Pathophysiology of Dentine Hypersensitivity

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Abstract

On account of novel insights of dentine hypersensitivity implications on the pathophysiology of dentine hypersensitivity. The dentine hypersensitivity is an increase in pain sensation which affects to quality of life. The pathophysiology of dentine hypersensitivity had still studied; therefore, this article will also focus on dentine hypersensitivity effects on the physiology of disease, immune systems, and related oral diseases, particularly physiology of the diseases and molecular mechanisms on dentine hypersensitivity by periodontal disease, tooth defects, and orthodontic tooth movement.

Keywords: Dentine hypersensitivity, Pathophysiology, Hypersensitivity, Molecular mechanism, Immune response

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Introduction

Dentine hypersensitivity is an ordinary oral sensation including pain, sensitivity. The dentine hypersensitivity affects quality of life such as difficult to eating, sensitive to cold or hot water, and psychological condition (1,2). The prevalence of dentine hypersensitivity is ranged from 3 to 57 % depending on the subjective patients' concerning and study sample (3). The pathophysiology of dentine hypersensitivity has multifactorial etiology. Recent studies have highlighted in the pathophysiology of dentine hypersensitivity including the physiology of disease and pathophysiology of oral diseases related to dentine hypersensitivity and the immune system.

Physiology of disease: dentine hypersensitivity

Hypersensitivity of teeth is a pain sensation. This pain sensation is a sharp, shooting pain (4). Hypersensitivity indicates an abnormal pain sensation evoked by innocuous and noxious stimuli (5). The innocuous stimulus is a stimulus that is evoked by touch and air-flow. The airflow can evoke a pain sensation from prolonged or excessive stimuli. Noxious stimuli such as cold water and hypertonic solution can stimulate dentine hypersensitivity. Examples of oral diseases that cause dentine hypersensitivity are tooth surface loss and periodontal disease (6). However, dental caries, pulpitis, or defected restoration are not classified as dentine hypersensitivity (7-9).

The pathophysiology of dentine hypersensitivity is associated with the anatomy of dentine. Dentine is a particularized calcified mineral connective tissue that covered with enamel and cementum. Dentine and pulp tissue complex are responsible for nutrition and sensory function such as protect and against response to stimulus in the teeth. The dentine contains specialized cells called odontoblasts. The odontoblasts are columnar cells that originating from neural crest cells. An extension of the odontoblasts is called odontoblast process or also called Tomes's fibers. The dentinal tubule contains an odontoblast cell process and free nerve ending nociceptive receptors (10). The free nerve ending plays a role in the transduction pain mechanisms (11).

The proposed theories for dentine hypersensitivity are the odontoblastic, nerve and hydrodynamic theories (12). For the odontoblastic theory, odontoblastic processes are exposed on the dentine surface. The exposed dentine surface can be stimulated by chemical and mechanical stimuli. For the nerve theory, the presence of unmyelinated nerve fibers and neurogenic peptides at the odontoblast process receive external stimuli leading to the development of dentine hypersensitivity (13,14). Nowadays, the hydrodynamic theory is proved by Brännström and mostly supported dentine hypersensitivity. The changes in fluid movement are caused by physical changes such as thermal stimulus, mechanical stimulus, and osmotic changes. All of the stimulations cause the movement of dentinal fluid and consequence to stimulate a physiological detector in the odontoblast. This process leads to a neural discharge response to pain signaling (15,16).

However, the nerve theory and odontoblastic theory are associated with hydrodynamic theory. The proposed mechanisms of three theories cannot be distinguish (14). The behind mechanisms of these theories are the presence of nerves and odontoblastic process within the dentinal

tubules, bathing in the dentinal fluid, and also odontoblasts are close apposition subodontoblastic plexus. Therefore, the fluid movement can stimulate the ion channels, present in the nerve ending innervation and the odontoblast in the dentinal tubule, that causes pain transduction.

