Design of a scalpel clamp for viscoelastic properties assessment in soft brain tissues

K N Silva¹, C R Torres SanMiguel¹, F Jimenez Ponce², G M Urriolagoitia Calderón¹
¹Instituto Politécnico Nacional, Escuela Superior de Ingeniería Mecánica y Eléctrica, Unidad Zacatenco, SEPI, 07738, Ciudad de México.
²Instituto de Seguridad y Servicios Sociales para los Trabajadores del Estado. Av. San Fernando No. 547, 1er Piso, Col. Toriello Guerra, Tlalpan, 01405, Ciudad de México.

E-mail: ctorchress@ipn.mx

Abstract. Parkinson’s disease (PD) is the second most common chronic degenerative brain disorder in the world preceded by Alzheimer’s disease, affecting one in every hundred people over sixty worldwide. This research shows the evaluation of hydrolyzed collagen specimens that emulate the viscoelastic properties of brain tissue. Also, an electromechanical clamp-type device is proposed for data acquisition as well as a graphic interface that displays samples values.

1. Introduction

The importance of the study of the viscoelastic properties of the brain lies in the knowledge of the current diagnosis of healthy and damaged tissue, and subsequently the establishment of physical parameters for comparison and validation of numerical models. This model can originate an innovative technique for brain diagnosis. Research on the mechanical properties of the brain [1] has been conducted for more than 30 years, mainly to prevent traumatic injuries, e.g., car accidents, and brain structural failures [2]. One of the fastest-growing fields of research since the 1970’s is the study of the viscoelastic properties of brain tissue. In previous research [3-4] have proposed models of viscoelasticity of this tissue, the most widely accepted model being the Maxwell and Kelvin model. Research in animals and humans (in vivo and ex vivo) have been conducted experimentally using magnetic resonance imaging and mechanical devices called indenters. For this reason, there is a large amount of information available in the open literature on the mechanical properties of brain tissue [5-7]. The investigation is still ongoing because of a lack of information on deep structures within the brain, such as the subthalamic nucleus, basal ganglia, among others, to ensure that measurements have an appropriate outcome. The numerical models do not have experimental validation. Also, the question arises as to whether the mathematical models present a biofidelity close to that of a living specimen. Experimental techniques are necessary even if the mathematical model is very accurate and the computer equipment used is of high performance. There are instruments capable of measuring the mechanical properties of the brain tissue, but they do not get deep structures, so it is necessary to know the mechanical and viscoelastic properties of the brain tissue from the design of clamp instrumented. For this reason, the present work shows the design of a tweezer device based on a surgical clamp,
which has the capacity to obtain the viscoelastic properties of the brain from post-mortem humans. In the methodology, the CAD-CAE design of the scalpel clamp is described. Also, electronic circuits and programming are defined. The results show the experimental evaluation of the viscoelastic properties found in hydrolyzed collagen specimens.

2. Materials and Methods
The methodology proposed for the design can be seen in Figure 1. This methodology considers the design of the electromechanical clamp-type device, the control, and acquisition of data; also, a numerical algorithm in a computer program for the processing and analysis of information.

Figure 1. Clamp design methodology for measuring viscoelastic properties

2.1. Electromechanical device design
The design of various electromechanical devices used in surgeries to open and close soft tissue like brain tissue, such as harmonic scalpels, was taken as a starting point. Besides, the design was carried out following the guidelines established in the normative of good practice for the design of medical instruments in Mexico. Therefore, some physical characteristics were identified, such as the fact that the device should be used with only one hand. Also, the device must be lightweight. Finally, a mechanism was implemented to exert a vertical pressure on the tissue to be studied, which through the data of the force and pressure is determined the mechanical properties of the deep brain tissue. The design of the casing of the electromechanical device contemplates the anthropometric percentiles of the human hands [8]. Also, they are considered the ergonomics and comfort offered by the device to the user. The design of the trigger control was carried out with additionally suitable for clockwise and counterclockwise rotation. This design has two limit switches that control the opening of the pliers that compress the examined tissue. Once the design of the casing and the control trigger was completed, the action mechanism was selected. The mechanism selected was the rack and pinion type, which uses a rotational actuator. This mechanism was selected due to the smaller number of components to be used. The next figure shows the prototype for obtaining the viscoelastic properties of brain tissue.
2.2. Control and instrumentation strategy for scalpel clamp.
The physical prototype of the clamp establishes a PDI control strategy that allows to have the grips compression position. Next, in the flow chart of Figure 3, the control process for the system is shown.

