

Narrative
ReviewPediatric
Obturation
Materials and
Rheology

Advances in Root Canal Filling Materials for Primary Teeth: How Rheology Helps Predict Obturation Success

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ABSTRACT

Purpose: The success of a pulpectomy in primary teeth depends on the material used in the root canal filling process. This material needs to have a complex anatomy and a small volume of empty space. It also needs to be resorbed at a similar rate to the root. This article aims to highlight the latest developments in primary teeth root canal fillings and their materials and the role of their rheological properties.

Methods: This is a narrative review of lab, in vitro, and clinical studies on four different types of root canal fillings: zinc oxide-eugenol, calcium hydroxide paste, iodoform paste, and bioactive and bioceramic materials from March 2025 till August 2025.

Results: The most important factor is the material's apparent viscosity and flow under shear stress. Thixotropy is also a critical factor in root canal fillings. The yield stress is a measure of the material's resistance to flow when there is a force applied. The time dependency is a measure of the material's flow when time is a factor.

Conclusion: The success of a root canal filling is dependent on the three-dimensional material used. Rheological properties play a critical role in the success of a root canal filling in primary teeth.

Key Words: Primary teeth; Root canal obturation materials; Rheology

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INTRODUCTION

The retention of primary teeth with pulpal infection is of paramount importance for pain relief, mastication, speech development, and arch length space preservation until the time of exfoliation. The success of a pulpectomy procedure lies in the removal of the lower microbial load and the canal being sealed to prevent leakage and reinfection¹⁻².

The obturation of primary molar teeth has proven to be technically challenging. The primary molar canal is ribbon-shaped and irregular.

The presence of many accessory canals and the thin dentinal walls make the procedure even more challenging. The process of root resorption also makes the apical anatomy of the primary molar more challenging and increases the risk of overextending the canal during the obturation process³⁻⁵.

The success of an obturation paste lies in its biological properties and its physical properties and behavior. The physical property of interest in this case would be the rheology of the paste. The rheology of the paste would determine its flow behavior and the success of the obturation process⁶⁻⁸.

This review aims to discuss the commonly used pediatric obturation materials and the newer obturation materials being introduced into the field. The review would also discuss the relationship between rheology and the success of the obturation process. The gaps in the literature and the recommendations would also be discussed.

SEARCH STRATEGY AND SCOPE OF THE REVIEW

This narrative literature review is specifically designed to be of interest to clinicians and researchers. Information is based on peer-reviewed dental literature and appropriate literature in material sciences, including systematic reviews, randomized controlled trials, and in vitro studies. It deals with (i) material types used in primary tooth pulpectomy, (ii) rheological properties that are significant in syringe delivery and 3D filling, and (iii) rheological properties and their

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relation to resorption and sealing in the special biological environment of primary teeth. No changes are made to the references, and tense is appropriate.

WHY RHEOLOGY MATTERS IN PRIMARY-TOOTH OBTURATION

Rheology is defined as the study of the deformation and flow of a material under stress and the material's response when stress is relieved. In the context of paste materials used in endodontic obturation, this means the material's ability to reach the working length, flow into canals and irregularities, and maintain stability after placement^{6,7}. Canals in primary teeth are challenging due to their irregular cross-sections and short working times. In addition, there is a need to minimize time in the dental chair when working with children. This makes syringe delivery a popular approach. Lack of flow means potential areas for bacteria to reside, and too much flow means a potential increase in extrusion forces with the possibility of irritating tissues or the developing tooth^{3-5,8}.

Rheology is clinically relevant in two ways: it is used to predict material handling or ease of placement and the material's ability to fill the canal space uniformly under clinically relevant shear conditions^{8,9}.

KEY RHEOLOGICAL PARAMETERS AND CLINICAL INTERPRETATION

Table No. 1: Rheological parameters and their clinical relevance for obturation in primary teeth.

