GEORGIAN BIOMEDICAL NEWS

VOLUME 2 ISSUE 4. OCT- DEC 2024

Balance of Calcium and Magnesium in Tooth Enamel and Dentin

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DOI: 10.52340/GBMN.2024.01.01.90

ABSTRACT

Background: The structural integrity of hard dental tissues—enamel, dentin, and cement—is critical to dental and oral health. Irreversible degradation of these tissues due to trace element imbalances can weaken tooth function.

Objectives: This study aims to investigate magnesium (Mg) concentrations in enamel and dentin and examine its correlation with calcium (Ca) to assess the influence of these trace elements on dental tissue stability and integration.

Methods: The study sample consists of 20 extracted, intact teeth, and Ca and Mg concentrations were measured via X-ray spectral analysis.

Results: Findings indicate that a high concentration of Ca in enamel corresponds to low Mg levels. In contrast, Mg levels increase at the enamel-dentin junction in the presence of reduced Ca, suggesting an antagonistic relationship.

Conclusions: These results underscore that the balance between Ca and Mg is essential for dental tissue mineralization and structural stability.

Keywords: Calcium (Ca); Cementum; Dental tissues; Dentin; Enamel; Magnesium (Mg); Mineralization; Oral health; Structural integrity; Trace elements.

BACKGROUND

The structural integrity of hard dental tissues—enamel, dentin, and cement—is essential for tooth and oral health. Structural degradation in these tissues, which various factors can provoke, is largely irreversible and compromises tooth function. The health and structural stability of teeth are influenced by local and systemic factors, notably the proper balance of mineral components within the body.[1-3]

In previous studies, we investigated the concentrations of key trace elements—calcium (Ca), phosphorus (P), and fluoride (F)—in enamel and dentin, where results indicated that the levels of calcium and phosphorus in enamel were approximately twice those in dentin, while fluorine content was six times higher.[2]

The current study focuses on analyzing the concentration of magnesium (Mg) in hard dental tissues and examining its correlation with calcium (Ca) to better understand their roles in maintaining structural integrity.

Magnesium (Mg) is an essential mineral critical to numerous physiological processes, and its deficiency is associated with the exacerbation and etiology of various diseases.[4-6] The human body contains approximately 21-28 grams of magnesium, with over 53% localized in bone tissue, while the remainder resides primarily in soft tissues and only about 1% in extracellular fluid.[7-9]

Magnesium primarily functions as an intracellular ion and acts as a cofactor in cellular metabolism, participating in nearly 200 enzymatic reactions in the cellular cycle. Key physiological roles of magnesium include:

- **Cardiovascular support:** Regulates heart rhythm and enhances cardiac function;
- **Vasodilatation:** Facilitates blood flow and aids in lowering arterial pressure;
- **Neuromuscular function:** Essential for nerve-muscle impulse transmission, thus supporting heart and brain health;
- **Bone health:** Contributes to bone formation and improves bone mineral density, a vital factor in osteoporosis prevention;
- **Vitamin D activation:** Participates in vitamin D activation within the kidneys;
- **Calcium antagonism:** Magnesium helps prevent kidney stone formation as a calcium antagonist;
- **Glycemic control:** Plays a role in regulating blood sugar levels;
- **Mental health:** Reduces susceptibility to depression and irritability;
- **Anti-inflammatory effects:** Exhibits anti-inflammatory properties;
- **Gastrointestinal health:** Can partially neutralize excessive stomach acidity.[4,10-13]

Extensive medical literature indicates a direct correlation between magnesium levels and calcium absorption. Specifically, magnesium facilitates calcium absorption, which is crucial for maintaining healthy bone structure. Magnesium deficiency can result in excessive calcium accumulation, leading to complications within the muscular, cardiovascular, and skeletal systems.[8,10,11]

Magnesium also plays a pivotal role in regulating parathyroid hormone (PTH), essential for calcium homeostasis. A magnesium deficiency can impair PTH production, subsequently disrupting calcium balance.[14,15]

Furthermore, calcium and magnesium interact to regulate muscle contraction and relaxation. Insufficient magnesium can impair muscle contraction, thereby affecting calcium's efficacy and vice versa, underscoring the interdependent roles of these minerals in musculoskeletal health.

