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A study of the mechanical and electrical properties of the cortical bone based on age, biochemical factors and Nernst equation

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Abstract. - - This study presents the development of a mathematical model to assess the performance of oil strings during the drilling process of a reservoir, considering the dynamic conditions and operational characteristics of the equipment during its functions, and taking into account the mechanical properties of API K55 steel. The research resulted in a set of equations that model the behavior of stresses and deformations experienced by the oil tools when transmitting torque, facilitating the opening of the reservoir. A finite element analysis was conducted to evaluate the structural behavior of the strings and to estimate the time required to reach permanent deformations, as well as the time before failure occurs.

Keywords: aging, calcium, PTH, pH, cortical bone, Young modulus, electrical conductivity, Nernst equation and electro-stimulation.

Un estudio de propiedades mecánicas y eléctricas del hueso cortical a partir de la edad, factores bioquímicos y la ecuación de Nernst

Resumen: Este artículo presenta una exploración en profundidad de la intrincada interacción entre las propiedades mecánicas y eléctricas en sistemas biológicos, centrándose en las relaciones experimentales entre el envejecimiento, la concentración de calcio, el pH y la PTH. La ecuación de Nernst es un principio electroquímico fundamental, el cual se examinará por su relevancia en la comprensión de estos fenómenos y su futura aplicación de electroestimulación para procesos de sanación del hueso cortical. El artículo profundiza en el impacto del envejecimiento en el cuerpo humano, el papel del calcio y el pH en los procesos fisiológicos, la importancia de la PTH y la aplicación de la ecuación de Nernst en sistemas biológicos.

Palabras clave: envejecimiento, calcio, PTH, pH, hueso cortical, módulo de elasticidad, conductividad eléctrica, ecuación de Nernst y electroestimulación.

I. INTRODUCTION

Bioengineering is a multidisciplinary field that integrates biology, chemistry, physics, and engineering principles to develop innovative solutions in healthcare and biomedical applications [1], [2]. Understanding the mechanical and electrical properties of biological tissues, such as bone, is crucial for various bioengineering applications, including the design of medical devices, drug delivery systems, and assessments of bone health [3]. The Nernst equation, derived from electrochemistry, is a fundamental tool that allows researchers to quantify the behavior of ions and electrical potential differences across biological membranes [4]. In the field of bioengineering, especially in the characterization of cortical bone, the Nernst equation is applied to determine the electrical properties of bone and the amount of electricity needed to pass through bone membranes [5]. This article provides a comprehensive overview of the Nernst equation, its theory, applications in bioengineering, and its specific relevance to cortical bone characterization. Bone healing is a complex biological process influenced by various factors, including mechanical stress, growth factors, cellular activities, and signaling pathways. However, electrical stimulation has been explored as a potential modality to promote bone healing and suggests that specific electrical parameters can have a positive impact on bone regeneration [6]. When electrical stimulation is used for bone healing, several factors should be considered, including the type of electrical stimulation (e.g., direct current, pulsed electromagnetic fields), the frequency, duration, and intensity of the stimulation, and how these parameters affect cellular and tissue responses [7]. Vitamin D plays an indirect role in stimulating the mineralization of the unmineralized bone matrix. After the absorption or skin production of vitamin D, the liver synthesizes 25-hydroxyvitamin D, and subsequently, the kidneys produce biologically active 1,25-dihydroxyvitamin D [1,25-$(OH)_2D$]. Serum 1,25-$(OH)_2D$ is responsible for maintaining serum calcium and phosphorus concentrations adequate to allow passive mineralization of the unmineralized bone matrix. Serum 1,25-$(OH)_2D$ primarily accomplishes this by stimulating the intestinal absorption of calcium and phosphorus. Serum 1,25-$(OH)_2D$ also promotes the differentiation of osteoblasts and stimulates osteoblastic expression [8]. Vitamin D, specifically vitamin D3 (cholecalciferol), plays a crucial role in various physiological processes in the body, such as the regulation of calcium and phosphate metabolism. The primary active form of vitamin D is calcitriol, which is formed in the skin from vitamin D3 (cholecalciferol) in the presence of ultraviolet B radiation. Calcitriol acts in the intestines to increase the absorption of calcium and phosphate, additionally, calcitriol promotes the reabsorption of calcium in the kidneys, thereby preventing its loss through urine [9].

