Curren t(mA)
1000
500
0
0
100
200
No: of days
0.7V


Case-13
Current( mA)
400
300
200
100
0
0
50
100
No: of days
0....



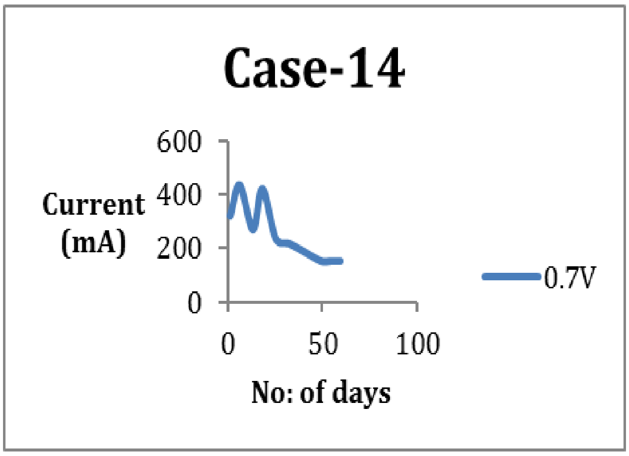




**Figure 7. Conduction responses of Type3 irregular fracture.**

**Table 2. Fracture healing indication in days for various fracture type**

| S.No | Type | Case | Experimental Output (Healing Indication) in days |
|---|---|---|---|
| 1. | 1 | case-6 | 92 |
| 2. | | case-7 | 56 |
| 3. | | case-15 | 28 |
| 4. | | case-16 | 38 |
| 5. | 2 | case-2 | 151 |
| 6. | | case-1 | 48 |
| 7. | | case-8 | 79 |
| 8. | | case-18 | 50 |
| 9. | | case-20 | 91 |
| 10. | 3 | case-3 | 292 |
| 11. | | case-4 | 189 |
| 12. | | case-5 | 106 |
| 13. | | case-9 | 160 |
| 14. | | case-10 | 67 |
| 15. | | case-11 | 85 |
| 16. | | case-12 | 37 |
| 17. | | case-13 | 48 |
| 18. | | case-14 | 75 |
| 19. | | case-17 | 45 |
| 20. | | case-19 | 49 |

## FIRST ORDER PLUS DEAD TIME WITH ZERO (FOPDTZ) MODEL

As explained already in our previous work[9], from the electrical data obtained, empirical model First order Plus dead time with Zero(FOPDTZ) its general structure as shown in equation(1) was developed.

$$G(s) = \frac{K_p(1+\tau_z s)e^{-\tau_d(s)}}{(1+\tau s)} \quad (1).$$

The effects of patients' factors on the values of parameters in the FOPDTZ model are described as follows. The various model parameters are process gain $K_p$, time constant (τ), and time delay ($\tau_d$). Here the time constant (τ) indicates the fracture gap. The parameter time delay $\tau_d$ indicates that fracture healing does depend on time to repair by itself. Model Estimation Algorithm using Prediction Error Method in Matlab7.4 with system identification toolbox was written to estimate the FOPDTZ process model with one pole, one zero, gain and time delay. The model obtained for fractures of type namely type1, type2 and type 3 is shown in table3.

