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Hexagonal Boron Nitride synthesis, its applications in dentistry and cytotoxicity: A literature review

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Abstract:

The advancement of nanomaterials has significantly influenced modern dentistry by enabling the development of materials with enhanced performance and improved clinical outcomes. Dental applications demand materials that exhibit high durability, wear resistance, excellent biocompatibility, and efficient thermal management. In recent years, increasing attention has been directed toward materials capable of effective heat dissipation, particularly in dental thermal interface applications.

Boron nitride has gained considerable interest in the dental field due to its versatile applications. Among its various forms, hexagonal boron nitride (H-BN) has emerged as a promising nanomaterial that fulfills these requirements.

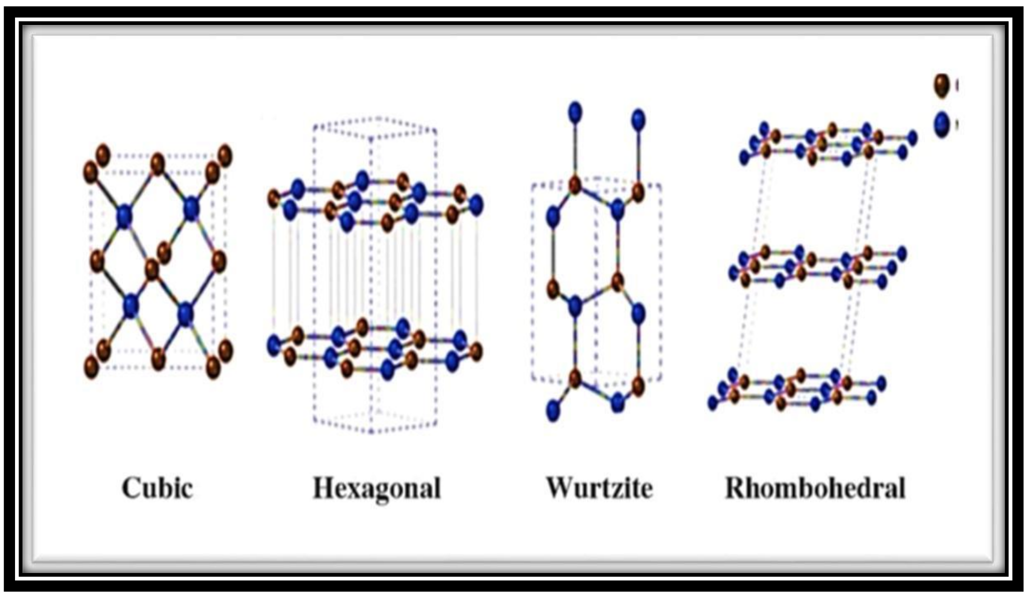
This review aims to comprehensively summarize and critically analyze the current literature regarding the application of hexagonal boron nitride in dentistry. Particular emphasis is placed on its thermal and chemical stability, antibacterial activity, biocompatibility, low density, electrical insulation, and high thermal conductivity, which collectively contribute to its potential in improving the performance and longevity of dental materials.

Keywords: Hexagonal Boron Nitride, Synthesis, Cytotoxicity, Applications in dentistry, Nanoparticle.

Introduction:

Hexagonal boron nitride (H-BN) is a synthetic layered inorganic crystal with high thermal conductivity [O](TC) and temperature stability. It has been utilized extensively as a ceramic material for lubricating, heat shielding, thermal management, and structural composite filler (Naclerio and Kidambi ,2022). A number of reviews on the manufacturing, uses, and characteristics of boron nitride (BN) and its polymer composites have been published in recent years. Boron nitride (BN) is an ideal additive option for nanocomposites in applications for thermal management because of is lower coefficient of thermal expansion (CTE) (-2.76×10^{-6} K^{-1}) and relatively higher thermal conductivity ^{O}(TC) (300–2000 $Wm^{-1}K^{-1}$). Thus, BN-based polymer nanocomposites can be utilized to produce materials that dissipate heat for contemporary electronic devices, such as heat-sinking substrates and thermal interface materials (TIMs). (Mazumder et al, 2022). The intriguing optoelectrical characteristics of (H-BN), along with its mechanical robustness, thermal stability, and chemical inertness, have made it a promising option for two-dimensional (2D) materials. Super-thin H-BN layers have drawn many of interest from the scientific society for a variety of uses, such as photonics, biomedicine, nanoelectronics, anti-corrosion, and catalysis (Roy et al, 2021). (BN) is composed of a single molecule of every of the elements boron and nitrogen (Rudolph, 2001). According to Figure (1), It also appears in four primary distinct crystalline structures: wurtzite boron nitride (W-BN), rhombohedral boron nitride (R-BN), hexagonal boron nitride (H-BN), and cubic boron nitride (C-BN).Their different crystalline forms provide them different physical and chemical properties (Xu et al, 2018).

