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Identification Of Time Constant For Healing Process Of Limb With Fractured Tibia Bone Using Step Response Techniques.

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ABSTRACT

In recent times fracture healing using electric stimulation is tred as a a tool to track fracture healing. For good assessment of fracture healing variables such as voltage, current, and time should be monitored, measured and controlled. These control implementations are accomplished via regulation of applied voltage to the patient. This paper presents identification of time constant of fractured limb using step response method. An open loop test was conducted and model parameters were determined. From the model parameters the time constant is identified.It varied between individual cases due to multiple factors like the age of the patient, the presenting time type of primary surgery and severity of injury.
Keywords: FOPDZ, voltage, tibia, current, anova

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INTRODUCTION

Biological systems are complex to manipulate the system to our advantage in health care one must understand it . This is the main aims before any system is handled i.e, manipulated or controlled. [1]

Finding a mathematical model of a real system will help predicting the performance of that system under different operating conditions. This will also be useful in designing controllers that will make the system perform in a desired manner. Identification of system parameters from observed input and output data is a key issue in mathematical modeling. Even if model is derived from basic physical laws, it often contains a number of unknown parameters which have to be estimated.

Another way of constructing models, which differ from the modeling based on physical insight, is system identification. In this method by means of experimental tests, one can identify the dynamic nature of processes and from the results obtain a process model, which can be used in designing control systems. A more basic approach is to formulate mass and energy balances for different components, resulting in a set of linear ordinary differential equations and taking Laplace transform for this equation and finally it is rewritten as a transfer function model in the case of single input single output system.

The main problem with theoretical models is that they are time consuming , making it is very difficult to write mass energy balance equation for big and complicated process. Even if the cost of developing a theoretical model can be met, it can often be inaccurate and all human process are highly non linear and time varying in nature. So experimental models are often a more realistic option. Mathematical model is difficult due to the complex nature of chemical processes. Hence, system identification is a valuable tool to identify lower order models, based on input–output data.

For unstable process using step response technique [2] experimental identification of a FOPDT model and comparison of the identified parameter with simulated model parameter was done . A higher order dynamics system is also identified by a FOPDT and SOPDT model, the conventional method identifies a negative time constant. [2]

In order to identify all the three parameters of a first order plus time delay (FOPDT) model and four parameters of second order plus dead time model using a single symmetric relay feedback test. further an improved auto tune identification method introduced with neglecting the error in higher order dynamics system output.[3] There have been experimental identification of open loop and closed loop FOPDT and SOPDT model for plate heat exchanger and the response were studied using simulated data. [4]

An identification algorithm is designed for continuous time delay signal under unknown initial conditions using step response and the obtained model best correlated with theoretical model and complexity problem in experimental data . Further a technique for analyzing the model complexity. is also designed .[5,6]

Model identification methods for transportation lag process are classified into time domain and frequency domain techniques- either offline or online. The online estimation requires a recursive estimation in a closed loop environment. [7,8] However most real life process are non linear to varying extents. Since non linearity can be of various types and varying times and also since the data may not be sufficient or adequately informative, both structure selection and parameter estimation for a real life non linear process is complex.. Recent advances in model based control systems necessitate the development of non linear mathematical models. One method commonly used for developing non linear models involves physical modeling of the system from the first principles of physical and chemistry.

Thus only meagre attention has been received for modeling using electrical stimulation and current as a measured variable for tibia fractured bone limb case. The development of suitable controller for fracture healing prediction using electric stimulation process have not been studied at all. Also the effect of conductance and capacitance and resistance on model parameters has not been fully investigated . Few recent studies have used electric stimulation in the diagnostic side to monitor fracture healing [9-11] where authors have looked upon the current stabilization alone. When the current has stabilized, with the help of radiographs , they were able to confirm that the fracture has healed. To simplify the fracture healing process, models have been proposed to relate all possible data and observation to understand this process better. Some authors have proposed a first order system which has been tested and validated only on animals. [12.] Recently a FOPDTZ model was arrived for the tibia fracture [13].

According to electronic and engineering control theory, a step response can be considered as the time behavior of the outputs of a circuit, when its input is altered from zero to one in a very short time.The present work aims at identification of tibia fracture model using K.R.Sundaresan and R.R.Krishnaswamy technique[1] and to obtain a time constant for the different tibia bone fractures.

