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Use of Bovine Teeth in Mexico as a Substitute for Human Dental Models

Uso de Dientes Bovinos en México como Sustituto de Modelos Dentales Humanos

María Stella Pacheco Hernández [a]

Abstract:

Preclinical research and teaching in dentistry require dental models that simulate the characteristics of human teeth. However, ethical and logistical limitations associated with using human teeth have driven the search for viable alternatives. Bovine teeth have emerged as a suitable option due to their availability, lower cost, and structural and chemical similarities to human teeth. This article reviews the reasons for their selection, the specific characteristics of bovine breeds used in Mexico, the types of teeth employed, and their preparation. It also presents size, content, and chemical composition data with comparative tables.

Keywords:

Bovine teeth, dentistry, preclinical research, dental models, dental chemical composition, bovine breeds in Mexico.

Resumen:

La investigación y enseñanza preclínica en odontología requieren modelos dentales que simulen las características de los dientes humanos. Sin embargo, las limitaciones éticas y logísticas relacionadas con el uso de dientes humanos han impulsado la búsqueda de alternativas viables. Los dientes bovinos han emergido como una opción adecuada debido a su disponibilidad, costo reducido, similitudes estructurales y químicas con los dientes humanos. Este artículo revisa las razones de su selección, las características específicas de las razas bovinas utilizadas en México, los tipos de dientes empleados y su preparación. Se presentan datos sobre tamaño, contenido y composición química, además de tablas comparativas.

***Palabras clave**:*

Dientes bovinos, odontología, Investigación preclínica, modelos dentales, composición química dental, razas bovinas en México

INTRODUCTION

Dental models play an essential role in preclinical research and teaching. Using human teeth presents ethical, legal, and logistical challenges, limiting their availability for experimental and educational studies. Bovine teeth have been frequently used in Mexico because of their structural similarities and availability in the livestock industry.[1]

In this context, bovine teeth have emerged as a viable alternative due to their structural and chemical similarities to human teeth, making them an effective model for different applications.[2]

This article analyzes the classification of cattle breeds in Mexico, their suitability to replace human teeth in dental studies, and bovine teeth's structural and chemical properties. In addition, comparative tables are presented with data on the size, composition, and content of bovine teeth compared to humans.

DENTAL MODELS IN DENTISTRY:

Modern dentistry relies on scientific research and evidence-based practice to improve treatments and oral health. In this context, dental models play a critical role in providing a means for the preclinical evaluation of techniques and materials before their application in human patients.[3] Models can be natural, such as human and bovine teeth, or artificial, such as resin replicas and digital simulators.

TYPES OF DENTAL MODELS AND THEIR APPLICATIONS

Dental models are classified into various categories according to their origin and purpose:

- **Natural models:** These include human and bovine teeth, broadly used in adhesion, abrasion, erosion, and biomaterial testing.[4,5]
- **Artificial models:** Made with synthetic resins or ceramics, they allow the standardization of comparative studies and the simulation of specific clinical conditions.[6]

[a] Corresponding author, Private Practice, https://orcid.org/0009-0005-2017-2269, Email: msph6193@gmail.com

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- **Digital models:** Computerized dentistry has allowed the creation of virtual models that facilitate the planning of treatments and the simulation of occlusal forces.[7]

IMPORTANCE OF DENTAL MODELS IN RESEARCH AND TEACHING

The use of dental models has allowed significant advances in different dentistry areas:

- **Biomaterial Evaluation:** Facilitate adhesion and strength testing of new restorative materials before clinical use.[8]
- **Training in restorative techniques:** They provide dental students with a tool to develop manual skills without risk in patients.[9]
- **Biomechanical analysis:** They allow the study of the distribution of forces in restorations, implants, and dental prostheses.[10]

LIMITATIONS AND CONSIDERATIONS

Despite its many advantages, the use of dental models has certain limitations:

- **Structural differences with human teeth:** Artificial models may not accurately reproduce the microstructure of enamel and dentin, which can affect their mechanical and functional behavior. In addition, there are differences in human dental anatomy, such as crown morphology and dentin tubule arrangement, which may influence the validity of comparative studies.[11]
- **Standardization of experimental conditions:** It is essential to follow strict protocols in the collection, storage, and use of models to ensure the reproducibility of studies.[12]

USE OF ANIMAL DENTAL MODELS IN DENTAL EXPERIMENTATION

Experimentation in dentistry requires models that allow treatments and biomaterials to be evaluated before their application in humans. Animal teeth have been demonstrated to be a viable alternative for in vitro and preclinical studies due to their anatomical and physicochemical characteristics comparable to those of human teeth.[13] In this context, selecting the appropriate model depends on the structural similarity, availability, and ethical considerations associated with its use.[13]