Calcium is an essential mineral that plays a vital role in many physiological processes, including muscle contraction, nerve function, and blood clotting. Calcium is the most abundant divalent cation in the body, representing about 2% of body weight, approximately 1,000 grams. It is distributed across various compartments, with constant exchange flows subject to complex regulatory mechanisms. More than 98% of the body's calcium is found in the bone compartment, of which approximately 1% is freely exchangeable with extracellular fluid [10], [11]. Serum calcium exists in three (3) different forms: ionic or free form, which accounts for approximately 50%; protein-bound, approximately 40%; and finally, about 10% forms complexes with anions such as bicarbonate, citrate, phosphate, and lactate [12]. Ionic calcium and calcium bound to anions constitute the ultra-filtrable fraction, with the ionic fraction being the only one with biological activity and, therefore, subject to hormonal control. The circulating extracellular calcium pool exists in three (3) different states, protein-bound, anion-bound, and free or ionized. Protein-bound, anion-bound, and free or ionized calcium account for approximately 40-45 %, 5-10 %, and 45-50 % of the total calcium in circulation respectively [13]. When calcium measurements are needed, there are two (2) options to obtain the concentration, total calcium, and ionized calcium (iCa^{2+}). The total calcium measurement is the sum of the subfractions (protein-bound, anion-bound, and free or ionized). Total, calcium measurement

is widely used because it is an accurate representation of calcium homeostasis in most cases and can be included as part of a routine blood collection. While total calcium measurement is valuable in many patients, it can yield misleading results in situations where circulating protein concentrations are abnormal either by excessive protein loss or impaired protein synthesis [14].

For these reasons, there exists a pressing clinical and analytical demand for the direct measurement of iCa^{2+}. The difficulty in measuring iCa^{2+} arises primarily from the rigorous preanalytical conditions that must be met. The equilibrium is influenced by pH levels, as the binding of calcium to proteins is notably sensitive to changes in pH. Thus, pH change is inversely proportional to the concentration of iCa^{2+}. Typically, changes by 5 % for every 0.1-unit change in pH as hydrogen ions effectively compete with iCa^{2+} for available negative charges on proteins [15]. The application of pH-adjusted calcium was clinically useful, but a change in pH that occurred after collection would affect the accuracy of the results by an error of 10% approximately [16]. Therefore, ion practice to correct the pH-adjusted free calcium measurements are recommended to multiply the iCa2+ by 10 % approximately.

$$\text{True Calcium} = \text{Reported Total Calcium} + 0.8\ (4.0 - \text{Serum Albumin}) \quad (1)$$

where "True Calcium"; "Reported Total Calcium"; and "Serum Albumin" have units of mg/dL, m/dL, and g/dL respectively. The concentration of calcium in the blood is tightly regulated by the PTH and other factors [17]. Approximately, 90% of protein-bound calcium binds to albumin in a pH-dependent manner. Alterations that decrease serum albumin values will decrease total serum calcium but will have a smaller effect on ionized calcium concentration. In general, each g/dL of albumin binds approximately 0.2 mmol/L (0.8 mg/dL) of calcium, so to correct hypoalbuminemia, it is necessary to add 0.2 mmol/L to the total calcium concentration for every g/dL decrease in albumin concentration from the normal values of 4.0 g/dL [12], [18]. The binding of calcium to albumin is also affected by the pH of the extracellular fluid. Acidemia will decrease protein binding and increase ionized calcium. For every 0.1 decrease in ionized pH, calcium increases approximately by 0.05 mmol/L. The exact regulation of serum calcium is controlled by calcium itself through a calcium receptor and various hormones, the most important of which are PTH and 1,25-dihydroxyvitamin D_3($1,25(OH)_2D_3$). Maintaining appropriate calcium equilibrium, and therefore serum calcium levels, is a complex and dynamic process involving calcium absorption and excretion in the intestines, filtration, and reabsorption in the kidneys, and its storage and mobilization in the skeleton. Calcium homeostasis refers to the regulation of the calcium ions concentration in the extracellular fluid [19]. Normal serum calcium concentration varies between laboratories but is usually 8.5 to 10.5 mg/dL (2.1 to 2.6 mmol/L) and it represents the sum of the three circulating fractions mentioned above [20].

Table 1. Calcium intakes by life stage.

LSG (Yr.)	AI (mg)	EAR (mg)	RDA (mg)	TUIL (mg)
MALES				
19-30	—	800	1,000	2,500
31-50	—	800	1,000	2,500
51-70	—	800	1,000	2,000
> 70	—	1,000	1,200	2,000
FEMALES				
19-30	—	800	1,000	2,500
31-50	—	800	1,000	2,500
51-70	—	1,000	1,200	2,000
> 70	—	1,000	1,200	2,000

LSG = Life Stage Group; AI = Adequate Intake; EAR = Estimated Average Requirement; RDA = Recommended Dietary Allowance; TUIL = Tolerable Upper Intake Level, The LSG unit is years (Yr.). The symbol (>) means greater than [21].

