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Nano-Computed Tomography as a Benchmark for Sub-Micron Precision in Endodontics: A Narrative Review of High-Fidelity 3D Imaging

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Abstract

Research on oral health has fundamentally transformed as a result of studying dental structures and materials at the sub-micron level. For non-destructive 3D imaging, micro-CT is still the preferred method, but it is unable to capture those really tiny features under a micron. With its amazing sub-micron accuracy, which enables us to view things like dentinal tubules, microscopic fissures, cementum layers, and even the dispersion of filler particles, nano-CT is the best option in this situation. This review delves into the technical reasons why nano-CT is superior to other techniques, how it has become indispensable for researching restorative materials and complex root canal shapes, and its cutting-edge applications, such as using contrast agents to create virtual histology, testing the effectiveness of nanotechnology against biofilms, and providing hard data on biomechanics for more gentle endodontic techniques.

Keywords: Nano-Computed Tomography, Three-Dimensional Imaging, Endodontics, Sub-Micron Imaging, Root Canal Morphology, Dental Materials.

INTRODUCTION

Dental imaging has evolved significantly, transitioning from conventional radiography to advanced three-dimensional Computed Tomography systems and medical scanners that provide highly detailed volumetric views [1,2]. Researchers and clinicians now have access to diagnostic insights that are increasingly precise. Nano-Computed Tomography (Nano-CT) represents the pinnacle of this technological progression, facilitating the non-destructive assessment of dental tissues and biomaterials at an unprecedented sub-micron level of detail [3,4].

Conventional micro-CT systems, which emerged in the early 1980s, typically deliver isotropic voxel resolutions in the range of several microns [5]. While these systems are excellent for evaluating gross anatomy and overall geometric configurations, they often lack the resolution required to investigate intricate microporosities, complex interfaces, or the ultrastructural features critical to material science and biological pathology [6,7].

Nano-CT systems effectively overcome these limitations by utilizing nano-focal spot sources, typically under 500 nm, paired with high-power X-ray tubes [8,9]. These systems achieve isotropic spatial resolutions that frequently fall below 1 µm, with contemporary studies routinely reaching resolutions as sharp as 450 nm per voxel [10,11]. This level of precision is significantly superior to even high-end micro-CT configuration [12]. Furthermore, Nano-CT provides an enhanced signal-to-noise ratio (SNR) and high-quality image production-sometimes further improved by nano-phosphorus scintillators-ensuring precise and reliable volumetric data [13].

Table 1: Comparison of Imaging Modalities and Research Implications

Feature	Nano-CT	Micro-CT (High-End)	Research Implication
Voxel Resolution	<1 µm (down to 450 nm)	~2-10 µm	Resolution of dentinal tubules, microcracks, and cementum layers [12, 14, 15].
Focal Spot Size	Nano-Focus (<500 nm)	Micro-Focus (~1-5 µm)	Reduced blurring; superior signal-to-noise ratio (SNR) [8,10].
Porosity Detection	High Sensitivity	Low Sensitivity	Accurate quantification of micro-voids in filling materials [3, 12, 17].

The ability of Nano-CT to generate "ground-truth" data is crucial for validating lower-resolution modalities such as Cone Beam Computed Tomography (CBCT), which are frequently susceptible to blooming artifacts [18-20].

Applications in Endodontics: Morphology, Pathology, and Biomechanics

Endodontics relies heavily on the precise analysis of complex internal structures, establishing it as a primary field for the application of Nano-CT [1, 21].

Anatomical Characterization and Treatment Assessment

Nano-Computed Tomography has established itself as the definitive benchmark for geometric precision. It serves as the essential reference standard for characterizing intricate root canal anatomy and evaluating treatment efficacy [22, 23]. By delivering high-fidelity spatial data, this technology functions as the "gold standard" to validate the accuracy of measurement protocols in lower-resolution imaging systems [18].

The significance of this technology is particularly evident when analyzing complex morphologies, such as the C-shaped canal systems found in mandibular molars [19, 24]. In these instances, Nano-CT is utilized to confirm the precision of filling quality assessments. Furthermore, in pediatric cases, Nano-CT research on primary maxillary anterior teeth has enabled the detailed mapping of canal conicity and dimensional variations along the root length [25, 26]. This aids in differentiating between rotary and hand file preparations and facilitates the assessment of calcified extraradicular deposits on root surfaces [27].

