

Morphological and Chemical Characterization of Conventional MTA versus Bacterial Cellulose-Reinforced MTA Using TEM and EDX

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Abstract

Aim: This study aimed to evaluate and compare the morphological and elemental characteristics of conventional Mineral Trioxide Aggregate (MTA) and Bacterial Cellulose-Reinforced MTA (BC-MTA) using Transmission Electron Microscopy (TEM) and Energy Dispersive X-ray Spectroscopy (EDX).

Materials and Methods: Cylindrical molds (6 mm in diameter × 4 mm in height) were fabricated from plexiglass in accordance with ASTM E385 standards using CNC laser cutting. Two groups were evaluated:

Group 1 comprised conventional MTA (MTA Plus™), and Group 2 comprised BC-MTA (Vedayukt India Pvt. Ltd.). The prepared samples were incubated under fully saturated conditions at 37°C for 24 hours. Following incubation, samples underwent morphological evaluation using TEM and elemental analysis using EDX. Statistical analysis was conducted using Student’s t-test, with results expressed as mean ± standard deviation (SD). A p-value < 0.0001 was considered highly statistically significant ($\alpha = 0.05$).

Results: TEM imaging revealed distinct structural differences between MTA and BC-MTA, with BC-MTA exhibiting a more aggregated nanoparticle morphology. EDX analysis demonstrated statistically significant differences in elemental composition between the two groups ($p < 0.0001$), confirming the influence of bacterial cellulose incorporation on the physiochemical properties of MTA.

Conclusion: The incorporation of bacterial cellulose into MTA resulted in notable structural and elemental modifications, potentially enhancing its mechanical strength and bioactivity. These findings suggest that BC-MTA holds promise as an improved bioactive material in pediatric endodontic and restorative applications. Further clinical studies are warranted to assess its long-term efficacy and biocompatibility.

Keywords: Mineral Trioxide Aggregate, Bacterial Cellulose Reinforced Mineral Trioxide Aggregate, Transmission Electron Microscopy, Energy Dispersive X-Ray Spectroscopy, Physiochemical Property.

Introduction

In recent years, pediatric dentistry has seen significant progress in dental materials, striving to enhance oral health care for infants, children and adolescents. Among these advancements calcium silicate based materials have gained attention as a promising category of dental materials, offering unique properties and applications that could transform, pediatric dental treatments. Their development represents a crucial step towards safer, more effective and biocompatible restorative materials for young patients ¹.

Mineral Trioxide Aggregate (MTA) is a bioactive cement based on calcium silicate, originally derived from portland cement ². MTA was introduced in dental literature by Lee et al ³. It was the first calcium silicate based cement approved by the FDA in 1998 and is

recommended by the AAPD for pulp capping ⁴⁻⁶. It is composed of a hydrophilic powder, where the MTA powder reacts with the liquid to produce calcium hydroxide and a calcium silicate hydrate gel, which solidifies into a hardened cement within approximately four hours ⁷⁻⁸.

MTA was initially designed for clinical approach where maintaining a dry oral environment posed a challenge. It is widely used in endodontical procedures such as perforation repair, apexification, root-end filling, apexogenesis, pulp capping and pulpotomy ⁹⁻¹⁰. Although both in vitro and in vivo studies have shown that MTA cements outperform calcium hydroxide-based cements in pulp capping, certain drawbacks have been identified in its original formulation. These include poor handling properties, extended setting time, tooth discoloration, high cytotoxicity in its freshly mixed state, low compressive strength and high cost ^{8,10}. To overcome these limitations, researchers have explored modifications to hydraulic cement by incorporating substances like methylcellulose, calcium chloride, zinc oxide, eugenol, and chitosan ¹⁰⁻¹¹. Notably, the inclusion of bacterial cellulose nanocrystals (BCNCs) has significantly improved the physiochemical properties of MTA ¹⁰.

Cellulose is obtained from abundant sources, including plant-based materials and specific bacterial strains ¹⁰⁻¹¹. Bacterial cellulose, a naturally occurring hydrogel and eco-friendly polymer, has been gaining significant attention. This unbranched polymer consists of (1→4) β-glycosidic linked glucose units and forms nanofibrils produced by certain aerobic bacteria, primarily from the *Komagataeibacter* genus. Among these, *Komagataeibacter xylinus* is the most notable species responsible for its synthesis, utilizing glucose as a substrate ¹²⁻¹⁴.