On the other hand, the body's pH is regulated by various systems, including calcium regulation systems. Acid-based balance is important for maintaining the normal functioning of enzymes and metabolic processes. When blood calcium levels decrease, the release of PTH can be activated, which in turn can influence acid-base balance. Acidosis, characterized by a lower-than-normal blood pH, can affect the binding of calcium to proteins and, as a result, influence ionized calcium levels in the blood. This can have an impact on hormonal response and calcium homeostasis. The PTH is secreted by the parathyroid glands in response to low levels of calcium in the blood. PTH increases the reabsorption of calcium in the kidneys, thereby releasing more calcium into the bloodstream. PTH stimulates the release of calcium and phosphate from the bones, which raises the concentration of calcium in the blood. Additionally, PTH plays a crucial role in regulating calcium levels in the body, with one of its primary targets being bone tissue. Below, it is describing the mechanism of action of PTH in bone and its principal functions:

- Stimulation of Osteoclast Activity: PTH activates osteoclasts, which are cells that resorb bone.
- Inhibition of Osteoblast Activity: Although PTH primarily stimulates bone resorption, it can also indirectly inhibit the activity of osteoblasts, reducing bone formation under certain conditions [23].
- Calcium Homeostasis: PTH plays a central role in maintaining serum calcium levels within a narrow range. This calcium is then available for vital physiological functions such as muscle contraction and nerve signaling.
- Response to Hypocalcemia: When blood calcium levels decrease, the secretion of PTH increases. This hormone acts rapidly to mobilize calcium from bone tissue, ensuring that the body maintains the necessary levels for normal physiological processes.
- Bone Remodeling: PTH is a key regulator of bone remodeling, which involves both bone resorption and formation. By promoting bone resorption, PTH contributes to the removal of old or damaged bone tissue and the release of stored calcium. This, in turn, allows for the deposition of new bone matrix when conditions are appropriate.

In this study, the investigation was carried out to explore the relationship between calcium concentration, age, PTH, and pH using an electrochemistry equation and experimental data from mechanical and electrical properties of the cortical bone. We have explored the significance of the Nernst equation in elucidating ion transport across biological membranes and its role in maintaining cellular electrical potentials, let's delve into the complexities of determining the precise electrical requirements for bone healing.

II. FIELDS OF INTEREST TO THE SUBJECT

The Nernst equation describes the relationship between the concentration of ions and the electric potential difference (voltage) across a membrane or at an electrode interface. This equation is crucial for understanding ion transport phenomena across biological membranes, including cell membranes, and provides insights into how cells maintain their electrical potential as well as the electrical potentials at a cellular level. However, determining the exact amount of electricity needed for bone healing would require a more comprehensive approach that considers all relevant biomechanical factors and mechanisms. For that reason, experiments were conducted to determine the mechanical and electrical properties of the cortical bone, emphasizing the experimental correlation between both properties through a statistical analysis. Additionally, biochemical factors and components such as pH, PTH, and calcium concentration were analyzed to understand their interaction and the biological response when electrical stimulation is applied.

The Nernst equation is typically expressed as follows:

$$E = E_0 - \frac{\mathrm{R} \cdot \mathrm{T}}{(2) \cdot F} \cdot \ln\left(\frac{[Ca^{2+}]_{in}}{[Ca^{2+}]_{out}}\right) \qquad (2)$$

Where:

- E represents the electric potential difference (in volts) across a membrane or at an electrode.
- E_0 is the standard electrode potential, a reference value.
- R is the universal gas constant.
- T is the absolute temperature (in Kelvin).
- n is the number of electrons transferred in the reaction.
- F is the Faraday constant.
- $[A^-]$ y [A] are concentrations of the ion Ca^{2+} on either side of the membrane or at the electrode interface.

According to (2) above, the potential difference across a membrane is proportional to the concentration gradient of the ions involved, where $[Ca^{2+}]$ in is the concentration of calcium ions inside the cell, and $[Ca^{2+}]$out is the concentration of calcium ions outside the cell and n is 2 due to the number of electrons transferred from Ca^{2+}. The Nernst equation illustrates how changes in ion concentrations can affect the electric potential across a membrane. The electrical characterization of biological tissues is a great interest in the bioengineering field, especially, obtaining electrical properties of biological tissues such as bone structures. The most common electrical properties associated with bone studies include electrical conductivity, permittivity, and impedance, which provide information about the composition, health, and functionality of the tissue. The Nernst equation can be applied to assess the electrical behavior of biological tissues and explore how different ions influence their electrical properties.