MATERIAL AND METHODS

This work was conducted in the Thanjavur Medical College hospital . The experimental set-up for fracture healing prediction analysis is shown in Figure 1.Initial arrangement for the process is explained is similar to our earlier works [13] where Teflon coated- carbon ring fixator is used to stabilize the tibia fracture, using K-wires. the conduction in the apparatus is minimized as no conducting materials is there across the fractured limb. The current is recorded across the fracture by the K-wire that act as a electrode for the study. Power supply is from VI Micro systems ® which works with an input of 230 volts AC, this is converted into 15V DC .in this study we used a range of 0.1 to 1Volts.

During the DC application, voltage level of the voltmeter at the fracture input side was fixed at 0.1Volts. A step change in voltage level from 0.1 volts to 0.2volts was introduced and a change in response was recorded.The same procedure was done again for other voltages. The tibia fractured limb model parameters was determined experimentally by an open loop step response method.

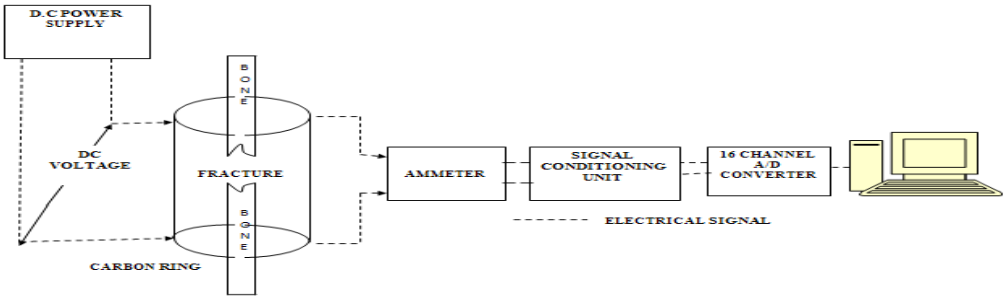

Figure 1. Experimental setup for fracture healing prediction analysis.

Details of individual cases

Case 1 is a 65 year old male asthmatic who presented on the day of injury as a fresh injury with an open fracture of upper tibia.His details are provided in table 1. His wound was debrided and a above knee plaster was applied. later he had Ilizarov external fixation apparatus application afte a delay of 20 days. He had DC electric voltage of 0.1 to 1.0V was applied daily and the output recorded. his output current stabilized on the 37th day of application of the fixator. his rings were removed on the 70th day. on a long follow up of 52 months he had no refractures.

Table 1. Details of patient 1

Blood pressure in Hg	Blood Sugar in mg/dl	Blood Urea in mg/dl	Serum Creatinine in mg/dl	Bleeding time in minutes	Clotting time in minutes	Hameoglobin in gm%
140/86	80	30	0.8	1.36	5.00	10

Case 2 is a 37 year old male non diabetic non smoker who presented six months after injury and the initial procedure of external fixator application. This was later converted to internal fixation in the form of intramedullry nailing. When this got infected he presented only later to our institute when the nail needed to be removed. The details of this patient is provided in table 2.The Ilizarov fixator was applied. and the electrical voltage was applied and output was recorded. the current output stabilized on 137th day .The rings were removed on the 158th day.

Table 2. Details of patient 2

Blood pressure in Hg	Blood Sugar in mg/dl	Blood Urea in mg/dl	Serum Creatinine in mg/dl	Bleeding time in minutes	Clotting time in minutes	Hameoglobin in gm%
120/80	76	25	0.7	1.26	4.14	10.5

Case 3 is a diabetic man of 55 years. He had an open injury to the middle third of both bones of the leg.. His details can be seen from table 3.He initially had an external fixator application to stabilize the fracture and later had a split thickness skin grafting. This was folloJwed by application of Ilizarov ring fixator two months after the trauma. This was followed by the diagnostic electric stimulation across the site of fracture and also was followed by serial radiographs. His current output was stabilized on 91st day. His rings were removed on the 134th day.

