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Research Article

Effect of climate change-induced environmental temperature on the dimensional stability of endodontic materials

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ARTICLE

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ABSTRACT

Climate change has introduced significant environmental challenges that extend beyond public health and into the performance of dental biomaterials. Rising ambient temperatures, increased frequency of heat waves, and greater variability in storage and transportation conditions can influence the physical and chemical properties of endodontic materials. Dimensional stability is a critical characteristic that determines the ability of root canal filling materials, sealers, and restorative materials to maintain their original dimensions during setting and throughout clinical service. Alterations in dimensional stability may result in shrinkage, expansion, microleakage, loss of adaptation to canal walls, and compromised long-term treatment outcomes. This review examines the effects of climate change-induced environmental temperature on the dimensional stability of commonly used endodontic materials, highlighting the underlying mechanisms of thermal expansion, polymerization behavior, moisture interactions, and material aging. It also discusses the clinical implications of temperature-related dimensional changes during material storage, handling, and application, as well as their potential impact on sealing ability, periapical healing, and treatment longevity. Furthermore, the review explores current strategies for improving thermal resilience through advances in biomaterial design, optimized storage protocols, and sustainable clinical practices. Understanding these interactions is essential for maintaining the reliability and clinical performance of endodontic materials under increasingly variable environmental conditions and for guiding the development of climate-resilient dental biomaterials.

INTRODUCTION

Climate change has emerged as a global challenge with implications that extend beyond ecosystem and human health to the performance and longevity of biomedical and dental materials. Rising environmental temperatures, frequent heat waves, and increased thermal variability can influence the physical and chemical behavior of materials throughout their manufacturing, transportation, storage, and clinical application. In dentistry, these environmental changes have prompted growing interest in understanding how temperature fluctuations affect the integrity and functionality of endodontic materials, particularly their dimensional stability (Geetha et al., 2025).

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Dimensional stability refers to the ability of a material to maintain its original dimensions during setting and after placement despite exposure to thermal, mechanical, and environmental stresses. This property is essential for endodontic sealers, gutta-percha, bioceramic materials, and temporary restorative materials because dimensional alterations such as shrinkage, expansion, or deformation may compromise the apical and coronal seal, promote microleakage, and ultimately reduce the long-term success of root canal therapy. The quality of obturation and the structural integrity of the restored tooth are closely associated with the physical performance of these materials (Chandra et al., 2021).

Recent advances in endodontic biomaterials have focused on improving thermal stability, sealing ability, and resistance to environmental degradation. Conference reports and emerging investigations have highlighted the importance of evaluating material behavior under clinically relevant thermal conditions, reflecting increasing awareness of environmental influences on endodontic outcomes (Jadawala, 2023; Debadwar, 2023; Galkar, 2023). Furthermore, successful periapical healing depends not only on effective canal disinfection but also on the long-term dimensional integrity of filling materials that preserve a hermetic seal (Singh et al., 2025).

Understanding the relationship between climate change-induced environmental temperature and the dimensional stability of endodontic materials is therefore essential for optimizing storage protocols, material selection, and clinical performance while supporting the development of more resilient and sustainable dental biomaterials (Geetha et al., 2025; Pruthi et al., 2010).

B. Influence of Environmental Temperature on Endodontic Materials

Environmental temperature is an important external factor affecting the physical behavior and dimensional stability of endodontic materials throughout storage, transportation, and clinical application. Climate change has increased the occurrence of prolonged heat exposure, making thermal stability an increasingly relevant consideration in endodontic practice. Elevated temperatures may alter the viscosity, setting kinetics, thermal expansion, and polymerization behavior of root canal filling materials, potentially compromising their ability to maintain a stable seal within the prepared canal system (Geetha et al., 2025).