For example, the electrical conductivity of cortical bone depends on various factors, including ion concentrations and the porosity of the bone matrix. Ions such as calcium (Ca^{2+}) and phosphate (PO_4^{3-}) play a crucial role in bone tissue. The Nernst equation can be used to calculate the equilibrium potential for these ions and understand how they influence the electrical conductivity of cortical bone. Studies have shown that changes in bone health, such as osteoporosis or the presence of fractures, can alter the electrical properties of cortical bone. By measuring the electrical conductivity of bone tissue, bioengineers can assess bone quality and monitor bone health, providing valuable information for clinical diagnoses and treatment planning. Electrostimulation has proven to be promising in promoting bone healing and regeneration. Techniques such as Pulsed Electromagnetic Field Therapy (PEMF) involve the application of electric fields to bone tissue to stimulate cellular responses that enhance bone growth. Bioengineers can utilize the Nernst equation to calculate the electric potential required to influence specific ion concentrations within bone tissue. This information helps optimize the design of electric stimulation devices for bone healing, potentially speeding up the recovery process for individuals with bone fractures or orthopedic surgeries [34].

III. METHODOLOGY

A. Methodology for literature review

The methodology described herein outlines a systematic and rigorous approach to the selection of research papers in the fields of bioengineering and science. The process, consisting of thirteen distinct steps, is designed to curate a collection of papers that meet stringent criteria for scientific excellence, relevance, ethical standards, and potential impact on the advancement of knowledge within the realm of engineering applications to biological systems. By employing a comprehensive and meticulous screening process, we aim to ensure that only the most valuable and deserving research contributions are included in our final selection. This methodology serves as a robust framework for the critical evaluation of scientific literature,

facilitating the identification of papers that make significant contributions to the fields of science and bioengineering while upholding the highest standards of quality and ethics.

1. Initial Screening - Collecting a pool of research papers related to bioengineering and science topics.
2. Peer Review Evaluation - Exclude papers that have not undergone a thorough peer review process.
3. Relevance Assessment - Evaluate papers for their relevance to science and bioengineering fields. Exclude papers that are not directly related to engineering applications to biological systems, or related topics.
4. Scientific Rigor Evaluation - Assess the scientific rigor of the selected papers. Exclude papers that lack well-designed experiments, appropriate statistical analysis, or robust methodology.
5. Clear Objectives and Hypotheses - Examine the papers for clear and well-stated objectives and hypotheses. Exclude papers that do not effectively address these objectives.
6. Originality Check - Verify whether the research presents novel findings, methods, or applications that contribute to the advancement of bioengineering knowledge. Exclude papers that do not meet this criterion.
7. Significance Assessment - Determine whether the paper makes a substantial contribution to the science and bioengineering fields. Exclude papers that do not tackle important problems, or advance understanding in a meaningful way.
8. Clarity and Coherence Evaluation - Evaluate the organization and clarity of the papers. Exclude papers poorly organized or with unclear writing that hinders effective communication of results, and conclusions.
9. Ethical Review - Ensure that the research follows ethical standards, including the protection of human and animal subjects and proper citation practices. Exclude papers that violate ethical guidelines.
10. Interdisciplinary Assessment - Consider whether the research demonstrates a strong interdisciplinary approach, combining principles from engineering, biology, and other relevant sciences. Favor papers that exhibit interdisciplinary characteristics.
11. Impact Factor Consideration - Consider the potential impact of research on healthcare, technology, or engineering and science applications. Consider this as a positive factor when evaluating the papers.
12. Exclusion Criteria Application - Apply the exclusion criteria to the selected papers to exclude any that meet any of the criteria mentioned in the exclusion list.
13. Final Selection - After applying all the criteria, select the papers that meet the inclusion criteria while excluding those that meet any of the exclusion criteria. See Table 2 for Inclusion and Exclusion criteria.

Table 2. Inclusion and exclusion criteria.