MAIN ANIMAL DENTAL MODELS

Animal models used in dental experimentation include:

- **Bovine teeth:** Broadly used due to their large size, availability, and structural similarity to human teeth, especially in dental adhesion and erosion studies.[14]
- **Porcine teeth:** They have a morphology and composition similar to human teeth, which makes them suitable for research in periodontics and implantology.[15]
- **Sheep and goat teeth:** Used in studies of bone regeneration and biocompatibility of biomaterials due to the similarity of their alveolar bone to the human one.[16]

ETHICAL AND METHODOLOGICAL CONSIDERATIONS

The use of animal dental models in research should follow ethical principles that minimize suffering and promote the responsible use of these models. International regulations, such as those established by the International Committee on the Care and Use of Animals in Research, recommend the application of the principles of replacement, reduction, and refinement to ensure ethical practices in experimentation in accordance with the provisions of NOM-062-ZOO-1999.[17]

IMPORTANCE OF USING BOVINE TEETH

The use of bovine teeth as models in dental research has gained relevance due to their morphological and histological similarities with human teeth and their accessibility and availability. This practice allows researchers and students to conduct in vitro studies and preclinical practices effectively and ethically.[18]

Bovine teeth have a histological composition and anatomical shape that make them ideal for use as substitutes for human teeth in research on dental materials.[19]

In addition, bovine tooth enamel has been used as an experimental model for dental research, providing updated information about bovine teeth characteristics relating to their use as substitutes for human teeth in research work.[20]

However, recognizing the differences between bovine and human teeth, such as variations, is relevant. These differences must be considered when interpreting the results of the practices and when extrapolating conclusions to clinical practice.[21]

Although bovine teeth have some anatomical similarities to human teeth, they are not identical; there are significant differences, such as variations in the enamel's microhardness, the arrangement and density of the dentin tubules, and the dentin's structural composition. These differences should be considered when interpreting the results of experimental practices and when extrapolating conclusions to clinical practice, as they can influence the biomechanical response and the interaction with dental materials.[22]

JUSTIFICATION FOR THE USE OF BOVINE TEETH

Below is a classification of typical breeds and their main attributes:

Table 1. *Classification of cattle breeds.*[23]

Race	Key features	Common Usage

Holstein	Uniform tooth size; Easy availability.	Adhesion and wear studies.
Brahman	High mechanical strength; thick enamel.	Testing of restorative materials.
Hereford	Homogeneous chemical composition; High durability.	Research in endodontic treatments.

These animals' teeth have structural characteristics similar to humans, making them ideal for dental studies.[24]

BOVINE DIET

Cattle are ruminant herbivores. Their diet mainly consists of grass, hay, silage, and mineral and protein supplements. Diet influences tooth structure and wear. These are crucial aspects of research into dental materials.[25]

REASONS FOR CHOOSING CATTLE AS DENTAL MODELS

Cattle are chosen due to several advantages:
Adequate tooth size: Teeth, especially premolars and molars, have dimensions similar to those of humans.[26]
Availability: They are easy to obtain in slaughterhouses and farms.[27]
Structure of enamel and dentin: The mineral and mechanical composition of bovine teeth resembles that of humans.[28]
Reduced cost: Compared to primates or other models, cattle represent a more accessible and ethical alternative.[29]

CLASSIFICATION AND ADVANTAGES OF BOVINE TEETH

Bovine teeth are classified according to their anatomical function and similarity to human teeth.[30] The main types used are:

- **Incisors:** Due to their simple surface, they are ideal for dental aesthetics and adhesion studies. They offer a flat and uniform surface, facilitating the analysis of adhesive materials.[31]
- **Premolars:** Suitable for strength testing and restorative procedures. The larger size of premolars and molars allow for more complex procedures and comparison of advanced clinical techniques. [31]
- **Molars:** Used mainly in biomechanical studies and endodontic treatments.[31]

DIMENSIONS OF BOVINE AND HUMAN TEETH

Table 2 shows a comparison of the average dimensions of bovine and human teeth, highlighting the key differences:

Table 2. *Comparative table of bovine and human teeth.[14]*

Tooth Type	Length (mm)	Width (mm)	Enamel thickness (μm)
Bovine incisor	15 - 20	6 - 8	300 - 400
Human Incisor.	10 – 12	5 - 7	200 – 300
Bovine molar	25 - 30	12 - 15	400 – 600
Human molar	20 - 25	10 - 12	300 - 500