Figure (1): Crystalline forms of boron nitride(Kar et al,2021).



Synthesize of hexagonal-boron nitride:

There are two main approaches for creating H-BN in dielectric materials:

Category 1: Top-Down Approach: This method involves mechanically exfoliating bulk multilayer H-BN to create nanosheets, which yield superior, flawless H-BN crystals that are usually a few microns thick.

Category 2: Bottom-Up Approach: This technique speeds up the creation of H-BN layers by chemically depositing nitrogen and boron atoms onto a substrate. Despite their bigger size, this process usually produces H-BN crystals of superior quality with few flaws (Ali et.al. 2025).

There was anther technique for synthesis boron nitride it is sol-gel method:

Sol-gel dip-coating is a method used to produce nanoparticles and thin films. The benefit of this synthesis method is that it creates tiny particles with a lot of surface area, increasing the dental composite's mechanical strength (Kadhum and Hamad, 2025). The dip coating method is being utilized more due to its benefits over other methods, including the fact that it requires less expensive tools, is straightforward, most cost-effective, coats substrates on both sides, covers a larger area, and gives greater control over the coating's structure. To develop BN thin films, two distinct precursors boric acid H_3BO_3 and boron nitrate are utilized. NH_3, or ammonia, was employed as a stabilizer. The molarity of the precursors BN and boric acid determines the characteristics of thin films. As molarity decreased, crystallite size decreased, but the preferred orientation stayed along the (002) plane. Boric acid (1.0.5) M sol and BN (1,0.5,0.25,0.15) M sol were produced. In order to produce the sol, boric acid and boron nitrate were first disintegrated in 20milliliters of water while being continuously stirred for two hours (Kayani et al, 2021).

Application of hexagonal boron nitride:

BN is a novel class of large bandgap nanomaterials with superior characteristics and possible uses (Wang, 2017). Is the most stable type of crystal in terms of both chemical and thermal stability (Su, 2019).It is sometimes called "white graphite" because of the structural similarities to graphite (Fang, 2016). In contrast to carbon-based materials, H-BN is more resistant to wear and corrosion, and in the upcoming years, its prospective uses and research will expand (Ouadah, 2022). Outstanding stability, resistance to oxidation, and heat conductivity below 3000°Care characteristics of H-BN. At room temperature, it cannot react with water, acid, or alkali due to its exceptional chemical stability (Sheng, 2022). Table 1 summery to the application of H-BN

Hexagonal-boron nitride nanopowder reinforcement physical and mechanical characteristics of polymethyl methacrylate self-cured:

In restorative dentistry, polymethyl methacrylate (PMMA) is the recommended resin due to its great aesthetics, reparability, ease of manipulation, poor solubility and sorption in water, and no toxicity. Non-modified PMMA when exposed to an impact force, becomes brittle. Numerous studies have tried to increase the acrylic resin's transverse strength, fatigue resistance, and impact strength. In order to create a co-polymerized acrylic with comparatively high impact strength, efforts are being made to use nanoparticles to reinforce the acrylic resins with metal powders, glass fibers, carbon fibers, and ultra-high molecular weight. This will result in a polymer nanocomposite with better mechanical and physical properties than those that are packed with microparticles. Particularly when the size of the filler is in the nanoscale range, mechanical mixing of ingredients is frequently unsuccessful and leads to inadequate distribution of filler inside the polymer matrix. Additionally, dental applications call for premium materials that are long-lasting, wear-resistant, and biocompatible, These requirements are fully satisfied by H-BN materials. The composites' hardness and flexibility properties were improved by the addition of H-BN nanoparticles to the acrylic resin. Independently of the mixing method used. BN hardness is often lower than diamond hardness, Due to its exceptional thermal and chemical stability, in mechanical applications, BN is frequently utilized. (Alqahtani, 2020). The implanted nanoparticles' type, size, shape, concentration, and interactions with the polymer matrix, all affect the characteristics of polymer nanocomposites. (Ihab and Moudhaffar (2011).