Bacterial cellulose exhibits several beneficial properties, including interconnected porosity, high water retention capacity, superior biocompatibility, and adaptability in shaping, with mechanical characteristics comparable to those of certain hard and soft tissues¹⁰⁻¹². It is non-toxic, hydrophilic, non-allergenic, and biodegradable when modified, making it highly valuable in both medical and dental applications¹³⁻¹⁴.

Moreover, bacterial cellulose has been granted "Generally Recognized as Safe" (GRAS) status for food applications by the U.S. Food and Drug Administration (FDA)¹⁵⁻¹⁶. Additionally, it was developed by the Council of Scientific and Industrial Research, Indian Institute of Integrative Medicine and classified under code 42 by the Drugs Controller General of India (DCGI) for dental materials¹⁶. Given these properties, bacterial cellulose holds significant promise as a biomaterial for dental and oral applications and can be integrated with various dental materials.

Energy Dispersive X-ray (EDX) and Transmission Electron Microscopy (TEM) analysis provide a comprehensive evaluation of MTA's structural integrity, chemical composition, and modifications, ensuring its clinical effectiveness. Therefore, the present study aimed to analyze and compare the chemical and morphological characteristics of MTA and Bacterial cellulose-reinforced MTA (BC-MTA) using EDX and TEM analysis.

Materials and Methods

Type of study

It is an invitro study. The study was performed under a controlled experimental setup which facilitated the reliable data collection and comparative assessment of the chemical composition and morphological structure of MTA and its bacterial cellulose-modified counterpart (BC-MTA). The materials used in this study were categorized into two groups: Group 1 consisted of MTA

[MTA Plus™], while Group 2 included BC-MTA [vedayukt india private limited].

Preparation of BC-MTA

This study employed bacterial cellulose, which holds a Generally Recognized as Safe (GRAS) designation under 21 CFR 182.1, as per the Federal Food, Drug, and Cosmetic Act (Section 321(s)). This classification is based on rigorous scientific assessment and independent review¹⁰. The samples were meticulously prepared in a controlled laboratory setting to guarantee reproducibility and accuracy.

For the BCNC-modified MTA, a precise ratio of 33.34% wt bacterial cellulose nanocrystals (BCNCs) and 66.66% wt MTA was homogeneously blended to ensure uniform distribution¹⁷. The mixture was then stored in an amber-coloured bottle under cool, dark conditions to prevent degradation from light exposure and maintain material integrity¹⁰.

Sample preparation of MTA and BC-MTA

A cylindrical plexiglass mold with dimensions of 6 mm in diameter and 4 mm in height was fabricated in accordance with ASTM E384 standards using a computer numerical control (CNC) laser cutting system. The fabrication was performed under optimized parameters—4200 watts power, 4400 mm/min cutting speed, and 0.8 MPa pressure—at the Saveetha Institute of Dental Sciences and Research, Chennai, India.

The manipulation of BCNC-reinforced MTA Plus™ was performed using a water-to-powder ratio of 3:1, while conventional MTA Plus™ was prepared in accordance with the manufacturer's guidelines, using a standard 1:1 powder-to-water ratio. Following preparation, the samples were incubated in fully saturated conditions at 37°C for a duration of 24 hours to ensure complete setting¹⁰.

EDX and TEM analysis

After a 24-hour incubation period, the pellets were retrieved, vacuum desiccated, and analyzed. For EDX, the materials were embedded in EpoFix resin (Struers, Rotherham, UK), then ground and polished using a Phoenix Beta system (Buehler, Coventry, UK). Imaging was performed with a TEM analysis (EVO MA10, Carl Zeiss, Cambridge, UK) in back scatter mode, while EDX analysis was conducted on selected areas¹⁸⁻¹⁹.

Statistical analysis

Statistical analysis was performed using Student's *t*-test to compare the elemental composition (in weight % and atomic %) between the BC-MTA and MTA groups based on EDX data. All measurements were expressed as mean \pm standard deviation (SD). A *p*-value of < 0.0001 was considered highly statistically significant, using a significance level of $\alpha = 0.05$. All statistical analyses were conducted using standard statistical software.