External Cervical Resorption (ECR)

Nano-CT has made a profound impact on the diagnosis and understanding of External Cervical Resorption (ECR) [28]. Traditional micro-CT often struggles to distinguish the lesion border between dentin and bone-like reparative tissue due to their similar X-ray attenuation [29]. Nano-CT overcomes these limitations by clearly visualizing the intricate borders of reparative tissue, associated resorption channels, and the periodontal ligament space [28,29]. When utilizing multi-modular approaches; such as Nano-CT integrated with histology; researchers can confirm a three-stage mechanism for ECR (initiation, resorption, and repair) and precisely highlight the formation and spread of bone-like reparative tissue [28, 30].

Obturation Quality and Void Analysis

A hermetic seal is vital for endodontic success, as microscopic voids in the obturation can facilitate bacterial re-entry and subsequent reinfection [1,31-33]. While micro-CT has been a standard tool for assessment, it frequently underestimates void volumes due to resolution limitations [16]. Research indicates a critical threshold at voxel sizes above 10 µm - common in micro-CT-where minute defects are entirely missed [12]. Nano-CT's superior precision provides the objective data necessary to differentiate material performance; for instance, it has demonstrated that bioactive sealers often achieve more homogenous, lower-void fills compared to resin-based standards such as AH Plus [34, 35].

Biomechanical Assessment and Crack Propagation

Preserving dentinal integrity is essential for preventing vertical root fractures, and Nano-CT provides high-resolution, time-lapse insights into micro-scale defects [36]. The technology facilitates the precise volumetric quantification of procedural damage, illustrating how aggressive instrumentation—such as extensive foraminal enlargement in curved canals; increases microcrack formation and apical transportation [37, 38]. While laser treatments may initiate micron-scale fractures, Nano-CT reveals how peritubular dentin redirects these fractures to maintain structural stability [39]. Time-lapse analysis also highlights the anisotropic nature of dentin, where crack propagation paths are primarily dictated by the alignment of dentinal tubules relative to applied loads [24, 40].

The Shaping Paradigm: Minimally Invasive Endodontics (MIE) Debate

The ongoing philosophical tension between Minimally Invasive Endodontics (MIE) and more aggressive shaping protocols is effectively mediated by the high-fidelity data provided by Nano-CT [41]. By resolving micro-fractures as small as1 µm, it offers objective evidence to quantify structural damage from various instrumentation systems, including modern nickel-titanium alloys [37,42]. Additionally, Nano-CT enables precise measurements of residual dentin thickness and canal centering ability, allowing researchers to accurately compare small-tapered MIE files with larger-tapered alternatives [43]. This identifies the critical therapeutic window where effective microbial disinfection is achieved without compromising structural preservation.

Characterization of Restorative Materials

The longevity and performance of dental composites are primarily determined by their microstructure, filler distribution, and porosity, all of which are characterized with significantly higher accuracy by Nano-CT compared to micro-CT or Scanning Electron Microscopy (SEM) [44, 45] Surface finishing and polishing procedures also significantly influence these structural outcomes [46, 47].

Porosity Quantification

Internal porosity is a mechanical vulnerability in dental composites, as it can serve as a site for staining or bacterial accumulation [48, 49]. Studies demonstrate that Nano-CT possesses significantly higher detection sensitivity than micro-CT; for example, in the analysis of the "Charisma" composite, one study found Nano-CT identified 4.56% porosity while micro-CT identified only 2.73% [3,50]. This discrepancy highlights how lower-resolution tools can seriously underestimate failure risks [51]. With its superior resolution, Nano-CT can characterize thin, thread-like voids and evaluate mechanically stressed dentin-adhesive interfaces [52].

Filler Particle Distribution and Size

Nano-CT has redefined the assessment of filler dimensions, correcting errors in lower-resolution micro-CT that blur sub-micron boundaries into aggregates and overestimate particle sizes [3,53]. It provides highly precise measurements for materials like Universal XTE and offers unmatched 3D views of nanoparticle arrangements [3,54]. Unlike traditional 2D SEM cross-sections, Nano-CT visualizes the complex clustering and distribution of zirconia and silica in nano-hybrid and bulk-fill composites [3,55]. This provides a comprehensive view of the material's internal architecture across both branded and "own-label" products [56, 57].