CHEMICAL COMPOSITION OF ENAMEL AND DENTIN

The chemical composition of bovine teeth is comparable to that of human teeth in terms of hydroxyapatite, collagen, water, and mineral content, as shown in Table 3.[13]

Table 3. *Chemical composition of enamel and dentin of human and bovine teeth.[13]*

	Enamel		Dentin	
Component	**Human (%)**	**Bovine (%)**	**Human (%)**	**Bovine (%)**
Hydroxyapatite	96	95	70	68
Collagen	0	0	20	22
Water	4	5	10	10
Minor minerals	<1	<1	<1	<1

Human tooth enamel coats the dentin in its crown portion like a cap, providing a protective barrier against the underlying dentin and pulp. It is the hardest tissue in the body due to its high mineralization and the orderly arrangement of its prisms, which extend from the amelodentinal limit to the external surface in contact with the oral environment. Its hardness lies in the absence of collagen and its chemical composition, characterized by 95% inorganic matrix and 0.36 - 2% organic matrix, composed mainly of proteins and polysaccharides.[32]
The inorganic component is made up of hydroxyapatite (HPA) crystals, composed of calcium phosphate and hydroxyl groups ($Ca_{10}[PO_4]_6[OH]_2$), with the possibility of incorporating ions such as magnesium, sodium, chlorine, potassium, carbonate,

and fluorine, which modify their physicochemical properties.[33] Despite its structural similarity to other mineralized tissues such as bone, dentin, and cementum, enamel is distinguished by the greater density and size of its HPA crystals.[34]

The structural unit of the enamel is the prism, which is made up of the compact arrangement of HPA crystals. However, its microscopic study is complex due to the optical interference generated by its crystalline composition and the variability in the orientation of the crystals within each prism. In addition, the enamel has secondary structural units caused by variations in the degree of mineralization, the arrangement of the prisms, the enamel-dentin interaction, and exposure to environmental factors.[35]

From a morphological point of view, HPA crystals adopt an elongated hexagonal shape when observed in cuts perpendicular to their longitudinal axis. While in parallel cuts, they present a rectangular configuration.[36] These crystals are formed by the aggregation of unit cells, constituting the structural basis of crystalline minerals.[37]

Water is the third component of enamel and is located on the periphery of the crystals, forming the so-called hydration layer. Deeper into the crystal, one finds the absorbed ions and compounds layer. The water content in the enamel progressively decreases with the age of the tooth, which influences its biomechanical properties.[38]

The enamel formation process, known as amelogenesis, begins in the sixth week of intrauterine life. This phenomenon involves the synthesis of an organic matrix on which mineral salts are deposited.[37] Classically, dental embryogenesis is described in four successive stages: yolk, cap, bell and tooth follicle.[38] During this process, ameloblasts and intermediate stratum cells secrete the organic matrix of HPA enamel and crystals, resulting in their mineralization.[39]

Three essential proteins are involved in this phase: amelogenin (90%), which regulates the initiation and growth of crystals; enamel (5%), involved in the nucleation and extension of crystals; and ameloblastin (5%), which participates in the differentiation of ameloblasts. After completing the enamel formation, the ameloblasts disappear by apoptosis during tooth eruption, which gives the enamel its acellular and highly mineralized character.[40]

The hardness of enamel is due to its high HPA content, ranking fifth on the Mohs scale.[41] This gives it high resistance to abrasion and external forces, although it has low elasticity and depends on its water and organic matter content.[42] When dentin support is absent, the enamel is prone to macroscopic and microscopic fractures. In addition, its translucency varies according to the degree of mineralization, which influences the perception of its color, which ranges from yellowish-white to grayish-white.[43]

Although enamel is highly impermeable, it can function as a semipermeable membrane, allowing the passage of water and specific ions present in the oral environment. Its high mineralization also gives it a remarkable radiopacity, facilitating its study using imaging techniques.[44]

For dental research, the use of extracted human teeth requires institutional ethical approval. Given the difficulty of obtaining enough human teeth, teeth from different animal species have been used as an alternative.[45] It has been observed that the teeth of cattle, pigs, primates, sheep and horses have similar structural and physicochemical characteristics to human teeth, which allows their use in experimental studies.[46]

Research has shown that bovine incisors, in particular, have been successfully used in adhesion studies, microfiltration, trace element analysis, and morphological evaluation. Ortiz Ruiz et al.[47] compared the enamel's crystalline composition and dentin of various species, finding that human enamel has wider and lower crystals than other species but with higher structural similarity to bovine enamel.