BN nanosheets added to polymeric dental adhesive system:

Adhesive technologies that can create strong connections between tooth surfaces and restorative materials. This work investigated the impacts of utilizing boron nitride nanosheets (BNNSs) functionalized with methacrylate with a system of polymeric dental adhesive in order to address the issue. A number of studies concentrated on creating dental adhesives with better qualities based on nanofillers. Two-dimensional nanosheets have drawn attention among many nanomaterials because of their superior modulus and strength (0.5 TPa), particularly graphene, an allotrope of carbon organized in a single hexagon-shaped atomic layer. However, due to its dark hue and high cost of production, graphene is not utilized in dentistry. Since hexagonal boron nitride (H-BN) is colorless in contrast to graphene, boron nitride nanosheets (BNNSs), an analog of graphene known as "white graphene," have shown promise in the field of dentistry. BNNSs have the ability to self-assemble into liquid crystals that are colloidal with excellent modulus, strength, wear resistance, and fracture resistance. In addition, it is biocompatible, chemically stable, and low in density. Additionally, because of its lamellar structure, composite viscosity may be decreased, allowing for higher filler loading. According to a study, adding BNNSs at various proportion of loading improved the adhesive's degree of recovery. However, the adhesive system's solubility and water absorption were unaffected by the addition of BNNSs. In relation to Young's modulus, a comparable occurrence was also noted. Rather, the flexural power of the adhesive was negatively impacted by the addition of high BNNS loading (1wt). According to microtensile bond failure and strength mode analysis, the adhesive system's performance and bond strength were not significantly impacted by the addition of BNNSs up to 1 wt. Nevertheless, the present investigation is restricted to in vitro testing, which may shed light on the use of BNNSs as a filler in dental adhesives. To fully understand the impact of BNNSs, more research is required with different BNNS loading proportions ranging from 0.1 wt% to 1 wt%. Further long-term mechanical testing could be carried out to more precisely assess the system (Kulanthaivel, 2023).

Effects of mesoporous silica nanoparticles and hexagonal boron nitride on the mechanical properties, morphology, and antibacterial activity of dental composites:

Dental composite a dental filling substance used to treat tooth damage. Resin-based substance is another word that is used in place of dental composites. Usually, a resin matrix dispersant segment makes up these polymeric dental composites and a reinforcement section that adds strength and durability by using materials including fibers, resin, and metal oxides. In terms of wear, erosion, and color stability, composite dental resins are highly durable in the dental environment. It is therefore often utilized in dental applications. The development of microcracks on the surface of dental composites, which allow germs or fungi to enter, is one of the issues with resins. Here, the proliferation of germs leads to gum disease and cavities. Antibacterial and antifungal characteristics are anticipated in composites created to address these issues. In this study, H-BN and mesoporous silica nanoparticles (MSN) were employed as dental composites' additives. 5% and 10% of H-BN by weight are included into the composite materials' structure , micro and nano-sized fillers are frequently used in the creation of dental composites. According to the research, (H-BN) and (MSN)'s antibacterial qualities may provide ways to lessen this problem. The addition of H-BN structures is essential to improving the composite's thermal characteristics. (Kıvanç et al. 2018) also reported that H-BN nanoparticles had strong antimicrobial and antifungal activity when applied at appropriate percentages, they successfully prevent the formation of biofilms by preventing the development of bacteria. These results imply that hexagonal boron nitride nanoparticles are effective against oral infections, which makes them a viable option for dental use (Usul et al,2024).

Dental ceramic reinforcement using boron nitride nanoplatelets:

Boron nitride nanoplatelets (BNNPs) are a good reinforcement for dental materials because of their superior mechanical qualities and biocompatibility. The BNNPs were made by dispersing H-BN on a zirconia matrix and exfoliating it using high-energy ball milling. When 1–1.5 vol.% BNNPs were added, the strength of the BNNP-dispersed zirconia increased by up to 27.3%, while the fracture toughness rose by up to 37.5%The inclusion of BNNPs improved tribological characteristics as well (B. Lee et al, 2020).