Therefore, the opening in the dentinal tubules and exposure of dentine are main causes for the development of dentine hypersensitivity (2,7,15,17,18). First, the opening of tubules are caused by the loss of smear layer and enamel (19). Normally, the smear layer is a physical barrier that declines a penetration of external environment into dentinal tubules (20). However, a smear layer which is a thin structure (thickness of smear layer around 1- to 2-μm) covered of dentinal tubules (21). The loss of smear layer is caused by improper brushing, tooth surface loss and scaling and root planning debridement. The loss of the smear layer might cause an activated dentine permeability. The increased dentine permeability causes an elevated movement of dentinal fluid. An elevated movement of dentinal fluid generates an initiated action potential at the free nerve ending which develops pain hypersensitivity (22). Secondly, the sensitized dentine exposure causes a stimulated free nerve ending innervated odontoblast in dentinal tubule. The odontoblasts are developed receptor potentials and consequently the generation of action potential pass through the trigeminal pain system (23).

Moreover, the pathology of dentine hypersensitivity might depend on the size of exposed dentinal tubule. The recent review found that a sensitive tooth has a greater number of open tubules per unit area when compared to a nonsensitive teeth (17,24). The flow of fluid movement relies on the radius of dentinal tubules which is approximately the biquadrate of a radius of tubules (25). The mean diameter's tubules in sensitive teeth is approximately twice large when compared to nonsensitive teeth (26). Therefore, the fluid flow in tubules of sensitive teeth should be 16 times when compared to the nonsensitive teeth (27).

The receptor potential on the odontoblast was stimulated and summated by the generation of a pain action potential in the odontoblast cell. The pain responses in dentine hypersensitivity are conveyed by a trigeminal pain pathway. The trigeminal nerve or cranial nerve V innervated pulp tissue and odontoblasts (28). The most peripheral nociceptors in odontoblasts are sodium channel and transient receptor potential groups. The transient receptor potential groups are mechanosensitive and cationic channels. The mechanosensitive channels are activated by mechanical stimuli and dentinal fluid flow. The activated transient receptor potential group channel causes increased calcium and positive charge influxes to the odontoblast (29,30). Free nerve ending innervated odontoblast in dentinal tubule are stimulated by the generation of receptor potentials (31), subsequently, the action potential occurs at the free nerve ending innervated odontoblast in dentinal tubule. The pain signal from odontoblasts is classified into the peripheral pain system (32). The odontoblasts are received the external stimulus which are contributes mechanoreceptors stimulation and subsequently the generation of pain action potentials. The pain signals are projected to the trigeminal ganglia. The trigeminal ganglia is a unipolar sensory nerve

that contains the trigeminal nerve branches. The pain signals from the trigeminal nerve are sent to the spinal trigeminal nucleus caudalis. The secondary order neuron contained in the trigeminal nucleus caudalis receives the pain signals and projects them to the thalamus and somatosensory cortex for pain perception and interpretation of dentine hypersensitivity (33,34).