Criteria	
Inclusion	Exclusion
Peer Review Journals: Papers should undergo a thorough peer review process to assess their quality and validity.	Unsubstantiated Claims: Research with unsupported or exaggerated claims should be rejected.
Relevance to Science and Bioengineering Fields: Relate to applications of engineering principles to biological systems, biomedical devices, or related topics.	Poor Methodology: Research with inadequate experimental design, data collection, or statistical analysis may be rejected.
Scientific Rigor: Demonstrate a high level of scientific rigor, including well-designed experiments, appropriate statistical analysis, and robust methodology.	Plagiarism and Ethical Violations: Papers found to contain plagiarism or ethical violations, such as fabrication or falsification of data, should be rejected.
Clear Objectives: The objectives and hypotheses should be clearly stated, and the paper should effectively address these objectives.	Insufficient Originality: Papers that do not present significant new contributions or merely replicate existing work may be rejected.
Originality: The research should present novel findings, methods, or applications that contribute to the advancement of bioengineering knowledge.	Inadequate Presentation: Papers with poor organization, unclear writing, or insufficient data presentation may be rejected.
Significance: The paper should make a substantial contribution to science and bioengineering fields, either by tackling important problems, providing innovation, or advancing understanding in a meaningful way.	Inadequate Ethical Considerations: Papers that do not adhere to ethical standards regarding the use of human or animal subjects or fail to disclose conflicts of interest may be rejected.
Clarity and Coherence: The paper should be well-organized, with clear writing to communicate results, discussion, and conclusions effectively.	Lack of Relevance: Papers that are not related to science and bioengineering or do not have a clear connection to the fields should be rejected.
Ethical Practice: Research must follow ethical standards, including human and animal subject protection, as well as appropriate citation and avoidance of plagiarism.	Conflict of Interest: Papers with undisclosed conflicts of interest that could bias the investigation, or its interpretation should be rejected.
Interdisciplinary Nature: The research may be favored if it demonstrates a strong interdisciplinary approach, combining principles from engineering, biology, and other relevant sciences or fields.	Poor Presentation: Papers with disorganized writing, ineffective communication of results, unclear data presentation, or inadequate explanations may be excluded.
Impact Factor: Consideration of the potential impact of research on healthcare, technology, or any other applications within the bioengineering and science fields.	Outdated or Irrelevant References: Papers that heavily rely on outdated or irrelevant references may be rejected.

The keywords used to obtain the articles were as follows:

- "Calcium concentration" and "pH"
- "Calcium concentration" and "PTH"
- "Mechanical properties" and "Electrical properties"
- "Nernst equation" and "Electrochemical potentials"
- "aging" and "calcium"
- "Aging" and "Young modulus"
- "Vitamin D" and "Calcium absorption"
- "Calcium homeostasis" and "PTH mechanism"
- "Hormonal regulation" and "Bone health"
- "Bone healing" and "electrostimulation"

B. Methodology for experimental analysis

This methodology outlines the experimental procedures and analytical steps performed to correlate mechanical and electrical properties of cortical bones obtained in the first phase of this investigation with factors such as gender, age, calcium concentration, pH, and PTH levels, linking this data to the Nernst equation for clinical application. The process consists of twelve distinct steps to perform the experimental analysis of this research. The study aims to establish a relationship between these properties and use them to predict the electric potential difference across cortical bone membranes for safe electrostimulation in bone fracture healing.

1. Gather data related to demographic and biochemical factors such as gender, age, calcium concentration, pH, and PTH levels. The data obtained shall not be more than 10 years back from 2023.
2. Prepare an organized table for the factors mentioned in Step 1 and provide it in the Results section.
3. Correlate demographic data with biochemical factors.
4. Correlate the mechanical and electrical properties with demographic data and biochemical factors using statistical analysis.
5. Apply the Nernst equation to relate the electrical properties to ion concentration and membrane potential.
6. Use the correlation obtained in Step 4 and the Nernst equation to predict the electric potential difference (voltage) across cortical bone membranes.
7. Based on the predicted voltage, determine safe levels for electrostimulation in bone fracture healing.
8. Provide clinical recommendations for electrostimulation therapy.
9. Provide recommendations for healthcare practitioners regarding the application of electrostimulation for bone fracture patients, considering gender, age, calcium concentration, pH, and PTH levels.
10. Summarize the findings regarding the correlation between mechanical and electrical properties of cortical bones with biochemical factors.
11. Highlight the clinical implications and potential benefits of using the predicted voltage relationship for electrostimulation applications in bone fracture healing.
12. Include all relevant references to prior studies, methodologies, and scientific literature related to bone mechanics and fracture healing, bioimpedance, and electrostimulation.

IV. RESULTS

The basic analyzed data and corresponding results are described below.

A. Demographic and biochemical data

The gathered data used jointly with the mathematical model so developed is presented in Table 3 below.

Table 3. Demographic data based on biochemical factors.

AG (Yr.)	CCB (mg/dL)	PTH-L (pg/mL)	pH Sc. (0-14)
MALES			
19-30	8.6 - 10.0	10 - 55	7.35 - 7.45
31-50	8.6 - 10.2	10 - 50	7.35 - 7.45
51-70	8.6 - 10.4	10 - 55	7.35 - 7.45
> 70	8.6 - 10.5	10 - 65	7.35 - 7.45
FEMALES			
19-30	8.6 - 10.0	10 - 50	7.35 - 7.45
31-50	8.6 - 10.2	10 - 50	7.35 - 7.45
51-70	8.6 - 10.4	10 - 55	7.35 - 7.45
> 70	8.6 - 10.5	10 - 65	7.35 - 7.45

AG = Age Group; CCB = Calcium Concentration in Blood; PTH-L = Parathyroid Hormone Levels; pH Sc. = Acidity/Alkalinity Scale. AG unit is years (Yr.). The symbol (>) means greater than., CCB, PTH-L, andpH Sc. Values were obtained from [35], [36], [37].