Titanium dental implants covered with boron nitride:

Dental implants must have their surfaces modified in order to promote osseointegration and corrosion resistance. Surface characteristics and elemental makeup of BN-coated implant surfaces were analyzed, they showed additional peaks and holes as well as the sponge-like qualities that enhanced its surface microroughness. The coated surface's boron to nitrogen ratio was found to be between 0.8 and 1.6. The results showed that titanium implants may be successfully coated with BN and that this coating enhances the surface characteristics of dental implants using X-ray photoelectron spectroscopy (XPS), scanning electron microscopy (SEM), and energy dispersive X-ray spectrometer (EDS)(Çakal et al, 2019).

Polymethyl methacrylate resin improved by boron nitride/silver nanocomposite for use in oral denture bases:

Denture breakage is a frequent clinical occurrence in prosthodontic services and is still an unresolved issue, despite the covert usage of polymethylmethacrylate (PMMA) in dental prosthetics. Nanoparticle reinforcement has been used to help polymers overcome their mechanical and physical constraints (Alnamel and Mudhaffer,2014). To enhance PMMA's chemical and physical characteristics, numerous nanomaterials have been added, such as nanoparticles, nanosheets, and nanotubes. Silver nanoparticles (AgNPs) with hexagonal boron nitride nanosheets (H-BNNs) were introduced to PMMA as nanofillers, the pure PMMA's flexural and compressive strengths rose by 56.7% and 53.5%, respectively. The H-BNNs/AgNPs content was 1 wt%. The antibacterial rate was 92.1% at a nanocomposite concentration of 1.4 wt% in PMMA resin. All things considered, using a multi-dimensional nanocomposite structure to synergistically reinforce

PMMA composite resin offered a fresh viewpoint for increasing the use of resins in clinical settings as well as the investigation and creation of novel composite resins (M. Li et al 2022).

Effect of incorporation boron nitride nanoparticles on heat cure poly methyl methacrylate resin:

Heat-cured acrylic resin has been the most popular substance used in the creation of complete and partial dentures. Due to its favorable aesthetics, physical, and cost-benefit properties (Taha and Abass, 2025). Regrettably, the material still has several drawbacks, including its tendency to change color over time and its propensity to absorb oral fluids, which is often associated with the potential for certain organisms to inhabit the surface of the denture (Al-Rubaie and Al-Khafaji,2024), However, due to its poor fatigue resistance and impact strength, it is not the best biomaterial. In order to improve PMMA's physical characteristics, greater attention is now being paid to adding different elements like rubber, fibers, or nanosilver(Hussein et al 2023).The use of nanoparticle fillers is one method that has successfully improved the characteristics of dental resin matrix(Al-Najati and Jani, 2025). BN is a refractory substance with remarkable chemical and heat resistance. In dental science, it is widely utilized for things like filler in resin-based dental sealants and reinforcement of dental ceramics. When BN is added to PMMA at concentrations of 1% and 1.5% w/w, impact strength is improved at 1.5% percentages, but surface roughness is negatively increased (Hussein et al 2023).

Hexagonal boron nitride's impact on high-performance polyether ether ketone composites:

One type of high-performance polymer with superior mechanical and thermal qualities is polyether ether ketone (PEEK). Applications for these polymers and related composite materials can be found in the sectors of coating, insulating materials, and aerospace. Numerous studies have documented the notable enhancement of PEEK's mechanical, frictional, and physicochemical characteristics following nanoparticle reinforcement (Gan et al, 2001). The addition of H-BN nanoparticles to the PEEK at different percentages enhanced the final nanocomposites' characteristics. It demonstrated the best possible improvement in wear and friction characteristics, hardness, thermal conductivity, and storage modulus at 5 wt% of H-BN, Therefore, we demonstrated that PEEK nanocomposites reinforced with H-BN hold a lot of promise as multipurpose materials for upcoming industrial uses (Liu et al, 2016).