Virtual Histology: Contrast-Enhanced Soft Tissue Imaging

A historical challenge with X-ray tomography in dentistry was the radiolucency of soft tissues. Recent protocols utilizing contrast agents have overcome this, allowing for non-destructive 3D analysis termed "virtual histology" [58, 59].

Contrast Enhancement Protocols

Phosphotungstic Acid (PTA), a heteropoly acid, is highly effective as a contrast agent because it binds to collagen and proteins in soft tissues, thereby increasing X-ray attenuation [60,61]. Optimal results are typically achieved by soaking specimens in a 0.7% PTA solution for a duration ranging from 24 h to 5 days [57]. This timeframe is scaled to the specimen's size to ensure thorough contrast without tissue oversaturation.

Ultrastructural Soft Tissue Visualization

Advanced contrast-enhanced Nano-CT provides histology-level resolution for endodontic soft tissue interfaces, enabling precise 3D segmentation of the pulp-dentin complex [58,15]. It allows for the detailed visualization of the pulp, pre-dentine, and odontoblast layers, specifically highlighting the sigmoidal architecture of dentinal tubules and the extension of odontoblast processes within them [24,29] Furthermore, Nano-CT accurately maps Cellular Intrinsic Fiber Cementum (CIFC) thickness along the root and visualizes the periodontal ligament, providing vital morphological data for investigating periodontic-endodontic interactions [62, 63].

The Nanotechnology Frontier: Validation of Disinfection Strategies

Endodontic failure is primarily attributed to microbial biofilms residing in complex anatomical areas, such as lateral canals, isthmuses, and dentinal tubules that are only 1-5 µm in diameter [30]. Nano-disinfection strategies utilize metal nanoparticles (e.g., silver or zinc oxide) and liposomal nanocarriers designed for deep penetration into tubules and sustained antimicrobial release [63, 64]. Nano-CT serves as the definitive non-destructive validator in this context, quantifying the penetration depth of radiopaque nano-agents into the apical delta [1,14]. It also enables the modeling of efficacy by visualizing the disruption of mineralized biofilms.

Challenges and Future Perspectives

While Nano-CT delivers transformative insights, its widespread adoption is hindered by high equipment costs, the requirement for specialized expertise, and its current limitation to advanced research centers [1,19]. High-resolution imaging is also time-consuming, often requiring a full hour per sample, which reduces throughput compared to micro-CT [9, 63]. The small field of view limits analysis to tiny specimens typically 1 mm^3, requiring extremely precise selection of the region of interest [10,64]. Future advancements will depend on improved processing algorithms, reduced scan times, and increased accessibility to ensure the technology reaches its full potential in clinical and material science applications [8,19].

CONCLUSION

Nano-CT has fundamentally redefined the standards for dental imaging and analysis [1,19]. Through its robust sub-micron resolution, it has exposed the limitations of micro-CT in accurately detecting voids in composites, quantifying filler characteristics, mapping complex root canal morphologies, and identifying subtle early resorption patterns [3,12,18]. When integrated with contrast-enhanced protocols, Nano-CT seamlessly bridges the gap between radiology and histology, offering comprehensive, non-destructive 3D analysis for both hard and soft dental tissues [57,58]. Ultimately, it is an indispensable tool for evaluating and advancing the next generation of materials and techniques to improve outcomes in endodontics and restorative dentistry.

Conflicts of Interest

The author reports no conflicts of interest.