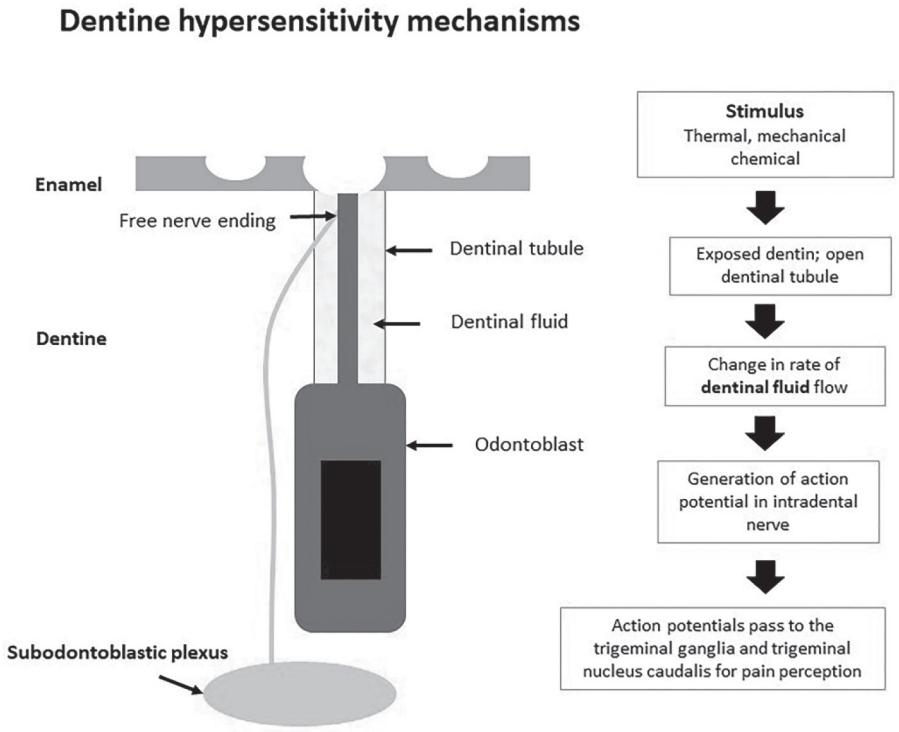

Fig 1. Focus on pathophysiology of dentine hypersensitivity.

Effect of periodontal disease on dentine hypersensitivity

Periodontal disease is a condition which affects to loss of periodontium. The causes of periodontal disease are the accumulation of plaque, calculus, and food debris. The previous study reported that the root surface with plaque accumulation has a large dental mineralization. (35). The demineralization of tooth structure contributes to the loss of dentine. Moreover, the high accumulation of plaque and calculus may potentially cause a gingival recession. The gingival recession may result in dentine hypersensitivity because of the change of position in a gingival margin to from the apical to enamel junction, leading to an exposure of cementum at the root surface.

The gingival recession has resulted in improper tooth brushing and recession related to periodontal disease and periodontal disease following treatment (36). The improper tooth brushing might cause tooth surface loss, particularly, abrasion leading to loss of cervical tooth surface. Loss of tooth enamel is a precondition for exposure of dentin, and it occurs both of above and below the cemental- enamel junction. The loss of tooth enamel can also cause exposure of cementum. The cervical region has a low

thickness of enamel near the cementum leading to easily exposed of dentin. Exposed dentin causes an enhanced dentinal fluid flow leading to dentine hypersensitivity. Also, the patients who have used toothpaste during brushing do not affect to the enamel, but prolonged and improper tooth-brushing techniques with high amount of abrasive substances in toothpaste can cause an exposure of dentine (37). Thus, the level of wear correlation to abrasive toothpaste is related to dentin abrasively and subsequently the development of dentine hypersensitivity (13,38).

Recession linked to periodontal disease and periodontal disease following treatment is caused by the treatment of severe periodontitis disease (39). These procedures in periodontal therapy cause healing of gingiva resulting in the recession of gingiva (40). Therefore, periodontal disease and its following treatment might cause exposure of dentinal tubule and dentine, resulting in the development of dentine hypersensitivity.

Effect of teeth defects on dentine hypersensitivity

Tooth surface loss is a tooth defect that was deprived of bacteria induction at enamel and dentine. Tooth surface loss consists of abrasion, abfraction, erosion and attrition (41). The effect of acidic drinks and beverages causes erosion leading to the exposure of tubule's dentine. The previous study found that the diameter of dentinal tubules in teeth after consuming of sour drinks became larger compared to normal teeth (42). The commonness of taking erosive drinks could be allowed a formation of plaque accumulation and hardening of the surface with acid-softened exposures (43). There is a previous report found that patients who had experience in various conditions such as gastric regurgitation, Bulimia nervosa, Anorexia nervosa, exposed to water with chlorine which is pH less than 2.7 can subsequently develop dentine hypersensitivity. Moreover, patient who had history of erosion can cause dentine hypersensitivity (44-47).

Attrition and abfraction are associated with habitual chewing on hard foodstuffs and bruxism (48,49). Attrition is the most disarranged occlusal surface including enamel and dentine. Abfraction is caused by forces placed on the teeth during grinding in the cervical lesion. The patients with a history of bruxism also reported dentine hypersensitivity (50). Moreover, it has been reported that selective 5-hydroxytryptamine reuptake inhibitor drugs may cause bruxism, especially an initiated taking this drug (51).

Regarding abrasion on teeth, it is classified into the loss of enamel at the cervical areas and also, the dentine hypersensitivity. All of these are is related to the abrasion and periodontal disease (52).