Parameter	What it means	Why it matters in primary teeth	Practical target (conceptual)
Apparent viscosity	Resistance to flow	Controls penetration vs. extrusion	Moderate; not too stiff or too soft
Shear-thinning	Viscosity falls under injection shear	Improves filling of irregular canals	Clear shear-thinning with recovery at rest
Thixotropy	Time-dependent thinning and recovery	Helps controlled placement in short working times	Rapid recovery after injection
Yield stress	Stress needed to begin flow	Limits migration in resorbing apices	Enough to prevent drift; low enough for syringe placement
Time dependence	Viscosity changes after mixing	Affects chairside reliability	Stable within clinical working time

Apparent viscosity: This is the measure of resistance to flow when subjected to a certain amount of shear. High viscosity may prevent apical penetration in narrow canal spaces, while low viscosity may cause uncontrolled flow or extrusion^{7,9}.

Shear thinning behavior: Shear thinning behavior or pseudoplasticity is also a desirable property of dental pastes. Shear thinning behavior occurs when the viscosity of the paste decreases with increased shear rate⁸⁻¹⁰.

Thixotropy or time-dependent recovery: This property is desirable in dental pastes as it reduces the formation of voids or extrusion of the paste when subjected to a certain amount of shear. This is particularly desirable when the placement process is interrupted or when the process is repeated^{9,10}.

Yield stress: This is the minimum amount of stress required to initiate the flow of the paste. This property is desirable in dental pastes as it prevents the movement of the paste in resorbed canal spaces while allowing placement under syringe pressure^{9,10,11}.

Working time and temperature sensitivity: Some dental pastes exhibit changes in viscosity with time or with changes in temperature. This may affect the placement of the material in the canal space, resulting in voids when the working time is exceeded.^{6,12}

RHEOLOGY OF COMMON PEDIATRIC OBTURATION MATERIALS

Zinc Oxide–Eugenol (ZOE): ZOE is still an important reference material because of long clinical experience and its antimicrobial properties. Nevertheless, ZOE's rheology is operator-dependent, with powder-liquid mix ratios and mixing times significantly affecting material viscosity and flow^{13,14}. ZOE materials can be quite viscous, and there can be some limitation in flow into small canals and accessory anatomy, particularly in multi-rooted primary teeth. Inconsistencies in material flow can affect void formation and three-dimensional adaptation^{13,15}. Concerns with ZOE's use are those of long resorption times in situations where material extrudes beyond the apex, which can cause tissue irritation and delay exfoliation^{3,16}. This is the reason ZOE is being compared with calcium hydroxide and iodoform paste in contemporary trials and systematic reviews¹⁷.

Calcium Hydroxide–Based Pastes: Calcium hydroxide pastes have been introduced to enhance biocompatibility and facilitate resorption in a physiological manner, in sync with root resorption. In general, many of these have shown improved injectability characteristics over conventional ZOE^{18,19}. In terms of rheology, vehicle composition and filler content can affect viscosity, yield stress, and time dependency. Some of these materials, however, may have a tendency to resorb too quickly, which can compromise a long-term seal and potentially lead to

internal voids and spaces^{18,20}. However, available evidence suggests that maintaining a consistent and well-controlled flow is more critical than simply achieving a high flow rate. As a result, researchers have proposed viscosity-optimized and otherwise modified formulations to better support this stability^{21,22}.

Iodoform-Containing Pastes (e.g., Vitapex/Metapex)

The use of iodoform pastes has been favored owing to convenience and premixed formulations in syringe form. The flow and shear-thinning properties of the pastes favor canal filling in complex anatomy and minimize operator variability^{19,23}. The drawback of using resorbable pastes has been resorption beyond physiological root resorption if extruded or in thin layers, potentially causing canal voids and reinfection^{24,25}. Consequently, studies have focused on modifying the iodoform pastes and using optimized pastes containing iodide in the context of improving rheological stability and reducing canal filling failure^{21,26}.