Results

The results confirmed the homogeneity and reliability of the sampled data, revealing statistically significant differences in the elemental composition between the two cements.

Figure 1: Elemental Composition Analysis of MTA using EDX

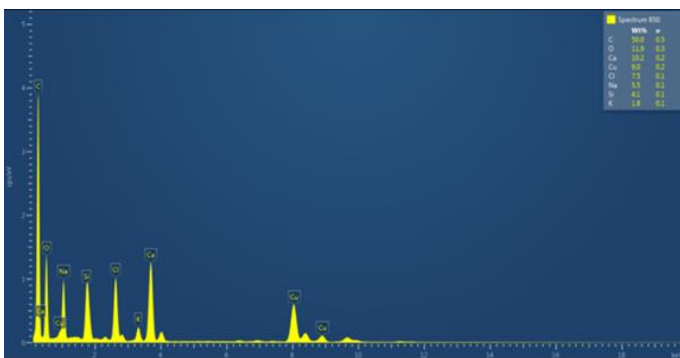


Fig. 1 represents EDX analysis of MTA provided detailed insights into its elemental composition, which directly influences its Physiochemical properties and clinical performance. The predominant element detected

was Carbon (C), which likely originated from organic components, contamination, or the embedding resin used during sample preparation. Oxygen (O) played a crucial role in the hydration process of MTA, forming calcium hydroxide and contributing to its bio activity. Sodium (Na) was detected, which may affect the setting kinetics and mechanical properties. Silicon (Si) was identified, likely originating from the calcium silicate phases of MTA, which are essential for its hydration reaction and mechanical integrity. Chlorine (Cl) was present, potentially due to calcium chloride additives that enhance setting and mechanical performance. Potassium (K) appeared in trace amounts, possibly from minor impurities. Calcium (Ca) was a key component, reinforcing MTA's bio activity and contributing to hydroxyapatite formation, which aids in dentin remineralization. The presence of Copper (Cu) may be attributed to instrument artifacts or contamination during sample handling. This compositional analysis confirms that Ca, Si, and O are fundamental to MTA's hydration and setting, while Cl enhances material performance. Additionally, the presence of Na, K, and Cu may indicate environmental interactions or minor impurities.

Figure 2: Elemental Composition Analysis of BC-MTA using EDX

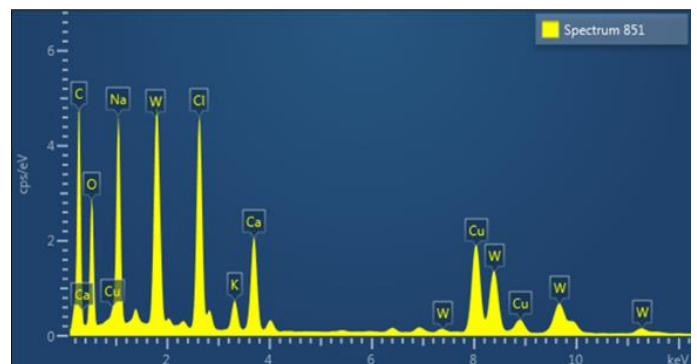


Fig. 2 represents EDX analysis of BC-MTA identified its elemental composition, emphasizing key components that influence its physiochemical characteristics. Like MTA, BC-MTA primarily contained Carbon (C),

Oxygen (O), Sodium (Na), Chlorine (Cl), and Copper (Cu). Potassium (K) was present in trace amounts, while Calcium (Ca) played a vital role in enhancing bio activity and mechanical strength. Additionally, Tungsten (W) was incorporated as a radiopacifier to improve visibility

in radiographic imaging. The elemental distribution suggests that Ca, O, and Cl contribute to BC-MTA's hydration, setting, and bioactive properties, whereas W ensures the necessary radiopacity, making it suitable for clinical applications.