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REFERENCES

1. Özdemir O, Kaşıkçı S, Kopac T. Nanoidentification in endodontics: Bibliometric analysis and comprehensive review on the basis of characterisation research by nano-computed tomography imaging. *Jpn Dent Sci Rev*. 2025;61:55-78.
2. Winter AA, Pollack AS, Frommer HH, Koenig L. Cone-beam volumetric tomography vs. medical CT scanners. *N Y State Dent J*. 2005;71(4):28-33.
3. Haugen HJ, Qasim SB, Matinlinna JP, Vallittu P, Nogueira LP. Nano-CT as tool for characterization of dental resin composites. *Sci Rep*. 2020;10(1):15520.
4. Ahmed HM. Nano-computed tomography: Current and future perspectives. *Restor Dent Endod*. 2016;41(3):236-46.
5. Versiani MA, Keleş A. Applications of micro-CT technology in endodontics. In: Versiani MA, editor. The Root Canal Anatomy in Permanent Dentition. *Cham: Springer International Publishing; 2019*. p. 183-211.
6. Parkinson CR, Sasov A. High-resolution non-destructive 3D interrogation of dentin using X-ray nanotomography. *Dent Mater*. 2008;24(6):773-7.
7. Cuijpers VM, Jaroszewicz J, Anil S, Al Farraj Aldosari A, Walboomers XF, *et al*. Resolution, sensitivity, and *in vivo* application of high-resolution computed tomography for titanium-coated polymethyl methacrylate (PMMA) dental implants. *Clin Oral Implants Res*. 2014;25(3):359-65.
8. Ou X, Zhang Z, Tian Y, Liu F. Recent development in X-ray imaging technology: Future and challenges. *Research (Wash D C)*. 2021;2021:9892152.
9. Kampschulte M, Gassenmeier J, von Sternberg N, Kanli MS, Langheinrich AC, Roeb E, et al. Nano-computed tomography: Technique and applications. *Rofo*. 2016;188(2):146-54.
10. Brunke O, Menzel M, Kopsch T. NanoCT: Visualizing of internal 3D-structures with submicrometer resolution. *MRS Online Proc Libr*. 2007;990:0990-B06-03.
11. Sasov PL, Sasov AY. Application of nano-CT and high-resolution micro-CT to study bone quality and ultrastructure, scaffold biomaterials and vascular networks. *Adv Bioimaging Technol*. 2007:323-31.
12. Orhan K, Jacobs R, Celikten B, Huang Y, de Faria Vasconcelos K, Nicolielo LF, *et al*. Evaluation of threshold values for root canal filling voids in micro-CT and nano-CT images. *Scanning*. 2018;2018:9437569.
13. Sasov A, Van Dyck D. X-ray nanotomography: A review of the technique and its applications. *J Microsc*. 2010;239(2):162-77.