Calcium and magnesium are integral to the blood coagulation process. Magnesium helps to prevent excessive calcium activity, which is critical for maintaining proper coagulation function.[12,17] While magnesium's importance in general health is well-documented, the specific effects of its deficiency or excess on hard dental tissues remain underexplored.

Enamel and dentin are complex structural tissues with a unique mineral composition rich in inorganic elements, including magnesium. However, magnesium's precise quantity and role relative to other trace elements, such as calcium and phosphorus, have been less extensively studied.

Among the four inorganic tissues in the human body—bone, enamel, dentin, and cement—enamel is the most highly mineralized. Its composition is predominantly hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), along with carbonated apatite ($Ca_{10}(PO_4)_6(CO_3)_2$), chlorapatite ($Ca_{10}(PO_4)_6Cl_2$), and strontium apatite ($Ca_{10}Sr(PO_4)_6$), with hydroxyapatite being the most prevalent.

Although magnesium is present in only small amounts in enamel, it plays a crucial role in the stability and integration of enamel crystals, promoting the incorporation of calcium and phosphorus.[18-20] Magnesium is essential to dentin, facilitating complete mineralization through enhanced calcium absorption.

Based on this, we hypothesize that magnesium deficiency may disrupt calcium metabolism, potentially leading to the demineralization of hard dental tissues.[11,21]

Our study aimed to determine the concentrations of calcium (Ca) and magnesium (Mg) in intact human teeth' enamel and dentin and investigate their correlation. To accomplish this, we determined the distribution of trace elements in the enamel and dentin of extracted human teeth using X-ray spectral methods.

METHODS

To determine target trace elements' concentrations and distribution characteristics, 20 intact, extracted human teeth were selected. Indications for tooth extraction included trauma or decisions made by orthodontists or periodontists, with patient ages ranging from 16 to 60 years. Extracted teeth were stored by the national clinical management protocol, Infection Prevention during Handling of Extracted Human Teeth, Parapulpar Tissues, and Surgical Materials (2020. 21. 02, #01-282/ო).

Trace element concentrations of calcium (Ca) and magnesium (Mg) were examined in three distinct regions: enamel (Zone 1), the enamel-dentin junction (Zone 2), and the parapulpar area (Zone 3). Each tooth was longitudinally sectioned using a separating disk, dividing it into two halves to expose all layers of hard tissue for analysis, yielding 40 experimental specimens.

Half of these samples (20 specimens) were used to study trace element concentrations in enamel and dentin. Acid etching was performed on these samples using 35% phosphoric acid ("Ultra-Etch") as per the protocol stages (Fig.1). Following washing and drying of the control samples, their elemental composition was analyzed. This study utilized a JEOL scanning electron microscope for analysis.

FIGURE 1. Preparation of samples for study: separation and acid etching

The atoms of elements in any material, including dental tissues, exhibit characteristic radiation with specific wavelengths and intensities. This principle forms the basis of X-ray spectral analysis methods, which enable the determination of a material's elemental composition.

For this study, the distance between the electron emission tube and the surface of the tooth samples was set to 15 mm. To minimize surface charging effects, samples were coated with a 10 nm thick layer of platinum using a JEOL vacuum coating device (Fig.2 and Fig.3). The analyzer's software generated results in a Word document format, containing the X-ray emission spectra for the targeted regions, expressed in both mass and atomic percentages, and tables detailing the identified elements and their concentrations.

FIGURE 2. JEOL vacuum coating device

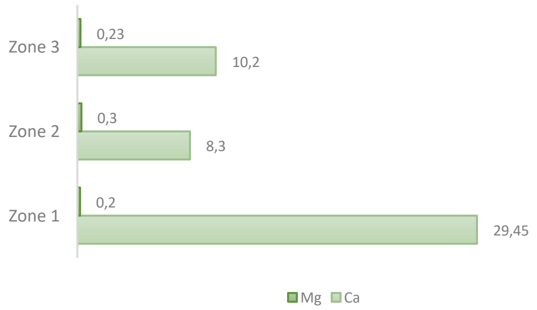
ISSN (Online): 2720-8796 ISSN (Print): 2720-7994

FIGURE 3. Experimental samples coated with a 10 nm thick layer of platinum

RESULTS

The study results demonstrated, consistent with prior research, that calcium concentration was highest in the enamel layer, reaching 29.45. This concentration was nearly threefold lower in the dentin adjacent to the cement (10.2) and approximately 3.7 times lower at the enamel-dentin junction (8.3) (Fig.4).