Effect of orthodontic tooth movement on dentine hypersensitivity

The aim of orthodontic treatment is a rearrangement of teeth and normal occlusion. Malocclusion is a rationale for poor oral hygiene and periodontal disease, particularly the gingival recession. The clinical study about the association of orthodontic treatment and gingival recession is controversial (53). The gingival recession might contribute to dentine hypersensitivity. Several studies demonstrated that the extent of gingival recession is related to patients who have infraversion and open bite (54). The duration of orthodontic treatment causes an increase in overloading occlusal force. The increase in overloading occlusal force often results in an

alveolar bone resorption contributed to the gingival recession (55). Moreover, the labial or lingual plate are a procedure in orthodontic treatment that might cause bone dehiscence formation at the lingual or labial side. Bone dehiscence formation at the gingiva leads to loss of periodontium, and subsequently, the development of dentine hypersensitivity (6,56). However, the association of orthodontic treatment and dentine hypersensitivity is still controversial. The further study will be required.

Effect of the immune system on dentine hypersensitivity

The immune system relates to protection against external and noxious stimuli. Normally, the immune cells, particularly neutrophils, kill the noxious stimulus. Furthermore, the protective system of odontoblasts plays an essential role on an initiated hurdle of the pulpal tissue which can against external stimulation. The odontoblasts can detect the thermal and mechanical stimuli by mechanosensitive and thermosensitive ion channels in the free nerve ending innervated to odontoblast cells (57). The ion channels and receptors that involve in dentine hypersensitivity such as voltage sodium channel, transient potential receptors. The activated ion channels cause an accumulation of positive charge leading to an generation of action potentials (58). Moreover, the process of odontoblast responses is a deposition of reactionary dentine (59). The reactionary dentine can protect an injury of the pulp tissue. Odontoblasts have expressed many classes of receptors and ion channels which are involved in nociceptive signal and signal transmission (60). The opening of dentinal tubules causes a change in dentinal fluid flow leading to activated ion channels in odontoblasts. Odontoblasts can receive and recognize external stimuli for transforming to pain signals (61). The generation of pain signals passes through nerve fibers in the pulp tissue and subsequently, dentine hypersensitivity is developed. However, the relationship of immune system and dentine hypersensitivity is not elucidated. The further study will be required to clarify this relationship.

Conclusion

Sharp or sudden pain is the main symptom of dentine hypersensitivity in the teeth. This symptom is initiated by activated noxious stimuli. Pathophysiology of dentine hypersensitivity involves in exposed dentine and opening of dentinal tubules. The opening of dentinal tubules causes a response immune system that produces odontoblasts and changes the dentinal fluid. Repetitive external stimuli and the opening of dentinal tubules lead to the augmented pain action potential and the development of dentine hypersensitivity. However, our further study will examine the nociceptors and immune system of odontoblast responses.

References

1. Addy M. Dentine hypersensitivity: New perspectives on an old problem. Int Dent J. 2002;52(5):367-375.

2. Addy M, Pearce N. Aetiological, predisposing and environmental factors in dentine hypersensitivity. Arch Oral Biol. 1994;39(Suppl): 33S-38S.

3. Orchardson R, Gillam DG. Managing dentin hypersensitivity. J Am Dent Assoc. 2006; 137(7):990-8; quiz 1028-9.

4. Idon PI, Sotunde OA, Ogundare TO. Beyond the Relief of Pain: Dentin Hypersensitivity and Oral Health-Related Quality of Life. Front Dent. 2019;16(5):325-34.

5. Douglas-de-Oliveira DW, Vitor GP, Silveira JO, Martins CC, Costa FO, Cota LOM. Effect of dentin hypersensitivity treatment on oral health related quality of life - A systematic review and meta-analysis. J Dent. 2018;71:1-8.

6. Tugnait A, Clerehugh V. Gingival recession-its significance and management. J Dent. 2001;29(6):381-94.

7. Addy M, Urquhart E. Dentine hypersensitivity: its prevalence, aetiology and clinical management. Dent Update. 1992;19(10):407-8, 10-2.

8. Absi EG, Addy M, Adams D. Dentine hypersensitivity. A study of the patency of dentinal tubules in sensitive and non-sensitive cervical dentine. J Clin Periodontol. 1987;14(5): 280-4.

9. Absi EG, Addy M, Adams D. Dentine hypersensitivity. The development and evaluation of a replica technique to study sensitive and non-sensitive cervical dentine. J Clin Periodontol. 1989;16(3):190-5.