Table 1: Percentages of elements found in the BC-MTA through EDX

| BC-MTA | C (Carbon) | O (Oxygen) | Na(sodium) | Cl (chlorine) | K (Potassium) | Ca(calcium) | Cu (Copper) | W (Tungsten) |
|----------|------------|------------|------------|---------------|---------------|-------------|-------------|--------------|
| Element | 22.86 | 9.81 | 10.32 | 13.59 | 1.89 | 6.39 | 10.89 | 24.07 |
| (wt%) | 22.83 | 9.79 | 10.31 | 13.55 | 1.96 | 6.33 | 10.93 | 24.01 |
| | 22.04 | 9.83 | 10.32 | 13.53 | 1.97 | 6.23 | 10.98 | 24.19 |
| | 22.79 | 9.33 | 9.99 | 13.44 | 2.01 | 6.22 | 10.79 | 24.77 |
| | 22.63 | 9.14 | 10.44 | 13.32 | 1.99 | 6.43 | 10.99 | 24.89 |
| Element | 49.27 | 15.88 | 11.62 | 9.91 | 1.32 | 4.13 | 4.48 | 3.39 |
| (at wt%) | 49.17 | 15.98 | 11.02 | 8.90 | 1.33 | 4.18 | 4.45 | 3.14 |
| | 48.09 | 15.76 | 11.53 | 8.89 | 1.45 | 4.29 | 3.89 | 3.88 |
| | 49.37 | 15.81 | 11.54 | 9.76 | 1.23 | 4.30 | 4.45 | 3.48 |
| | 49.23 | 15.77 | 11.69 | 9.56 | 1.19 | 4.13 | 3.99 | 3.40 |

wt% - weight percentage ^a

at wt% - Atomic weight percentage ^b

Table 1 represents the weight (wt%) and atomic weight (at%) percentage of BC-MTA. The database revealed that Tungsten (W) was the most abundant element, with an average concentration of approximately 24.39 wt%, followed by Carbon (C) at 22.63 wt%, and Chlorine (Cl) at 13.49 wt%. Other elements such as Sodium (Na), Copper (Cu), Oxygen (O), Calcium (Ca), and Potassium (K) were present in varying amounts, averaging 10.28 wt%, 10.92 wt%, 9.58 wt%, 6.32 wt%, and 1.96 wt% respectively. These values demonstrate a relatively

consistent elemental distribution across the tested samples, indicating good homogeneity of the cement.

In terms of atomic percentage (at%), Carbon was the predominant element with an average of 49.03 at%, followed by Oxygen (15.84 at%), Sodium (11.48 at%), and Chlorine (9.40 at%). Elements such as Potassium, Calcium, Copper, and Tungsten were found in smaller proportions, ranging between 1.19 to 4.48 at%. The presence of key elements such as Calcium and Tungsten reflects the characteristic constituents of MTA, while the presence of Carbon and Oxygen indicates the incorporation of bacterial cellulose, highlighting the composite nature of BC-MTA.

Table 2: Percentages of elements found in the MTA through EDX

| MTA | C (Carbon) | O(Oxygen) | Na (sodium) | Cl (chlorine) | K (Potassium) | Ca(calcium) | Cu (Copper) | Bi(Barium) |
|---------|------------|-----------|-------------|---------------|---------------|-------------|-------------|------------|
| Element | 24.28 | 21.66 | 1.52 | 0.81 | 20.61 | 6.26 | 24.66 | 0.22 |
| (wt%) | 23.14 | 20.01 | 1.54 | 0.88 | 20.66 | 6.13 | 24.08 | 0.22 |
| | 24.20 | 21.62 | 1.86 | 0.81 | 20.62 | 6.14 | 24.32 | 0.21 |

| | | | | | | | | |
|----------|-------|-------|------|------|-------|------|-------|------|
| | 23.42 | 22.01 | 1.42 | 0.89 | 20.08 | 6.23 | 24.13 | 0.19 |
| | 24.89 | 21.79 | 1.52 | 0.83 | 21.09 | 6.33 | 24.62 | 0.25 |
| Element | 44.56 | 29.83 | 1.43 | 0.66 | 11.77 | 3.96 | 8.91 | 0.04 |
| (at wt%) | 44.86 | 29.88 | 1.86 | 0.59 | 11.76 | 3.46 | 8.86 | 0.01 |
| | 43.46 | 29.79 | 1.59 | 0.39 | 10.98 | 3.96 | 7.46 | 0.02 |
| | 43.13 | 29.89 | 1.49 | 0.49 | 11.66 | 3.33 | 7.99 | 0.03 |
| | 44.76 | 29.99 | 1.46 | 0.50 | 10.62 | 3.45 | 8.56 | 0.02 |