Self-healing polyurethane bonded with hexagonal boron nitride that has good heat conductivity:

Polyurethanes (PUs) are polymers that include urethane repeating units. They are mostly created when polyisocyanates and macropolyols are additionally polymerized when there are chain extenders. Because of its exceptional qualities—such as exceptional mechanical strength, excellent resistance to abrasion, durability, and flexibility at low temperatures, etc. it has been widely used in many different fields (Li et al, 2022). In general, Polymer materials could not be very effective at transferring heat. This is mostly because polymers have a very low intrinsic thermal conductivity, which results in slower heat transfer. In order to increase polymer materials' thermal conductivity, high thermal conductivity fillers including carbon nanotubes, alumina, and H-BN are commonly added. H-BN is thought to be the perfect additive for very thermally conductive materials and great insulation from electricity because of its ultra-high heat conductivity (600 W·m−1·K−1), superior insulation (bandgap of 5.5 eV), and strong chemical stability. H-BN surfaces were functional modified non-covalently using polyvinylpyrrolidone (PVP). Next, a self-repairing matrix of polyurethane (PU) was mixed with the modified BN (BN@PVP). The dispersion of BN@PVP was facilitated by the structure of hydrogen bonds at the interface between BN@PVP and PU, resulting in a heat conductive composite substance that is self-recovery (Zheng et al, 2017).

Hexagonal-boron nitride addition to maxillofacial silicone:

The most widely used and suitable material for creating maxillofacial prostheses is maxillofacial silicone, although it is not flawless in every way. More property upgrades are needed to increase their efficacy (Kareem and Hamad 2023). The purpose of the current research has been to improve the physical and mechanical characteristics of silicone elastomers by adding various fillers to Silicones including microparticles and nanoparticles, these additions' special qualities such as their big surface area, intense chemical reactivity, polarity, or high surface energy may be connected to the enhancement of reinforced polymers' mechanical and physical features. H-BN is more resistant to corrosion and wear and in the upcoming years, more studies and potential uses are anticipated. Adding 0.5 wt of H-BN to the maxillofacial silicone was the ideal amount since the tensile strength did not decrease significantly (Ali and Abdul-Ameer, 2025).

Table 1. Hexagonal boron nitride applications in dentistry.

Form of H-BN	Applications	Objective	Outcomes	Ref.
H- BN Nanopowder	Applied to Self-Cured Polymethyl methacrylate	Reinforcement Physical and Mechanical Properties	Improved PMMA's flexural strength and hardness properties.	Alqahtani, (2020).
BN nanosheets (BNNSs)	To polymeric dental adhesive system.	Identify the composite adhesive system's mechanical characteristics	The degree of adhesive cure was raised by adding BNNSs at varying loading percentages.	Kulanthaivel al (2023)
H-BN 5%,10%wt and Mesoporous Silica Nanoparticles	To Dental Composites	Impact on the prepared dental composites' mechanical, physicochemical, and antibacterial characteristics	The use of large surface area nanoparticles in dental composites, made possible through resin-filler interaction, has produced dental composites with enhanced mechanical and chemical properties.	Usul, et al (2024)
BN	To Dental ceramics	Reinforcement material	The addition of 1-1.5 vol.% of BNNPs	Lee. et al (2020)

Nanoplatelets			increased strength (up to 27.3%) and fracture toughness (up to 37.5%). Moreover, tribological features were improved.	
BN as coating	Applied to surface of implants	Increase their resistance to corrosion and osseointegration	The surface characteristics of dental implants can be enhanced by successfully coating titanium implants with BN.	Çakal, et al (2019)
BN nanosheet/silver nanocomposite in 1wt%	Added to PMMA denture base	Enhancing PMMA's mechanical and antimicrobial qualities	Pure PMMA's flexural and compressive strengths increased by 56.7% and 53.5% in 1 wt, respectively, and its antibacterial rate was 92.1% in 1.4 wt.	M. Li, et al (2022)
BN Nanoparticles(NPs) in concentrations of 1% and 1.5% wt	PMMA Heat Cure	Impact on Surface Roughness and Impact Strength	Increases surface roughness while improving impact strength at a concentration of 1.5%.	Hussein et al (2023)
(H-BN) nanofille 1% to 5% wt	To polyether ether ketone (PEEK)	Examined the nanocomposites' mechanical and thermomechanical characteristics, morphology, thermal conductivity, and wear and friction characteristics.	It showed the best improvement in wear and friction characteristics, thermal conductivity, hardness, and storage modulus at 5% wt H-BN.	Liu, et al (2016)
H-BN with Polyvinylpyrrolidone (PVP)	To polyurethane (PU)	Reinforced self-healing polyurethane	Producing a thermally conductive BN@PVP/PU composite material that can cure itself.	Zheng, et al (2017)
H-BN Particles 0.5 wt% and 0.7 wt%	To Maxillofacial Silicone	Evaluating the mechanical properties of Maxillofacial Silicone	Tensile strength, surface roughness, and shore hardness decreased while the amount of H-BN rose and tear strength improved.	Ali and Abdul-Ameer (2025)