14. Menzel M, Kiesow A, de Souza e Silva JM. Nano-CT characterization of dentinal tubule occlusion in SDF-treated dentin. *Sci Rep*. 2023;13:15895.
15. He P, Wei B, Wang S, Stock SR, Yu H, Wang G. Piecewise-constant-model-based interior tomography applied to dentin tubules. *Comput Math Methods Med*. 2013;2013:892451.
16. Chen B, Lin W, Liu X, Iacoviello F, Shearing P, Robinson I. Pore structure development during hydration of tricalcium silicate by X-ray nano-imaging in three dimensions. *Constr Build Mater*. 2019;200:318-23.
17. Candemil AP, de Faria Vasconcelos K, Pauwels R, Jacobs R, de Sousa-Neto MD. Assessment of the root filling volume in C-shaped root canal on cone-beam CT and micro-CT in relation to nano-CT. *Clin Oral Investig*. 2023;27:6413-20.
18. Mazzi-Chaves, J.F, de Faria Vasconcelos K, Pauwels R, Jacobs R, Sousa-Neto, *et al*. Cone-beam computed tomographic-based assessment of filled C-shaped canals: Artifact expression of cone-beam computed tomography as opposed to micro-computed tomography and nano-computed tomography. *J Endod*. 2020;46(11):1702-11.
19. Hou X, Xu X, Zhao M, Kong J, Wang M, Lee ES, Jia Q, Jiang HB. An overview of three-dimensional imaging devices in dentistry. *J Esthet Restor Dent*. 2022;34(8):1179–1196.
20. Aksoy U, Küçük M, Versiani MA, Orhan KA. Publication trends in micro-CT endodontic research: A bibliometric analysis over a 25-year period. *Int Endod J*. 2021;54:343-53.
21. Rodrigues CT, Jacobs R, Ezeldeen M, Vasconcelos KD, Lambrechts P, Tanomaru Filho M, *et al*. How does nano-focus computed tomography impact the quantification of debris within the root canal system? *Braz Oral Res*. 2023;37:e059:p1-10.
22. Lobo NS, Jacobs R, Vasconcelos KD, Wanderley VA, Santos BC, Marciano MA, *et al*. Influence of working length and anatomical complexities on the apical root canal filling: A nano-CT study. *Braz Dent J*. 2022;33:1-7.
23. Molina MA, Silva GO, Candemil AP, de Camargo RV, Pauwels R, Jacobs R, *et al*. Evaluation of 2- and 3-dimensional anatomic parameters of C-shaped root canals using nano-CT. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2023; 1;136(6):759-68.
24. Torres-Ramos G, Silva-Sousa YTC, Versiani MA. Root canal conicity estimation of primary maxillary central and lateral incisors: A study by nano-CT. *Int J Paediatr Dent*. 2020; 30(6):764-74.
25. Balaji S, Jeevanandan G, Ravindran V, Assiry AA, Vishwanathaiah S, Maganur PC. Comparative evaluation of volumetric changes following rotary and hand files' canal preparation in primary teeth using nano-CT analysis. *Eur Arch Paediatr Dent*. 2024;25(2):227-35.
26. Petitjean E, Mavridou A, Li X, Hauben E, Cotti E, Lambrechts P. Multimodular assessment of a calcified extraradicular deposit on the root surfaces of a mandibular molar. *Int Endod J*. 2018;51:375-85.
27. Mavridou AM, Pyka G, Kerckhofs G, Wevers M, Bergmans L, Gunst V, *et al*. A novel multimodular methodology to investigate external cervical tooth resorption. *Int Endod J*. 2016;49:287-300.
28. Hildebrand T, Nogueira L, Sunde PT, Ørstavik D, Glasmacher B, Haugen HJ. Contrast-enhanced nano-CT reveals soft dental tissues and cellular layers. *Int Endod J*. 2021;54(8):1275-88.
29. Mavridou AM, Hauben E, Wevers M, Schepers E, Bergmans L, Lambrechts P. Understanding external cervical resorption patterns in endodontically treated teeth. *Int Endod J*. 2017;50:1116-33.
30. Siqueira JF Jr, Rôças IN. Clinical implications and research needs of endodontic failures. *J Endod*. 2013;39(12):1499-502.
31. Gencoglu N, Oruçoglu H. Comparison of the two obturation techniques on the sealing ability of the root canal system. *Int Endod J*. 2007;40(6):448-53.
32. Shabahang S, Fillery ED, Moshirfar H. Comparative study of the quality of apical seal obtained by five different obturation techniques. *J Endod*. 1999;25(10):689-93.
33. Holmes S, Gibson R, Butler J, Pacheco R, Askar M, Paurazas S. Volumetric evaluation of 5 root canal obturation methods in TrueTooth 3-dimensional-printed tooth replicas using nano-computed tomography. *J Endod*. 2021;47:485-91.
34. Huang Y, Celikten B, de Faria Vasconcelos K, Ferreira Pinheiro Nicolielo L, Lippiatt N, *et al*. Micro-CT and nano-CT analysis of filling quality of three different endodontic sealers. *Dentomaxillofac Radiol*. 2017;46:2017022.
35. Lu X, Fernández MP, Bradley RS, Rawson SD, O'Brien M, Hornberger B, *et al*. Anisotropic crack propagation and deformation in dentin observed by four-dimensional X-ray nano-computed tomography. *Acta Biomater*. 2019;96:400-11.
36. Pinto JC, de Faria-Vasconcelos K, Leite AF, Pedano MS, Guerreiro-Tanomaru J, Jacobs R, *et al*. Effect of foraminal enlargement on microcrack formation and apical transportation: A nano-CT assessment. Sci Rep. 2023;13:4881.
37. Versiani MA, Pécora JD, de Sousa-Neto MD. Micro-CT evaluation of initial and final root canal volumes after instrumentation. *Int Endod J*. 2013;46(8):745-52.
38. Aljdaimi A, Devlin H, Dickinson M, Burnett T, Slater TJ. Micron-scale crack propagation in laser-irradiated enamel and dentine studied with nano-CT. *Clin Oral Investig*. 2019;23:2279-85.
39. Park K, Memari AM, Hojati M, Radlińska A, Duarte JP, Nazarian S. Effects of anisotropic mechanical behavior on nominal moment capability of 3D printed concrete beam with reinforcement. *Buildings*. 2024;14(10):3175.
40. Peters OA. Cone-beam computed tomography and minimally invasive endodontics: Time for a paradigm shift? *J Endod*. 2015;41(4):437-9.
41. Plotino G, Grande NM, Testarelli L. Cytotoxicity of a new nickel-titanium alloy endodontic instrument. *J Endod*. 2015;41(6):951-5.
42. Swathi S, Antony DP, Solete P, Jeevanandan G, Vishwanathaiah S, Maganur PC. Comparative evaluation of remaining dentin thickness, canal centering ability and apical deformity between ProFit S3 and ProTaper Gold: A nano-CT study. *Saudi Dent J*. 2024;36:650-5.
43. Ferracane JL. Resin composite: State of the art. *Dent Mater*. 2011;27:29-38.
44. Pallesen U, van Dijken JW. A randomized controlled 27 years follow up of three resin composites. *J Dent.* 2015;43:1547-58.
45. Jefferies SR. Abrasive finishing and polishing in restorative dentistry. *Dent Clin North Am*. 2007;51:379-97.
46. Schmitt VL, Cogo-Muller K, Cechinel R. Effect of the polishing procedures on color stability of three resin composites. *ISRN Dent*. 2011;2011:617672.
47. Drummond JL. Degradation, fatigue, and failure of resin dental composite materials. J Dent Res. 2008;87:710-9.
48. Kaisarly D, Gezawi ME. Polymerization shrinkage assessment of dental resin composites. *Odontology*. 2016;104:257-70.
49. Kim YJ, Lee JH, Kim SY. Effect of different resin composites on marginal adaptation and porosity using micro-CT. Oper Dent. 2013;38(4):423-31.
50. Chiang YC, Rösch P, Dabanoglu A, Lin CP, Hickel R, Kunzelmann KH. Polymerization composite shrinkage evaluation with 3D deformation analysis. *Dent Mater*. 2010;26:223-31.
51. De Santis R, Mollica F, Prisco D, Rengo S, Ambrosio L, Nicolais L. A 3D analysis of mechanically stressed dentin-adhesive-composite interfaces using X-ray micro-CT. *Biomaterials*. 2005;26:257-70.
52. Burke F. The evidence base for 'own label' resin-based dental restoratives. *Dent Update*. 2013;40:5-6.
53. Hussain B, Le Thieu MK, Johnsen GF, Reseland JE, Haugen HJ. Can CAD/CAM resin blocks be considered as substitute for conventional resins? *Dent Mater*. 2017;33:1362-70.