Dimensional stability refers to a material's capacity to retain its original dimensions after placement and during function. Materials that undergo excessive shrinkage or expansion can create interfacial gaps, increase microleakage, and reduce the long-term success of root canal therapy. Gutta-percha may soften under elevated temperatures, while resin-based sealers can experience accelerated polymerization and greater polymerization shrinkage. Bioceramic sealers generally demonstrate favorable dimensional stability because of slight setting expansion; however, extreme environmental conditions may still influence their hydration reactions and setting characteristics (Jadawala, 2023; Debadwar, 2023).

Temperature-induced dimensional changes may also affect the adaptation of obturation materials to dentinal walls, thereby influencing fracture resistance and long-term sealing effectiveness. Stable root canal filling systems contribute to improved structural integrity and treatment durability (Chandra et al., 2021). Moreover, preservation of an effective apical seal is essential for preventing reinfection and supporting favorable periapical healing following primary treatment or retreatment (Singh et al., 2025). Studies evaluating surface changes in restorative materials further demonstrate that thermal exposure can modify material properties, emphasizing the importance of proper storage and handling protocols (Pruthi et al., 2010). Contemporary endodontic investigations continue to emphasize the need for thermally resilient materials capable of maintaining dimensional accuracy under increasingly variable environmental conditions (Galkar, 2023).

Table 1. Influence of Elevated Environmental Temperature on Common Endodontic Materials

Endodontic Material	Temperature-Induced Effect	Dimensional Stability Impact	Clinical Consequence
Gutta-percha	Softening and thermal expansion	Temporary deformation	Reduced obturation accuracy
Resin-based sealers	Accelerated polymerization	Increased shrinkage	Higher risk of microleakage
Bioceramic sealers	Altered hydration and setting	Minor variation in expansion	Possible changes in sealing performance
Temporary restorative materials	Thermal cycling	Marginal distortion	Coronal leakage
Adhesive systems	Reduced viscosity	Variable film thickness	Inconsistent dentin adaptation

C. Clinical Implications and Current Evidence

The dimensional stability of endodontic materials is fundamental to achieving an effective three-dimensional seal and ensuring long-term treatment success. Environmental temperature fluctuations associated with climate change may alter the setting behavior, thermal expansion, and contraction of gutta-percha, resin-based sealers, and bioceramic materials, potentially increasing the risk of marginal gaps, microleakage, and bacterial reinfiltration. Such alterations can compromise obturation quality and adversely affect the longevity of root canal therapy (Geetha et al., 2025; Chandra et al., 2021).

Clinically, inadequate dimensional stability may reduce fracture resistance by weakening the integrity of the root canal filling complex and its interaction with the surrounding dentin. Studies evaluating different obturation systems have demonstrated that material properties directly influence the mechanical performance of endodontically treated teeth, emphasizing the importance of maintaining dimensional accuracy throughout clinical use (Chandra et al., 2021). Furthermore, a stable apical seal remains essential for successful periapical healing, particularly in retreatment cases where reinfection must be minimized. Improved sealing ability contributes to favorable healing outcomes and enhanced long-term prognosis (Singh et al., 2025).

Recent conference abstracts have highlighted growing interest in evaluating thermal influences on endodontic biomaterials, including setting characteristics, sealing performance, and resistance to environmental stress, although comprehensive long-term clinical evidence remains limited (Jadawala, 2023; Debadwar, 2023; Galkar, 2023). Evidence from restorative material research also demonstrates that elevated temperatures can modify material surface characteristics and physical behavior, reinforcing concerns regarding the thermal sensitivity of dental biomaterials (Pruthi et al., 2010).