wt%- weight percentage ^a

at wt%- Atomic weight percentage ^b

Table 2 represents the weight (wt%) and atomic weight (at%) percentage of MTA. The elemental analysis of MTA revealed its complex yet consistent composition across five analyzed samples. Weight percentage (wt%) analysis showed that Copper (Cu) and Carbon (C) were the most predominant elements, averaging 24.36 wt% and 23.59 wt% respectively. This was followed by Oxygen (O) at 21.82 wt% and Potassium (K) at 20.61 wt%, all contributing significantly to the material's matrix. Minor yet consistent levels of Calcium (Ca) (~6.22 wt%) were observed, supporting MTA's bio activity and setting capabilities. Sodium (Na), Chlorine (Cl), and Barium (Bi) were found in much smaller

concentrations, with Barium averaging just 0.22 wt%, possibly included for radiopacity purposes.

In terms of atomic percentage (at%), Carbon remained the dominant element with an average of 44.55 at%, followed by Oxygen at 29.88 at% and Potassium at 11.36 at%. Elements like Copper, Calcium, Sodium, and Chlorine made up the remainder in smaller amounts, while Barium was detected in trace quantities (averaging 0.02 at%). This composition is reflective of MTA's characteristic constituents, combining calcium silicate phases with radiopaque agents and minor additives, contributing to its well-documented sealing ability, biocompatibility, and radiopacity.

Table 3: t-test and p-values of percentages of elements in BC-MTA and MTA

| Element | BC-MTA (wt %) | MTA (wt %) | t-test | p-value |
|---------------|---------------|------------|----------|--------------|
| C (Carbon) | 22.63±0.34 | 23.99±0.70 | -3.873 | 0.0046*** |
| O (Oxygen) | 9.58±0.32 | 21.42±0.80 | -30.636 | < 0.00001*** |
| Na (sodium) | 10.28±0.17 | 1.57±0.17 | 81.844 | < 0.00001*** |
| Cl (chlorine) | 13.49±0.11 | 0.84±0.04 | 246.88 | < 0.00001*** |
| K (Potassium) | 1.96±0.05 | 20.61±0.36 | -115.406 | < 0.00001*** |
| Ca (calcium) | 6.32±0.09 | 6.22±0.08 | 1.810 | 0.1089*** |
| Cu (Copper) | 10.92±0.08 | 24.36±0.27 | -106.835 | < 0.00001*** |

wt%- weight percentage ^a

*** = p < 0.0001 (Statistically significant at α = 0.05)

Table 3 presents the results of the independent t-test comparing the mean weight percentages of selected

elements in BC-MTA and MTA. Statistically significant differences (p < 0.05) were observed in the elemental composition of all components except for calcium.

Carbon (C) content showed a statistically significant difference between the two materials ($p = 0.0046$), with MTA demonstrating a slightly higher mean value. Oxygen (O) levels were significantly elevated in MTA ($p < 0.00001$), while Sodium (Na) and Chlorine (Cl) were significantly more abundant in BC-MTA compared to MTA ($p < 0.00001$ for both), indicating the influence of bacterial cellulose on the overall elemental profile.

Potassium (K) and Copper (Cu) were both significantly higher in MTA than in BC-MTA ($p < 0.00001$),

Table 4: t-test and p-values of percentages of elements in BC-MTA and MTA

| Element | BC-MTA (at wt %) | MTA (at wt %) | t-test | p-value |
|---------------|------------------|---------------|--------|-------------|
| C (Carbon) | 49.03 ± 0.50 | 44.15 ± 0.74 | 12.39 | < 0.0001*** |
| O (Oxygen) | 15.84 ± 0.09 | 29.88 ± 0.07 | -262.3 | < 0.0001*** |
| Na (sodium) | 11.48 ± 0.25 | 1.57 ± 0.16 | 88.6 | < 0.0001*** |
| Cl (chlorine) | 9.40 ± 0.50 | 0.53 ± 0.10 | 48.1 | < 0.0001*** |
| K (Potassium) | 1.30 ± 0.10 | 11.36 ± 0.48 | -55.2 | < 0.0001*** |
| Ca (calcium) | 4.21 ± 0.08 | 3.63 ± 0.27 | 5.14 | 0.0009*** |
| Cu (Copper) | 4.25 ± 0.26 | 8.36 ± 0.59 | -16.8 | < 0.0001*** |

at wt%- Atomic weight percentage ^a

*** = $p < 0.0001$ (Statistically significant at $\alpha = 0.05$)

Table 4 presents the results of the *t*-test analysis comparing the atomic weight percentages of elements in BC-MTA and MTA. The findings indicate statistically significant differences ($p < 0.05$) in all measured elements.