The obtained results show that calcium concentration decreases with age due to changes in bone metabolism and hormonal regulation. It was also found that PTH levels increase with age as a compensatory mechanism to maintain calcium homeostasis. Furthermore, we observed that pH has a significant effect on calcium concentration due to its impact on ionization states.

B. Mechanical and electrical properties correlation with demographic data, and biochemical factors

To correlate the obtained experimental data, conductivity and permittivity variables were plotted as show in Fig. 1.

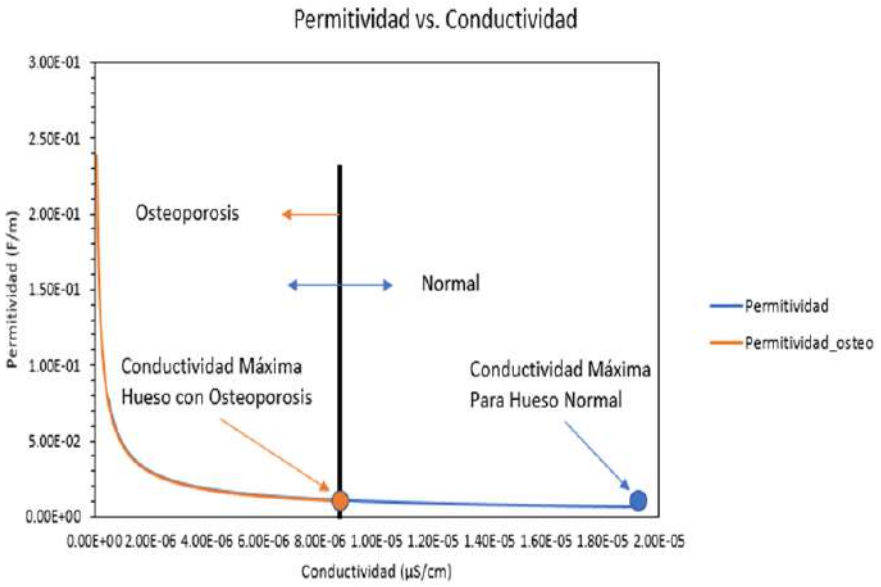

Fig. 1. Conductivity and Permittivity Relationship. Source: The authors.

For a better understanding of Fig. 1, it is assumed that the studied bone falls within either the osteoporosis or normal condition, but as the osteoporosis bone can resist a tension stress of about 18.28 MPa, when compared this value with the obtained value of 28.6 MPa thus it is 'possible to conclude as a normal bone. Nevertheless, by using (3) and (4), it is also possible to get $\sigma_{Elec\ Max}$ y ε_a values for the two bones conditions respectively.

$$\sigma_{\text{Elec. Max}_{(\text{normal})}} = \frac{\text{E} - 10{,}845}{8.82 \times 10^8} \qquad (3)$$

$$\sigma_{\text{Elec. Max}_{(\text{normal})}} = \frac{28.6 \times 10^6 - 10{,}845}{8.82 \times 10^8} = \boxed{0.0323(\mu\text{S/cm})}$$

$$\text{Y} = 3\ \text{x}\ 10^{-6}\ \text{X}^{-0.7} \quad \text{o} \quad \text{Permitividad}\ (\varepsilon_a) = \ 3\ \text{x}\ 10^{-6}\ (\sigma_{\text{Elec. Max}_{(\text{normal})}})^{-0.7} \qquad (4)$$

$$\varepsilon_a = 3\ \text{x}\ 10^{-6}\ (\sigma_{\text{Elec. Max}_{(\text{normal})}})^{-0.7} \rightarrow 3\ \text{x}\ 10^{-6}\ (0.0323(\mu\text{S/cm}))^{-0.7} =$$