Hexagonal-Boron Nitride Uses:

Owing to its special qualities, H-BN offers a range of uses; these are just a few:

1. Lubricant additive: H-BN is often utilized as a lubricant additive because of its low friction coefficient and strong temperature stability (Lim et al, 2023).
2. Thermal management: For applications that need thermal management, H-BN is a helpful material due to its strong thermal conductivity and high temperature resistance (chuah et al,2004).
3. Optoelectronics: In the ultraviolet (UV) spectrum, H-BN has unique optical properties like a wide bandgap and high transparency (Wang et al, 2022).
4. Delivery of drugs: Given that the majority of therapeutic agents (TA) contain intricate charges and/or structures, H-BN is a powerful adsorbent for a broad variety of TA. Furthermore, the creation of HBN/TA complexes may be made possible via van der Waals and/or electrostatic interaction between the elements (Shtansky et al,2022).
5. Engineering of tissues: BN material can be utilized to encourage cell adhesion and proliferation as well as to reinforce scaffolds used in tissue engineering.
6. Antibacterial and antifungal activity: To increase antibacterial and antifungal action, numerous hybrid NPs have been developed, such as BN-silver, BN-zinc oxide, BN-copper, BN-zirconium, BN-titanium dioxide, and antibiotic-loaded BN NPs and films (Shtansky et al,2022) (Li et al, 2022).

7.Cosmetics industry: Because of its unique properties (smooth texture, good adherence, dazzling white gloss, ease of application, high oil absorption capacity, moisture regulation), H-BN is a common multipurpose ingredient that works well in a range of cosmetic compositions and keeping skin from being parched) (Engler et al, 2007).

9. Composite materials:

The cytotoxicity of boron nitride in hexagonal form:

A crucial prerequisite for the safe and long-term usage of H-BN is an understanding of its cytotoxicity risk. The type of cell or tissue and the anatomical location determine the material's toxicity; particle clearance and healing processes may also have an impact (Domanico, 2022).

Kıvanç et al shown that at a dosage of 0.4 mg/mL, H-BN had a mild cytotoxic effect on Madin Darby canine kidney cells and normal human fibroblasts (NHF) (Kıvanç et al, 2018).

Domanico state that H-BN causes cytotoxicity at low concentrations in human corneal epithelial cells (0.004, 0.01, 0.02, and 0.04 mg/mL), at reasonable concentrations in human alveolar epithelial cells that have been immortalized (0.04 and 0.08 mg/mL), and at high concentrations in primary mouse tracheal epithelial cells (0.2 mg/mL) (Domanico et al,2022).

Kar report that laboratory rats (wistar albino) administered 1.6 and 3.2 mg/kg H-BN NPs may develop serious issues with their kidney, liver, spleen, pancreas, and heart. They also proposed that H-BN NPs could be appropriate for biological uses where 0.05–0.8 mg/kg dosages are safe (Kar et al.2021).

Mateti produced BN in two different groups. The first group had 100 nm in thickness and 1 µm in diameter. Second, it has 100 nm in diameter and 3 nm in thickness. When the materials were tested for cytotoxicity against cells similar to osteoblasts (Saos-2), the authors found that the presence of NPs significantly reduced cell viability in comparison to microparticles (Mateti et al,2018).

HBN is safe up to 1wt% when added to the silicone elastomer used to make maxillofacial prostheses (Ali and Abdul-Ameer, 2024).

Conclusion:

In conclusion, H-BN is used extensively in dentistry because of its antibacterial, biocompatible, low density, high electrical resistance, and strong thermal conductivity it improves osseointegration when used in implant coating. Consequently, H-BN shows promise for dental applications; nevertheless, further extensive clinical studies are required before this technology can be fully integrated into evidence-based treatment.

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Disclaimer of Conflict of Interest:

The researcher declares that he has no known financial interests or personal relationships that could influence the work presented in this paper.

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