The control strategy is established through proportional integral and derivative control (PID). Tuning is possible by approximating the transfer function of the electromechanical system using the rotational actuator to be controlled. The control of the machine will be carried out through variations in the applied potential difference. Moreover, once the transfer functions of the servomotor are obtained, the controller gains can be calculated, resuming the transfer function involving the difference of potential and the position of the rotor, where the manipulated variable of the system will be the difference of potential. The calculated parameters are $k_p=40.292$, $T_i=0.0274$, $K_i=1469.75$, $T_d=6.8535 \times 10^{-3}$ y $k_d=0.2761$. 
2.3. Digital controller and graphic interface of the clamp

A graphic interface was designed for the data acquisition of viscoelastic properties of the sample. In the first block, the interface programmer is presented, where the pins connection of the micro servomotor can be configured, its current position before being operated; as well as the input and output pins of the resistive force sensor. In the second block, there is a user interface. The stop button emergency, an opening setting knob clamp, and opening angle indicator clamp are shown; Two LEDs indicators are also shown, one to indicate if the clamp is activated and the other when the emergency stop button is pressed. In addition, the force sensor resistor (FSR) operation graph and indicator are shown. Finally, the different results of electrical power, mechanical power, speed, and a potential difference that the clamp produces when it is operated are shown. The components of the graphic interface are shown in figure 4.

3. Hydrolyzed collagen test

The specimens were made of hydrolyzed collagen to characterize the tweezers for measuring viscoelastic properties in soft tissues. This compound was selected because it comes from the hydrolyzed collagen of cattle, fish, or pigs. Collagen is an essential component in human skin, muscles and tissues, especially in soft tissues. Since the present research is focused on soft tissues focused on the brain, hydrolyzed collagen is the best material to simulate the components of soft tissues and to perform the appropriate characterization of the system. The hydrolyzed collagen used was branded Hydrolyzed collagen Duche® [9]. The mechanical properties of the soft tissues of the brain were considered when making the samples (see Table 1), as stipulated by [10]. The density and stress module were the main properties used for the sample’s preparation.

|                | Density (kg/m3) | Stress Module (kPa) | Decay constant (s⁻¹) | Bulk Module (GPa) |
|----------------|-----------------|---------------------|----------------------|------------------|
| Gray Matter    | 1.060           | 10.0                | 2.0                  | 80               | 2.19             |
| White Matter   | 1.060           | 12.5                | 2.5                  | 80               | 2.19             |
| Brainstem      | 1.060           | 22.5                | 4.5                  | 80               | 2.19             |
| Cerebelum      | 1.060           | 10.0                | 2.0                  | 80               | 2.19             |

The procedure for generating the specimens was also based on the identity tests for gelling grades as set out in the Pharmacopoeia of the United Mexican States [11]. For this study, the model developed...
by [12] is proposed, which consists of cylindrical specimens with a diameter of 30 mm and a height of 13 mm. Twenty-seven specimens were made based on the methodology established in [13] to assess the behavior of the material, which were characterized by different concentrations of grenadine. Figure 5 shows an example of the test with the scalpel clamp.