$$\boxed{3.316\ \text{x}\ 10^{-5}\ (\text{F/m})}$$

C. Mechanical and electric properties relationship

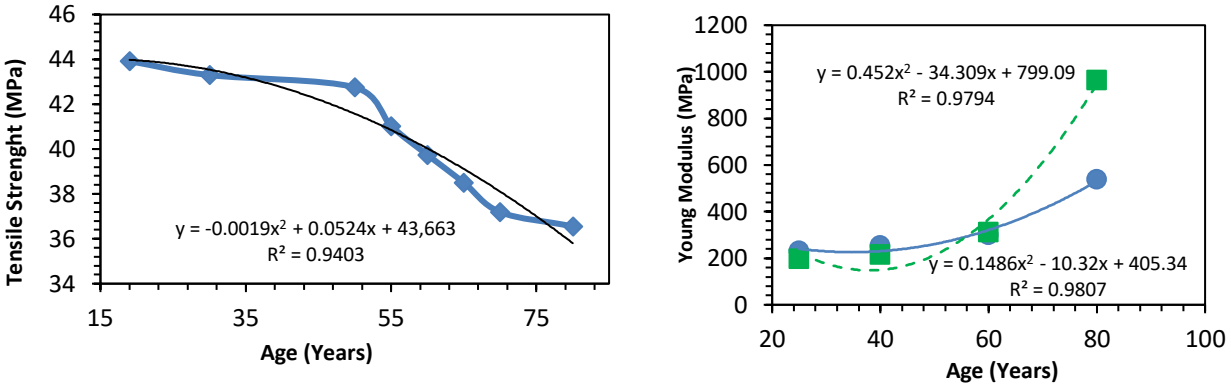

Fig. 2. (a) Left: Age effect on tensile stress; (b) Right: Young modulus (green male, blue women vs. age). Source: The authors.

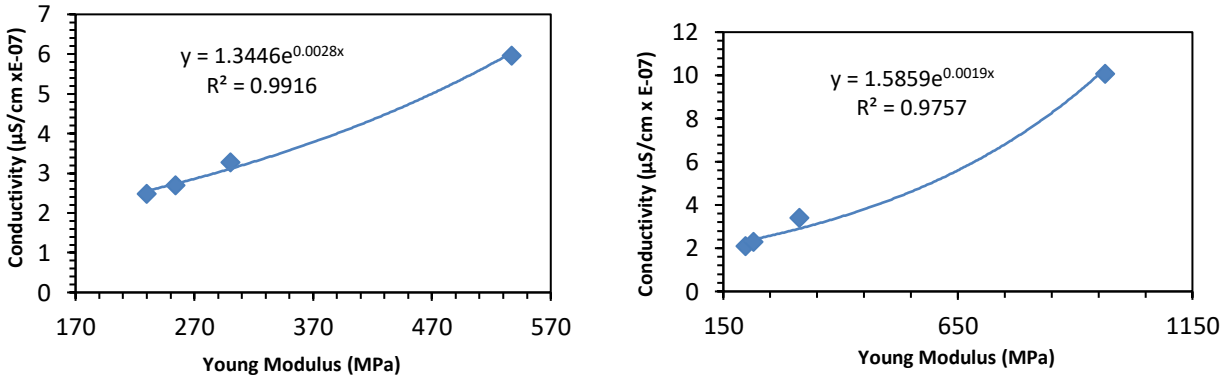

Fig. 3. Conductivity vs Young modulus, (a) left women, (b) right men. Source: The authors.

To investigate the relationships between mechanical and electrical properties, it was imperative to determine the slope of the mechanical graphs for each of the samples, which signifies the modulus of elasticity.

$$\text{Young Modulus (E)} = 8.82 \times 10^8 \times \text{Conductivity}_{\max}(\sigma_{\text{Elec. Max}}) + 10.845 \qquad (5)$$

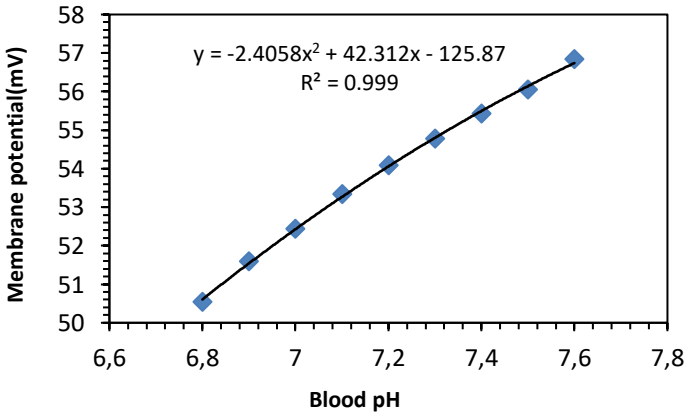

Fig. 4. Effect of pH in blood on the membrane's electric potential. Source: The authors.

CONCLUSIONS

In conclusion, the present research provides new insights into the complex relationship between calcium concentration, age, PTH, and pH. The Nernst equation has been identified as a valuable application in the field of bioengineering, particularly in the characterization of cortical bone. By understanding the electrical properties of cortical bone and applying the Nernst equation, researchers can assess bone health, and optimize electrical stimulation therapies for bone healing. This interdisciplinary approach demonstrates how the principles of science and engineering can be harnessed to advance healthcare solutions and improve the quality of life for individuals with bone-related conditions. The findings suggest that changes in these factors can have significant implications for human health and disease. Further research is needed to fully understand these relationships and develop effective interventions to prevent or treat related conditions by means of define stimulation parameters through iterative experiments to achieve the desired biological responses while minimizing potential side effects. Finally, further experimental tests will be useful to validate the effectiveness of the designed electrical stimulation involving in vitro studies using samples of bone tissue or in vivo studies with animal models.