**Table 3. FOPDTZ model for various fracture type.**

| S.No | Type | Case | Model | Model Parameters | | | |
|---|---|---|---|---|---|---|---|
| | | | | $K_p$ | τ | $\tau_d$ | $\tau_z$ |
| 1. | Type-1 | Case-6 | $\frac{23.3(1+2.24e^6 s)e^{-30s}}{1+26.3s}$ | 23.3 | 26.3 | 30 | $2.24e^6$ |
| 2. | Type-1 | Case-7 | $\frac{7.9(1+9.4331e^6 s)e^{-30s}}{1+4.5s}$ | 7.9 | 4.5 | 30 | $9.4331e^6$ |
| 3. | Type-1 | Case-15 | $\frac{5.14e^5(1-2321s)e^{-30s}}{1+0.001s}$ | $5.14e^5$ | 0.001 | 30 | -2321 |
| 4. | Type-1 | Case-16 | $\frac{4991(1+4874.3s)e^{-30s}}{1+5666.8s}$ | 4991 | 5666.8 | 30 | 4874.3 |
| 5. | Type-2 | Case-2 | $\frac{-74(1+7.746e^6 s)e^{-30s}}{1+113.8s}$ | -74 | 113.81 | 30 | $7.746e^6$ |
| 6. | Type-2 | Case-3 | $\frac{-14.6(1+6.186e^6 s)e^{-30s}}{1+6.85s}$ | -14.6 | 6.85 | 30 | $6.186e^6$ |
| 7. | Type-2 | Case-8 | $\frac{-56(1+5673s)e^{-30s}}{1+6.5s}$ | -56 | 6.5 | 30 | 5673 |
| 8. | Type-2 | Case-18 | $\frac{-9599.5(1+9923s)e^{-30s}}{1+165940s}$ | -9599.5 | 165940 | 30 | 9923 |
| 9. | Type-2 | Case-20 | $\frac{-74(1+7.746e^6 s)e^{-30s}}{1+113.8s}$ | -339 | 74232 | 30 | 2156.6 |
| 10. | Type-3 | Case-1 | $\frac{14294(1+1.65e^5 s)e^{-30s}}{1+79127s}$ | 14294 | 79127 | 30 | $1.65e^5$ |
| 11. | Type-3 | Case-4 | $\frac{16578(1+1.85e^5 s)e^{-30s}}{1+45787s}$ | 16578 | 45787 | 30 | $1.85e^5$ |
| 12. | Type-3 | Case-5 | $\frac{1.51e^6(1+3.24e^5 s)e^{-30s}}{1+1.5e^8 s}$ | $1.51e^6$ | $1.5e^8$ | 30 | $3.24e^5$ |
| 13. | Type-3 | Case-9 | $\frac{0.049(1-2.4e^5 s)e^{-30s}}{1+0.51s}$ | 0.049 | 0.51 | 30 | $-2.4e^5$ |
| 14. | Type-3 | Case-10 | $\frac{5.58e^5(1+2.24e^7 s)e^{-30s}}{1+1.13e^7 s}$ | $5.58e^5$ | $1.13e^7$ | 30 | $2.24e^7$ |
| 15. | Type-3 | Case-11 | $\frac{-1.8(1+107.8e^6 s)e^{-30s}}{1+10.11s}$ | -1.8 | 10.11 | 30 | $107.8e^6$ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 16. | Type-3 | Case-12 | $\frac{-0.91(1+55.6e^{6}s)e^{-30s}}{1+3.5s}$ | -0.91 | 3.5 | 30 | $55.6e^{6}$ |
| 17. | Type-3 | Case-13 | $\frac{-10.8(1+6.625e^{5}s)e^{-30s}}{1+10.43s}$ | -10.8 | 10.4 | 30 | $6.625e^{5}$ |
| 18. | Type-3 | Case-14 | $\frac{-37034(1+27346s)e^{-30s}}{1+0.001s}$ | -37034 | 0.001 | 30 | 27346 |
| 19. | Type-3 | Case-17 | $\frac{-91.27(1+2.61e^{5}s)e^{-30s}}{1+0.001s}$ | -91.273 | 0.001 | 30 | $2.61e^{5}$ |
| 20. | Type-3 | Case-19 | $\frac{-36.55(1+2.8e^{7}s)e^{-30s}}{1+7.9s}$ | 36.55 | 7.9 | 30 | $2.8e^{7}$ |

## RESULTS AND DISCUSSION

Various fractures were classified into three broad categories namely type1,type2 and type 3.From figure 6 it is observed that in conduction pattern of type 1 fracture(case-6, case-7 , case-15) there is no much irregularity and current flow is stable. Moreover from table 3 the FOPDTZ model parameters such as time constant is low for type 1 fracture namely 26.3, 4.5, 0.001 indicating fracture has completely healed while for case-16 it is 5666.8 indicates that fracture gap still exist.

From figure 7 for type 2 facture there is few irregularity present in the conduction pattern before it stabilizes. Moreover from table 3 the FOPDTZ model parameters such as time constant is low for type 2 fracture(case-2, case-3 , case-8) namely 113.81, 6.85, 6.5 indicating fracture has completely healed while for case-18 and case-20 it is 165940 and 74232 indicates that fracture gap still exist.

From figure 8 for type 3 facture there is enormous irregularity present in the conduction pattern before it stabilizes.

Current flow varying irregularly in initial period and stabilizing at the healing stage is observed in all types of fracture.

## CONCLUSION

The variation of conductance for the range of applied step input voltage 0.7V was measured. The response was plotted and fracture cases which showed similar pattern were grouped into 3 types namely stable, unstable and irregular. It is inferred from the pattern that once the fracture heals the current will decrease and stabilize later. The inference was validated with radiographs. In future, this pattern classification will help in predicting the number of visits the patients has to make i.e. the number of recording intervals needed for the fracture to heal completely.

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