Table 3.Details of patient 3

Blood pressure in Hg	Blood Sugar in mg/dl	Blood Urea in mg/dl	Serum Creatinine in mg/dl	Bleeding time in minutes	Clotting time in minutes	Hameoglobin in gm%
120/80	130	24	0.8	1.30	4.00	10.6

Case 4 is a young man , a mechanic of 25 years . He met with a vehicular accident .in which his right tibia was fractured in its middle third and lower third junction and a segment of bone was lost at the site of the injury His details can be seen from table 4.He initially had debridement and an external fixator application to stabilize the fracture. He also had a myocutaneous flap to cover the gap . This was followed by an Ilizarov ring fixator application and corticotomy for internal bone transport. Diagnostic electric stimulation across the site of fracture was done along with serial radiographs. The current stabilized only on the 292nd day which correlated with the radiographs. The rings were removed on the 355th day.

Table 4.Details of patient 4

Blood pressure in Hg	Blood Sugar in mg/dl	Blood Urea in mg/dl	Serum Creatinine in mg/dl	Bleeding time in minutes	Clotting time in minutes	Hameoglobin in gm%
120/80	80	25	0.8	1.20	4.10	10.0

The experimental response for tibia fracture cases for a given input voltage is given in the following figure 2. This figure shows response for 0.7 V D.C input. for the second patient . The asymptote of current flow occurred on the 137th day showing a delay in new bone formation and healing due to severe violence that caused the fracture , the spread of infection throughout the medulla of the bone due to nailing done along the inside marrow of the bone. This stabilization on the 137th day correlated with the clinical and radiological union as seen from figure 3.and the rings were removed after 158th days. The complete healing of this fracture is seen from figure 4.

Time constant Identification

The experimental results are shown in Figure 5.The data in figure 5 was fitted to a first order plus dead time Zero model (FOPDZ) given in Eq.(1)

The experimental and calculated values for the model are shown in Figure. 5. The model parameters was calculated for 4 patient presenting at the time for all the 4 case model parameters are calculated and listed in the table 6.

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

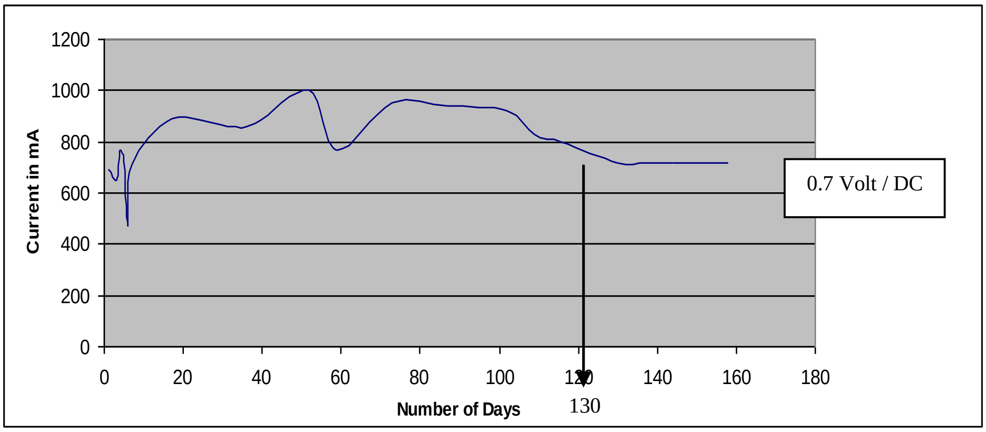

Figure 2. Current variations with time for case 2.the stabilization of cuent started in the 130th day.

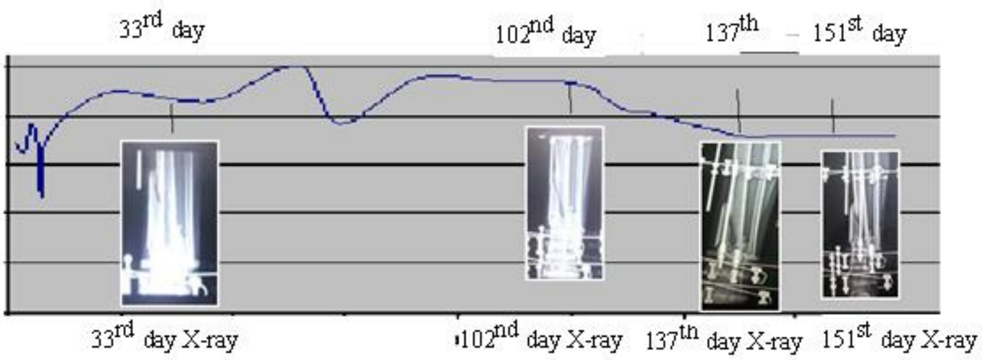

Figure 3. Progressive radiographs with time for case 2.