Carbon (C) was found to be significantly higher in BC-MTA (49.03 ± 0.50 at %) than in MTA (44.15 ± 0.74 at %), with a *t*-value of 12.39 ($p < 0.0001$). In contrast, MTA exhibited a significantly higher atomic percentage of Oxygen (O) (29.88 ± 0.07 at %) compared to BC-MTA (15.84 ± 0.09 at %), with an exceptionally high *t*-value of -262.3, suggesting a considerable difference in oxygen content.

Sodium (Na) and Chlorine (Cl) levels were notably greater in BC-MTA, whereas Potassium (K) and Copper

suggesting a denser mineral framework in the conventional formulation. Notably, no statistically significant difference was found in calcium (Ca) content between the two groups ($p = 0.1089$), indicating a shared base in terms of bioactive potential.

These differences confirm that the incorporation of bacterial cellulose notably alters the elemental distribution within the BC-MTA matrix, potentially affecting its physiochemical and biological properties.

(Cu) were significantly higher in MTA ($p < 0.0001$ for all), emphasizing the distinct chemical signatures of the two materials. Calcium (Ca) content was also statistically different ($p = 0.0009$), although the numerical difference was relatively smaller, indicating some level of compositional similarity.

These variations highlight the impact of incorporating bacterial cellulose into MTA, which appears to alter the atomic distribution of key elements, potentially influencing the material's behavior in clinical applications.

Figure 3: TEM and EDX Analysis of BC-MTA

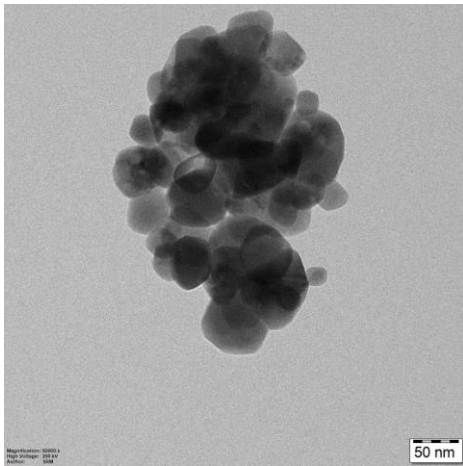


Fig.3 represents TEM micrograph of BC-MTA at 60000X magnification, taken during EDX analysis. The dark, clustered regions indicate agglomerated nanoparticles, suggesting the presence of bacterial cellulose nanocrystals (BCNCs) within the MTA matrix. The varying contrast levels signify differences in electron density, with denser regions likely corresponding to elements such as calcium (Ca), tungsten (W), and copper (Cu), previously identified in the EDX spectrum. The observed nanoscale morphology suggests a well-integrated composite structure, which may enhance the material's mechanical strength and bio activity. The scale bar (50 nm) confirms that the particles are within the nanometer range, supporting their potential role in improving the physiochemical properties of MTA.

Figure 4: TEM and EDX Analysis of MTA

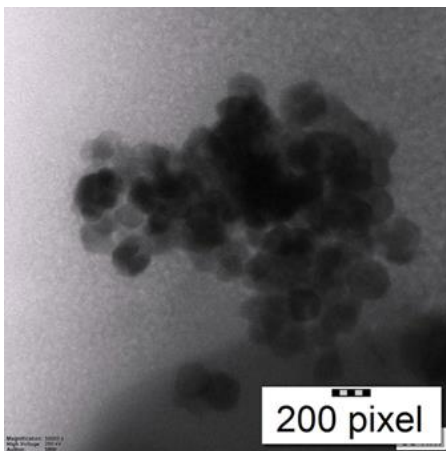


Fig.4 represents a TEM micrograph of MTA at 50000X magnification, taken during EDX analysis. The image reveals an agglomeration of nanosized or micro-sized particles, suggesting that MTA consists of irregularly shaped, loosely packed clusters. This could impact its handling properties and setting behavior. The dark contrast regions indicate areas of higher electron density, which might correspond to the denser phases in MTA, such as calcium silicates. The scale bar suggests that these particles are within the nanometer range. The variation in contrast and the apparent clustering of particles suggest potential porosity, which could influence hydration, bio activity, and mechanical strength. The observed morphology may contribute to the material's physiochemical properties, including its setting reaction, biocompatibility, and ability to form hydroxyapatite-like structures upon interaction with body fluids.