Bioactive and Bioceramic Materials: Bioactive or bioceramic materials are also being explored in pediatric obturation procedures to offer control in terms of flow, sealing, and bioactivity. For example, calcium silicates or calcium phosphates may induce apatite formation while providing stability to the interfaces with dentin tissue²⁹⁻³¹. From a rheological point of view, most modern bioceramic materials are capable of providing standardized flow values and film thickness requirements. However, research studies on bioceramic materials have utilized different approaches to rheometry studies, making it difficult to compare results directly^{6,30}. Some initial in-lab studies indicate favorable results in terms of sealing and handling properties, although more research is needed to evaluate the long-term clinical results in primary teeth²⁸⁻³¹.

CLINICAL IMPLICATIONS: LINKING RHEOLOGY TO OUTCOMES

From a clinical standpoint, the main factors in the failure of the obturation in primary teeth include insufficient fill volume (voids and short fillings), as well as uncontrolled over-extension. These are related to the material's flow under syringe pressure and recovery after injection^{8-9,32}.

Shear-thinning and thixotropic recovery in controlled materials are likely to result in better fillings in complex spaces and maintain the material after injection. This might help in minimizing the formation of internal spaces and maintaining the seal in the course of physiological resorption^{11,33}.

It is worth noting that the technique of delivery is also related to rheology. The needle depth, the rate of injection, and withdrawal might influence the shear. Standardization of the delivery technique is important in comparing the results and relating the rheology to the clinical results^{32,34}.

INNOVATIONS AND EMERGING TRENDS

Recent innovations address three issues simultaneously: antimicrobial activity, predictable rheology, and resorption in line with primary tooth resorption^{28,29,35}. Nanoparticles in pastes containing silver and hydroxyapatite aim to increase antimicrobial activity and alter rheological behavior. Although in vitro studies indicate promise in this regard, safety in pediatric populations and standardization of rheological behavior must be established before use³⁶⁻³⁸. Herbal and ozone-based systems containing plant extracts like *Ocimum sanctum* and ozonated oils represent alternatives to systems containing eugenol. Although studies indicate satisfactory results in the short term, there is considerable variability in the results and formulations. In addition, the rheological behavior must be established to determine when they can be effective in reducing voids without increasing extrusion¹⁹. The use of polymers and hydrogels in the form of injectable systems has also been proposed. These systems underscore the importance of matching resorption kinetics to primary tooth resorption in addition to the immediate density of obturation³¹.

EVIDENCE GAPS AND RESEARCH PRIORITIES

There are two main areas where a lack of good clinical guidance exists. One is the lack of well-designed randomized trials that evaluate contemporary pastes with controlled delivery method and operator effects. The other is the lack of standardization in rheological tests used in various studies. For example, temperatures and units used in rheological tests are inconsistent. This limits the ability to make a cross-comparison^{6,17}.

In future studies, the following are recommended: the need to standardize rheology tests that are pertinent to syringe delivery systems, including time-dependent properties; the need to provide clinically relevant benchmarks, such as the range of viscosities at given rates; the need to evaluate resorption in harmony with longitudinal imaging; and the need to relate rheology to hard clinical endpoints such as healing and survival^{24,28,29,33}.

CONCLUSION

Based on current evidence, a practical conclusion can be drawn rheology is an important factor in the quality of obturation, particularly in primary teeth, as the procedure can be considered a flow process. A material that exhibits good rheology, characterized by appropriate shear-thinning and recovery, will produce more homogeneous fillings, reduce the incidence of empty spaces, and minimize the risk of uncontrolled extrusion. Zinc oxide-eugenol (ZOE) cement, although considered a traditional material, is limited by its operator-dependent rheology and slow resorption when

used for extrusion. Calcium hydroxide and iodoform-based materials, although characterized by easy syringe placement, may present problems related to early resorption and loss of seal. Bioactive and bioceramic materials have been shown to be good candidates, although more long-term studies and standardized rheology reporting are needed. The use of rheology benchmarks can be considered an important step towards more evidence-based material selection for pediatric obturation.

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