For their part, Arango-Santander et al.[46] compared the microhardness of human and bovine enamel, finding similar values between the two, suggesting that bovine enamel could be a suitable experimental model for ex vivo studies in dental materials and shear resistance. However, it has been stated that the adhesion and tensile strength tests present some methodological heterogeneity, which requires a cautious interpretation of the results.[48]

Recent studies have shown that the dehydration of enamel influences its mechanical properties, increasing its hardness and reducing the coefficient of friction. These findings suggest that dehydrated enamel could exhibit superior mechanical behavior to hydrated enamel, which has implications for the research and application of dental biomaterials.[49]

BOVINE TEETH PREPARATION

- **Collection and storage**

Bovine teeth are primarily sourced from slaughterhouses, where they are collected in sanitary conditions. To prevent biological degradation, they are stored in disinfectant solutions such as sodium hypochlorite.[50]

- **Sterilization**

Microbiological safety is guaranteed by methods such as autoclaving or immersion in disinfectant solutions, preserving the tooth structure.[51]

- **Adaptation**

The cutting and modeling of bovine teeth is done to replicate the dimensions of human teeth, optimizing their use in research and teaching.[52]

BOVINE TEETH APPLICATIONS IN DENTAL RESEARCH

Bovine teeth have been used in studies, playing a crucial role in multiple research areas:[53]

- **Adhesion studies**:

They allow the strength of restorative materials bonding to the tooth structure to be evaluated.[54] Studies have shown that bovine teeth can help assess the adhesion of composite resins,

resin cements, and other restorative materials, providing results comparable to those obtained with human teeth.[55] Recent research has explored the influence of different surface preparation protocols on the adhesion of materials, analyzing techniques such as acid etching, the application of universal adhesives, and laser or plasma activation.[56,57]

Despite these advantages, it is relevant to consider the differences in microstructure and chemical composition between bovine and human teeth. For example, the lower density of bovine enamel and its prismatic characteristics can affect the infiltration of adhesive systems, which could influence the long-term bond strength.[58] However, when standardized protocols are implemented and comparative studies conducted, bovine teeth remain a valuable tool for dental bonding research.

- **Research on erosion and abrasion**:

They facilitate the analysis of the effects of acids and abrasive agents on the enamel structure.[59] Dental erosion and abrasion are wear processes that compromise the structural integrity of teeth and affect their long-term functionality. To study these phenomena, experimental models play a key role in dental research.[60]

Dental erosion, mainly caused by exposure to extrinsic (food, drink) or intrinsic (gastric reflux) acids, has been investigated using bovine teeth in vitro. Research has evaluated the ability of different remineralizing agents, such as fluorides, hydroxyapatite nanoparticles, and biomaterials, to prevent acid wear.[61,62] Models based on bovine enamel have made it possible to analyze the mineral loss and effectiveness of protective strategies before their application in clinical studies.

On the other hand, dental abrasion, caused by mechanical factors such as excessive brushing or using abrasive toothpaste, has also been analyzed using bovine teeth. Studies have compared the wear resistance of different restorative materials and enamels treated with protective agents.[63] Although bovine enamel has differences in microstructure and mineral density compared to human enamel, its controlled use under standardized experimental conditions allows extrapolable results.[64]

We understand that bovine teeth are a fundamental tool in dental erosion and abrasion research, facilitating the development and validation of preventive and therapeutic strategies. However, it is crucial to consider their limitations and complement the findings with studies in human teeth and clinical models to strengthen the validity of the results.

- **Biomaterial Testing**:

They examine the durability and compatibility of composite resins, cement, and dental adhesives.[65] Bovine teeth are used as substrates in biomaterial adhesion research to evaluate resin cements, dental adherents, and protective coatings. Studies have shown that surface preparation protocols, such as acid etching and primer application, influence the bond strength between biomaterials and bovine dental tissue, providing valuable information for the optimization of restorative materials.[66,67]

Likewise, bovine teeth have been used in mechanical resistance and wear tests of restorative materials. Research has evaluated the durability of composite resins, ceramics, and hybrid materials subjected to simulated masticatory forces, which makes it possible to predict their behavior in the oral cavity.[68] In addition, in biocompatibility studies, these teeth have been used to analyze the response of mineralized tissue to new biomaterials with remineralizing or antibacterial properties.[69]

Despite its advantages, it is relevant to consider specific differences between bovine and human teeth, such as the higher porosity of bovine dentin and variations in enamel microstructure, which can influence the extrapolation of the results. However, when standardized methodologies are employed, bovine teeth are still an essential resource in the preclinical evaluation of dental biomaterials.