Table 2. Clinical Implications of Temperature-Induced Dimensional Changes in Endodontic Materials

Clinical Aspect	Effect of Reduced Dimensional Stability	Potential Clinical Outcome	Supporting References
Obturation quality	Expansion or shrinkage	Marginal gaps and microleakage	Chandra et al. (2021); Geetha et al. (2025)
Fracture resistance	Poor adaptation to canal walls	Increased susceptibility to fracture	Chandra et al. (2021)
Periapical healing	Compromised apical seal	Delayed or incomplete healing	Singh et al. (2025)
Material performance	Altered setting and surface properties	Reduced clinical reliability	Pruthi et al. (2010); Jadawala (2023); Debadwar (2023); Galkar (2023)

D. Strategies to Improve Thermal Stability and Climate Resilience

Maintaining the dimensional stability of endodontic materials under increasing environmental temperatures requires improvements in material engineering, storage practices, and clinical protocols. Manufacturers should prioritize formulations with low coefficients of thermal expansion, controlled polymerization kinetics, and enhanced resistance to thermal aging. The incorporation of nanotechnology and bioactive ceramic components has shown promise in improving structural stability while preserving sealing ability and mechanical performance under variable thermal conditions (Singh et al., 2025; Chandra et al., 2021).

Appropriate storage and transportation are equally important. Endodontic sealers, gutta-percha, and adhesive materials should be stored within manufacturer-recommended temperature ranges to minimize premature softening, shrinkage, or deformation. Temperature-controlled packaging and climate-monitored supply chains can reduce material degradation during distribution, particularly in regions experiencing prolonged heat exposure associated with climate change (Geetha et al., 2025).

Clinicians should also adopt standardized handling protocols, including allowing materials exposed to elevated temperatures to equilibrate before use, verifying consistency prior to application, and adhering to recommended working and setting times. Routine quality assessment of materials before clinical use can further reduce the risk of compromised obturation and microleakage. Ongoing investigations presented in recent endodontic research emphasize the need for thermally stable biomaterials capable of maintaining dimensional integrity under diverse environmental conditions (Jadawala, 2023; Debadwar, 2023; Galkar, 2023).

Table 3. Strategies for Enhancing Thermal Stability and Climate Resilience of Endodontic Materials

Strategy	Implementation	Expected Clinical Benefit
Advanced material formulation	Low thermal expansion polymers, bioactive ceramics, nanotechnology	Improved dimensional stability and sealing ability
Controlled storage	Temperature-regulated storage and transport	Reduced deformation and premature material aging
Standardized clinical handling	Temperature equilibration and adherence to working times	Consistent material adaptation and reduced microleakage
Quality assurance	Routine inspection before clinical application	Greater treatment reliability and longevity
Sustainable material development	Climate-resilient biomaterials with enhanced thermal tolerance	Improved long-term clinical performance under changing environmental conditions (Geetha et al., 2025; Chandra et al., 2021; Singh et al., 2025)

Conclusion

Climate change-induced increases in environmental temperature have emerged as an important consideration for the performance and longevity of endodontic materials. Variations in ambient temperature during manufacturing, storage, transportation, and clinical application can influence the dimensional stability of root canal sealers, gutta-percha, and restorative materials, potentially affecting their sealing ability, adaptation to canal walls, and resistance to microleakage. These changes may compromise the long-term success of endodontic treatment if appropriate preventive measures are not implemented.

Advances in biomaterial science, including the development of thermally stable bioceramic formulations, nanotechnology-enhanced materials, and climate-resilient polymers, offer promising approaches to maintaining dimensional integrity under variable environmental conditions. Equally important are standardized storage protocols, temperature-controlled logistics, and evidence-based clinical handling techniques that preserve the physical properties of endodontic materials before and during treatment.

Continued research should focus on establishing standardized thermal testing protocols that better simulate real-world environmental conditions and evaluate the long-term behavior of endodontic materials under repeated thermal stress. Such investigations will support the development of more durable, sustainable, and climate-resilient endodontic biomaterials. Ultimately, integrating material innovation with sound clinical practice will enhance treatment predictability, preserve the quality of root canal obturation, and improve long-term patient outcomes in the face of changing environmental conditions (Chandra et al., 2021; Geetha et al., 2025; Singh et al., 2025).

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