![Image of test with scalpel clamp](image)

**Figure 5.** Test with the scalpel clamp.

### 4. Results

The characterization of the tweezers for the measurement of the viscoelastic properties is presented by means of samples made at different concentrations of hydrolyzed collagen. The clamp was configured to perform two cyclic and staggered loads to perform the measurements on the hydrolyzed collagen specimens. In addition, measurements were performed until a failure moment was obtained on the specimen. The characteristics of the compression of the specimens are based on the protocol for the use of the single-brand harmonic scalpel, in the cutting section. Since the clamp is based on this type of medical device and its measurement is required to be made in the same way as the cut made by such a device in neurosurgery, the loading condition before material failure. For the failure condition of the device, a clamp loading time was taken for all specimens, according to [14]. One of the most critical conditions for carrying out each measurement on the test tubes was the imitation of the real nature of the brain tissues. As it should be remembered, brain tissue is a hyper/viscoelastic material, so its deformation will depend on each load cycle to be performed by the clamp. For this reason, only three loading cycles were performed for each specimen, and one last one until failure.

![Graphs of indentation profile](image)

**Figure 6.** Measured indentation profile of the tests. a) Displacement-time curve. b) Load – time curve
Figure 6 represent the measurement profile of the test with the scalpel clamp. Test 1 presented a lower displacement due to the concentration of hydrolyzed collagen and therefore the peak force was the highest in 0.11 N. Compared to Test 4, where the displacement increased 10 mm more and the force peak was less to 0.06 N. Compared with the results of [15], the results present the optimal performance of the clamp in order to obtain the viscoelastic properties in the soft brain tissues.

5. Conclusions.
It is possible to design a scalpel clamp device that can be used to obtain the viscoelastic properties of brain tissues. The thresholds of displacement and force at a maximum time of 2 seconds react on the features established in [14-15], at different concentrations of hydrolyzed collagen that exemplify soft brain tissues.

Acknowledgements
The authors wish to express their gratitude to the Consejo Nacional de Ciencia y Tecnología (CONACyT) and the Instituto Politecnico Nacional for the support projects 20201964 and 20200930, as well as the EDI grant, all from SIP/IPN.

References
[1] Arbogast K B, Thibault K L, Pinheiro B S, Winey K I and Margulies S S 1997 tissues J. Biomech Eng. 30 757-9
[2] Hirata K, Inoue K, Kajita T, Kifune T, Kihara K, Nakahata M, and Totsuka Y 1990 Physical Review Letters, 65 1297
[3] Kaczmarek L and Chaudhuri A 1997 Brain Research Reviews. 23 237-56
[4] Fancelllo E, Vigneron L, Noels L, Ponthot J P, Bowman R and Stainier L 2007 Identificación de parámetros de viscoelasticidad finita aplicada a la simulación del comportamiento mecánico de masa encefálica (Congreso Iberoamericano de Ingeniería Mecánica)
[5] Cheng J and Zhang L T 2018 Int. J. Comp. Meth. 15 1850028
[6] Bilston L E, Liu Z and Phan-Thien N 1997 Bio rheology 34 377-85
[7] Donnelly B R and Medige J 1997 J. Biomech Eng. 119 423-32.
[8] Miller K and Chinzei K 1997 J. Biomech Eng.30 1115-21.
[9] Vélez Núñez L A, Sola P Y M and Alberto C 2018 Construcción, pruebas técnicas y evaluación de un prototipo para el análisis de cargas posturales en la mano de trabajadores de oficina (Bachelor’s tesis: Escuela Superior Politécnica de Chimborazo)
[10] Guerrero R F E, Torres D L, Anaya D M and Lugo V R 2010 Rev. Iberoam. Politém. 12 2
[11] Zhang L, Yang K H, Dwarampudi R, Omori K, Li T, Chang K and King A I 2001 SAE Technical Paper 2001-22-0017
[12] Sociedad Farmacéutica de México 1984 Nueva farmacopea mexicana de la Sociedad farmacéutica de México (Francisco Díaz de León)
[13] Izasa J A 2013 Comportamiento Mecánico de Tejidos Blandos Multicapa (Colombia: bachelor’s thesis)
[14] Rosen J, Brown J D, De S, Sinanan M and Hannaford B 2008 J Biomech Eng. 1300210201-17
[15] Elkin B S, Ilankova A and Morrission III B 2011 J. Biomech Eng. 133 071009-1-7