Figure 4 .Radiographs of the above patient after removal of fixator

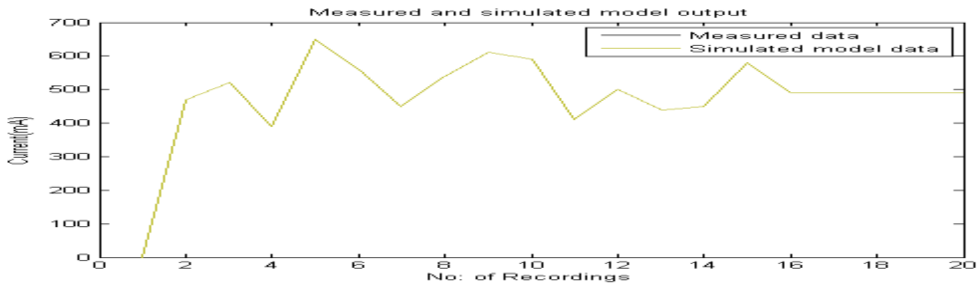

Figure 5. Experimental and calculated response for tibia fracture case for input voltage

Table 6. Model parameter for the tibia fractured limb case

S.No	Patient	Process Model	Order	Pole	Zero	Model Parameters					APE (%)
						K_p	τ	τ_1	τ_2	τ_d	
1.	Case-1	$\frac{-30e^{-8.69s}}{0.12s+1}$	First	1	0	-30	**0.12**	0	0	8.69	7.63
2.		$\frac{-3233.3(1-244.8s)e^{-30s}}{1+13846s}$	First	1	1	-3233	**.13846**	0	0	30	0
3.		$\frac{19.5(1-4.5s)}{(1+63.9s)(1+4.5s)(1+4s)}$	Third	3	1	19.5	**63.9**	4.5	4	0	0.10
4.	Case-2	$\frac{280}{(1+0.3636s)}$	First	1	0	280	**0.3636**	0	0	0	6
5.		$\frac{-2868(1+6e^{5}s)e^{-29s}}{1+0.003s}$	First	1	1	-2868	**0.003**	0	0	29	0
6.	Case-3	$\frac{230}{0.33s+1}$	First	1	0	230	**033**	0	0	0	25
7.		$\frac{-3.8e^{12}(1+4.2e^{8})e^{-30s}}{(1+16.4s)}$	First	1	1	$-3.8e^{12}$	**16.4**	0	0	-30	0
8.	Case4	$\frac{-560e^{-14.1s}}{4.308s+1}$	First	1	0	-560	**4.3**	0	0	0	8
9.		$\frac{-5.8e^{6}(1+2.6)e^{-30s}}{(1+17e^{6}s)}$	First	1	1	$-5.8e^{6}$	$17e^{6}$	0	0	30	0.2

RESULT AND DISCUSSIONS

Table 5 shows the calculation of time constant in all four cases. The time constant for the cases were 0.13846, 0.003, 16.4 and $17e^{6}$ The early presentation of case 1 may be the reason of changes showing early healing in the model for which the τ =0.13846**.** The time delay of 158 days in the second case may be due to very late presentation , the shape of fracture a wedge non union with intramedullary invasion of infection along with fracture in lower third of the tibia for which the τ =0.003. The time delay of 91 days in case three may be due to relatively late presentation , the site of fracture in the lower third of the tibia and the diabetic status of the individual for which the τ =16.4 For the fourth case the delay of 292 days in stabilizing of the current is due to the continous movement of the transporting segment during the treatment period for which the $\tau = 17e^6$.

CONCLUSION

In this work, model for tibia fracture was identified using Sunderson Krishnasamy (SK) algorithm. Time constant for the tibia bone under different case were obtained and results analysed. The multiple factors like time of presentation of individual patient after the fracture,the age of the individual patient,severity of the injury will decide the time of union of individual patient.

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