54. Haugen HJ, Marovic D, Par M, Khai Le Thieu M, Reseland JE, Johnsen GF. Bulk fill composites have similar performance to conventional dental composites. *Int J Mol Sci*. 2020;21:5136.
55. Shaw K, Martins R, Hadis MA, Burke T, Palin W. 'Own-label' versus branded commercial dental resin composite materials. *Eur J Prosthodont Restor Dent*. 2016;24:8;122-9.
56. Johnsen GF, Pallesen U, van Dijken JW. Own brand label restorative materials: A false bargain? *J Dent*. 2017;56:84-98.
57. Hildebrand T, Nogueira L, Sunde PT, Ørstavik D, Glasmacher B, Haugen HJ. Contrast-enhanced nano-CT reveals soft dental tissues and cellular layers. *Int Endod J*. 2021;54:1275-88.
58. Van Ende A, Kerckhofs G, Van Meerbeek B. High-resolution X-ray computed tomography in dental research. *MTM KU Leuven*. 2016.
59. Kerckhofs G, Sainz J, Wevers M, Van de Putte T, Schrooten J. Contrast-enhanced nanofocus computed tomography images the cartilage subtissue architecture. *Eur Cell Mater*. 2013;25:179-89.
60. Crica LE, Dinu M, Popescu D. Enhanced X-ray absorption for micro-CT analysis of low-density polymers. *J Biomater Sci Polym Ed.* 2016;27:805-23.
61. Yamamoto T, Hasegawa T, Yamamoto T, Hongo H, Amizuka N. Histology of human cementum: Its structure, function, and development. *Jpn Dent Sci Rev*. 2016;52:63-74.
62. Wilar G, Suhandi C, Wathoni N, Fukunaga K, Kawahata I. Nanoparticle-Based Drug Delivery Systems Enhance Treatment of Cognitive Defects. *Int J Nanomedicine*. 2024;19:11357-378.
63. Kishen A, Shi Z, Shrestha A. Nanoparticles and their application in dentistry. J Dent Res. 2015;94(8):1052-8.
64. Kopsch T, Sasov A, Haugen HJ. Nanotomography of dentin: Challenges and future prospects. *Acta Odontol Scand*. 2024;82(1):1-8.

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