- **Teeth whitening tests**:

They are used to investigate the use of bleaching agents on the enamel structure.[70] Teeth whitening is a procedure widely used in cosmetic dentistry to remove pigmentation and improve the appearance of teeth. To evaluate the effectiveness and safety of bleaching agents, it is necessary to have experimental models that simulate the structure of human enamel.[71]

In laboratory studies, researches have examined the effectiveness of various peroxides, including hydrogen peroxide and carbamide peroxide, on bovine teeth. These studies also investigated how factors such as the concentration of the whitening agent, the application duration, and the use of light sources for activation affect the results.[72] In addition, they have made it possible to evaluate changes in the structure of the enamel, measuring parameters such as microhardness, surface roughness, and mineral loss after whitening treatments.[73]

Another relevant application of bovine teeth in teeth whitening trials is the comparison of strategies to reduce adverse effects, such as tooth sensitivity and demineralization. Research has explored the use of remineralizing agents, such as hydroxyapatite and fluoride, to counteract the erosive effects of bleaching products and preserve the structural integrity of enamel.[74]

Although bovine teeth have specific differences from human teeth, such as higher permeability of the enamel and a slightly different prismatic arrangement, their use in controlled experimental conditions allows us to obtain valuable information on the safety and efficacy of whitening treatments before their application in clinical practice.[75]

CONSIDERATIONS IN THE USE OF BOVINE TEETH

Despite their advantages, the use of bovine teeth in dental research requires certain precautions:

- **Structural variability**: Factors such as the age of the animal and its diet can influence the composition of the enamel and dentin.[76]
- **Differences in dentin permeability**: Although similar to human dentin, bovine dentin has higher

permeability, which can affect the interpretation of adhesion studies.[77]

- **Need for standardization**: It is essential to establish uniform protocols for sample collection, storage, and preparation to ensure the reproducibility of the results.[78]

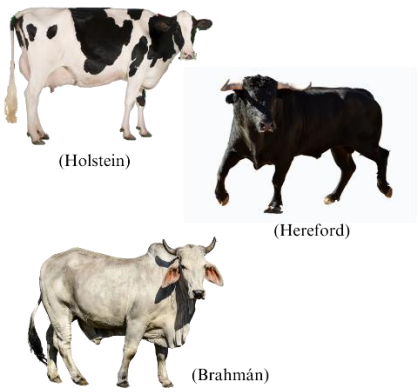

Figure 1. Cattle breeds used in dental studies.[79]
Mexico has several cattle breeds, including:
Meat breeds (examples: Charolais, Brahman, Beefmaster)
Dairy breeds (examples: Holstein, Jersey)
Dual-purpose breeds (examples: Simmental, Swiss Brown)

Figure 1 shows the cattle breeds used in dentistry and selected according to specific characteristics such as size, structure, and availability.[79]

PRECLINICAL TEACHING

In preclinical dental training in Mexico, using bovine teeth as models for practices and studies has gained relevance due to their similarities with human teeth and easy access. This practice allows students to develop clinical skills in a controlled environment before caring for real patients.[80]
Bovine teeth share histological and morphological features with humans, making them viable substitutes for dental teaching and research, considering the difference between tooth size and structure. Its use in preclinical activities facilitates understanding procedures such as cavity preparation and applying restorative materials and adhesion techniques. In addition, as they are more accessible and economical than human teeth, they represent a practical alternative for educational institutions.[81]
However, it is important to recognize differences between bovine and human teeth, such as variations in the enamel microhardness and the structure of the dentin. One of the main differences is the **size**, as bovine teeth are significantly larger than humans, which can affect the distribution of forces and the adhesion of dental materials.[14,30]
In addition, the morphology and arrangement of dental tissues also vary. For example, bovine dentin has more dentin tubules and a different orientation compared to human dentin, which can influence material leakage and structural strength. Also, the thickness of the enamel is different, which can alter the response to restorative and bonding procedures.[13,30]
For these reasons, although bovine teeth are frequently used in dental research due to their availability and overall structural similarity, it is crucial to acknowledge and consider these differences to interpret accurately the results and their clinical application.[82]
Although in Mexico, there is no specific data on the prevalence of using bovine teeth in preclinical education, several institutions have adopted this practice due to its pedagogical and logistical advantages. The use of bovine teeth in preclinical training contributes to developing technical competencies in students, effectively preparing them for their future professional practice.[83]
Incorporating bovine teeth in preclinical dental teaching in Mexico offers a valuable tool for student training, allowing the acquisition of practical skills in a safe and controlled environment.[64] However, it is essential that educators are aware of the limitations and differences between bovine and human teeth to ensure comprehensive and accurate training.[84]

CONCLUSION

Due to their chemical and structural similarities, using bovine teeth as models in dentistry represents an ethical, economic, and scientifically valid solution to human teeth. Therefore, it is a viable alternative for dentistry research and teaching in Mexico.

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