Discussion

The incorporation of bacterial cellulose (BC) into MTA has opened promising avenues in enhancing the performance of bioactive dental materials. The current study utilized TEM and EDX spectroscopy to evaluate the morphology and elemental composition of BC-MTA, comparing it with conventional MTA.

TEM analysis revealed a unique aggregated nanoparticle structure with irregularly shaped clusters in BC-MTA, suggesting a homogenous and well-integrated composite¹⁰. This morphology is likely to contribute to improved mechanical integrity, as nano cellulose is known for its high tensile strength and potential to enhance the physical properties of composites^{11,14-15}.

EDX analysis confirmed the presence of key elements such as calcium (Ca), oxygen (O), chlorine (Cl), and tungsten (W) in BC-MTA. The detection of tungsten, absent in traditional MTA, indicates its role as an

alternative radiopacifier, which is essential for clinical imaging¹⁰. Despite a slight reduction in calcium content compared to conventional MTA, BC-MTA maintains bioactive potential as calcium ions are crucial for hydroxyapatite formation and biomineralization^{2,6,8}.

Significantly, BC-MTA showed higher levels of sodium (Na) and chlorine (Cl), potentially impacting its setting reaction and antibacterial properties. Previous studies have shown that increased ion release, particularly calcium and chloride ions, enhances antimicrobial action and bioactivity^{2,7,18}. The absence of silicon (Si), commonly found in traditional MTA, might suggest altered setting characteristics, possibly due to the replacement or modification of its matrix by BC fibers¹⁰. Statistical analysis revealed significant differences in the elemental composition between BC-MTA and MTA ($p < 0.0001$), confirming that the incorporation of bacterial cellulose induces substantial physiochemical modifications. Furthermore, the consistency observed in the sampled data indicates material homogeneity and reproducibility, which are crucial for clinical reliability.

The biocompatibility of BC-MTA is supported by the natural origin and inert nature of bacterial cellulose. Materials containing calcium and derived from biopolymers typically exhibit excellent biocompatibility, low cytotoxicity, and favorable tissue response^{1,9,17}. BC also possesses high water retention and porosity, which may contribute to better ion exchange and facilitate cell adhesion and proliferation, essential for dental pulp healing^{12-13,16}.

In summary, the structural and compositional innovations introduced through BC reinforcement in MTA could potentially translate into better clinical outcomes. These include improved mechanical properties, enhanced bioactivity, and superior antibacterial performance. However, further in vivo studies and long-term

evaluations are essential to fully determine the clinical applicability of BC-MTA, particularly in pediatric endodontics where material performance plays a pivotal role.

Conclusion

The characterization of BC-MTA using TEM and EDX analysis has provided valuable insights into its structural and elemental composition. These findings suggest that BC-MTA has promising potential as an advanced dental material, offering improved physiochemical properties for clinical applications. Further studies are recommended to evaluate its long-term performance and biological interactions in pediatric endodontics and restorative dentistry.

Abbreviations

Mineral Trioxide Aggregate (MTA), Bacterial Cellulose-Reinforced MTA (BC-MTA), Transmission Electron Microscopy (TEM), Energy Dispersive X-ray Spectroscopy (EDX), standard deviation (SD), Food and Drug Administration (FDA), American academy of pediatric dentistry (AAPD), bacterial cellulose nanocrystals (BCNCs), Generally Recognized as Safe (GRAS), Drugs Controller General of India (DCGI), computer numerical control (CNC), Carbon (C), Oxygen (O), Sodium (Na), Silicon (Si), Chlorine (Cl), Potassium (K), Calcium (Ca), Copper (Cu), Tungsten (W)

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