FIGURE 4. Concentrations of trace elements (Ca, Mg) in tooth hard tissues



Explanations: Zone 1, enamel; Zone 2, enamel-dentin junction; Zone 3, parapulpar dentin.

In contrast to the elevated calcium levels, magnesium concentrations were considerably lower across all layers. Specifically, the magnesium concentration in the enamel (first layer) was 0.20, increased slightly to 0.3 in the dentin near the enamel (second layer), and was 0.23 in the dentin adjacent to the cement (third layer).

The statistical analysis of the obtained numerical data revealed a significant difference in the concentrations of calcium and magnesium in both the enamel and dentin layers. Specifically:

- In the first layer (enamel), the comparison of the average values of calcium and magnesium showed $t = 19.61$ ($P < 0.0001$), indicating that the difference is highly significant;
- In the second layer, the result was $t = 4.79$ ($P < 0.0001$), which is also statistically significant. A comparative analysis of the third layer is also important ($t = 8.05$; $P < 0.0001$).

Examination of the diagram revealed that the average calcium level at the dentin-enamel junction is significantly lower (8.3) than in the other two layers. At the same time, the concentration of magnesium is much higher in the second layer than in the first and third. This further confirms the antagonistic relationship between these two trace elements.

DISCUSSION

The findings of this study emphasize the critical role of calcium (Ca) and magnesium (Mg) in maintaining the structural integrity and stability of dental tissues. By identifying an antagonistic relationship between these two trace elements across different layers of tooth structure, this research provides valuable insight into the mineralization process and the interplay of essential minerals in enamel and dentin.

Significance of calcium and magnesium balance

Calcium is well-established as a primary contributor to the mineralization and hardness of enamel and dentin. As observed in this study, its high concentration in the enamel layer reinforces its role as a structural foundation for resisting external forces and protecting the underlying dentin. Conversely, magnesium exhibits significant variability across the tooth's structural layers while present in smaller amounts, particularly at the enamel-dentin junction. This variation indicates that magnesium serves a regulatory role, ensuring proper distribution and stabilization of calcium within the dental matrix.

The antagonistic relationship between Ca and Mg, evidenced by their inverse concentrations, suggests a delicate balance critical for dental tissue health. Magnesium's increased presence at the enamel-dentin junction may act as a buffering system, preventing excessive calcium mineralization and maintaining tissue flexibility and resilience.

Comparison with Existing Research

Previous studies have highlighted the importance of calcium and phosphorus in enamel and dentin; however, magnesium's role has yet to be explored. The current findings build upon earlier research by demonstrating that magnesium is not merely a passive trace element but an active participant in the mineralization process. The antagonistic interplay between Ca and Mg aligns with physiological mechanisms observed in bone tissue, where magnesium modulates calcium deposition and prevents pathological calcification.

Clinical Implications

The study's results have direct implications for both preventive and restorative dentistry. Magnesium deficiency, common due to dietary insufficiencies or systemic conditions, could compromise the balance between Ca and Mg, potentially leading to enamel demineralization or increased brittleness.

CONCLUSIONS

The antagonism between calcium and magnesium represents a physiological phenomenon characterized by the "competition" between these essential minerals within the human body. This competition extends to hard dental tissues, as evidenced by our study findings. Specifically, calcium

ISSN (Online): 2720-8796 ISSN (Print): 2720-7994

concentration in the enamel layer was the highest (29.45), whereas magnesium concentration was notably lower (0.20).

At the dentin-enamel junction, the average calcium level was significantly lower than the other layers (8.3). At the same time, the magnesium concentration reached its highest level relative to the enamel and dentin near the cement. This suggests that while calcium is crucial for maintaining the health and structural integrity of enamel and dentin, magnesium is essential in ensuring the proper balance and distribution of minerals within these dental tissues.

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Georgian Biomedical News
ISSN (Online): 2720-8796 ISSN (Print): 2720-7994