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REFERENCES

[1] M. F. Bear, B. W. Connors y M. A. Paradiso, Neuroscience: Exploring the Brain (4th ed.), Wolters Kluwer, 2016.
[2] B. Alberts, A. Johnson, J. Lewis, M. Raff, K. Roberts y P. Walter, Molecular Biology of the Cell (4th ed.), Garland Science, 2002.
[3] D. Purves, G. J. Augustine, D. Fitzpatrick, L. C. Katz, A. S. La Mantia y J. O. McNamara, Neuroscience (6th ed.), Oxford University Press, 2017.
[4] A. J. Bard y L. R. Faulkner, Electrochemical Methods: Fundamentals and Applications, John Wiley & Sons, 2000.
[5] C. T. Rubin, K. J. McLeod y L. E. Lanyon, «Prevention of osteoporosis by pulsed electromagnetic fields, » J Bone Joint Surg Am, vol. 71, nº 3, pp. 411-417, 1989.
[6] M. Griffin y A. Bayat, «Electrical stimulation in bone healing: critical analysis by evaluating levels of evidence, » Eplasty, vol. 11, nº e34, pp. 303-353, 2011.
[7] L. Leppik, K. M. C. Oliveira, M. B. Bhavsar y J. H. Barker, «Electrical stimulation in bone tissue engineering treatments, » Eur J Trauma Emerg Surg, vol. 46, nº 2, pp. 231-244, 2020.
[8] C. Chen, R. Adhikari, D. L. White y W. K. Kim, «Role of 1,25- Dihydroxyvitamin D3 on Osteogenic Differentiation and Mineralization of Chicken Mesenchymal Stem Cells, » Frontiers in Physiology, vol. 12, p. 1–13, 2021.
[9] M. F. Holick, «Vitamin D Deficiency, » New England Journal of Medicine, vol. 357, nº 3, pp. 266-281, 2007.
[10] R. Goswami, «Primer on the metabolic bone diseases and disorders of mineral metabolism, » Indian J Med Res, vol. 144, nº 33, p. 489–90, 2016.
[11] L. J. Deftos, «Calcium Metabolism, » de Clinical Essentials of Calcium and Skeletal Disorders, Caddo, OK, Professional Communications, Inc., 1998, pp. 44-71.
[12] F. Carral San Laureanoa, G. Olveira Fusterb y M. Aguilar Diosdado, «Homeostasis del calcio, fósforo y magnesio, » Medicina Integral, vol. 36, nº 7, pp. 261-266, 2000.
[13] A. Hamroun, J.-D. Pekar, A. Lionet, A. Ghulam, P. Maboudou, A. Mercier, T. Brousseau, G. Grzych y F. Glowacki, «Ionized calcium: analytical challenges and clinical relevance, » Journal of Laboratory and Precision Medicine, vol. 5, pp. 1-16, 2020.
[14] Z. D. Hu, Y. L. Huang, M. Y. Wang, G. J. Hu y Y. Q. Han, «Predictive accuracy of serum total calcium for both critically high and critically low ionized calcium in critical illness, » J Clin Lab Anal., vol. 32, nº 9, pp. 1-5, 2018.
[15] J. O. Joswig, J. Anders, H. Zhang, C. Rademacher y B. G. Keller, «The molecular basis for the pH-dependent calcium affinity of the pattern recognition receptor langerin, » J Biol Chem, pp. 1-16, 2021.
[16] N. Fogh-Andersen, «Ionized calcium analyzer with a built-in pH correction, » Clin Chem, vol. 27, nº 7, pp. 1264-1267, 1981.
[17] E. Yu y S. Sharma, «Physiology, Calcium, » StatPearls Publishing, Treasure Island, FL, 2023.

[18] D. A. Bushinsky y R. D. Monk, «Electrolyte quintet: Calcium, » The Lancet, vol. 352, nº 9124, pp. 306-311, 1998.
[19] L. A. Negrea, «Hypocalcemia and hypercalcemia, » de Nephrology Secrets (4 ed.), Elsevier, 2019, pp. 526-531.
[20] J. Feher, «9.7 - Calcium and Phosphorus Homeostasis I: The Calcitropic Hormones, » de Quantitative Human Physiology (2nd ed.), Richmond, VA, Elsevier, 2017, pp. 924-932.

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