10. Gunji T. Morphological research on the sensitivity of dentin. Arch Histol Jpn. 1982;45(1): 45-67.

11. Longridge NN, Youngson CC. Dental Pain: Dentine Sensitivity, Hypersensitivity and Cracked Tooth Syndrome. Primary Dental Journal. 2019;8(1):44-51.

12. Felix J, Ouanounou A. Dentin Hypersensitivity: Etiology, Diagnosis, and Management. Compend Contin Educ Dent. 2019;40(10):653-7; quiz 8.

13. Mason S, Young S, Araga M, Butler A, Lucas R, Milleman JL, et al. Stain control with two experimental dentin hypersensitivity toothpastes containing spherical silica: a randomised, early-phase development study. BDJ Open. 2019;5:8.

14. West N, Seong J, Davies M. Dentine hypersensitivity. Monogr Oral Sci. 2014;25:108-22.

15. Dowell P, Addy M. Dentine hypersensitivity--a review. Aetiology, symptoms and theories of pain production. J Clin Periodontol. 1983;10(4):341-50.

16. Brannstrom M. The hydrodynamic theory of dentinal pain: sensation in preparations, caries, and the dentinal crack syndrome. J Endod. 1986;12(10):453-7.

17. Krauser JT. Hypersensitive teeth. Part I: Etiology. J Prosthet Dent. 1986;56(2):153-6.

18. Collaert B, Fischer C. Dentine hypersensitivity: a review. Endod Dent Traumatol. 1991;7(4):145-52.

19. Zero DT, Lussi A. Erosion - Chemical and biological factors of importance to the dental practitioner Int Dent J. 2005;55(4 Suppl 1):285-90.

20. Pashley DH. Smear layer: overview of structure and function. Proc Finn Dent Soc. 1992;88(Suppl 1):215-24.

21. Van Landuyt K, Munck J, Coutinho E, Peumans M, Lambrechts P, Van Meerbeek B. Bonding to Dentin: Smear Layer and the Process of Hybridization. Eliades G, David Watts D, Theodore Eliades T, editors. Dental Hard Tissues and Bonding: Interfacial Phenomena and Related Properties. Heidelberg: Springer-Verlag Berlin; 2005. pp 89-122.

22. Cummins D. Recent advances in dentin hypersensitivity: clinically proven treatments for instant and lasting sensitivity relief. Am J Dent. 2010;23(Spec No A):3a-13a.

23. Walters PA. Dentinal hypersensitivity: a review. J Contemp Dent Pract. 2005;6(2):107-17.

24. Pashley DH. Dentin permeability, dentin sensitivity, and treatment through tubule occlusion. J Endod. 1986;12(10):465-74.

25. Miglani S, Aggarwal V, Ahuja B. Dentin hypersensitivity: Recent trends in management. J Conserv Dent. 2010;13(4):218-24.

26. Mantzourani M, Sharma D. Dentine sensitivity: past, present and future. J Dent. 2013;41(Suppl 4):S3-17.

27. Consensus-based recommendations for the diagnosis and management of dentin hypersensitivity. J Can Dent Assoc. 2003;69(4): 221-6.

28. Chung G, Jung SJ, Oh SB. Cellular and molecular mechanisms of dental nociception. J Dent Res. 2013;92(11):948-55.

29. El Karim IA, Linden GJ, Curtis TM, About I, McGahon MK, Irwin CR, et al. Human odontoblasts express functional thermo-sensitive TRP channels: implications for dentin sensitivity. Pain. 2011;152(10):2211-23.

30. Maurin JC, Couble ML, Thivichon-Prince B, Magloire H. Odontoblast: a key cell involved in the perception of dentinal pain. Med Sci (Paris). 2013;29(3):293-9.

31. Lee K, Lee BM, Park CK, Kim YH, Chung G. Ion Channels Involved in Tooth Pain. Int J Mol Sci. 2019;20(9):2266.

32. Huff T, Daly DT. Neuroanatomy, Cranial Nerve 5 (Trigeminal). In: StatPearls. Treasure Island (FL): StatPearls Publishing; 2020.

33. van der Bilt A, Engelen L, Pereira LJ, van der Glas HW, Abbink JH. Oral physiology and mastication. Physiol Behav. 2006;89(1):22-7.

34. Sole-Magdalena A, Martinez-Alonso M, Coronado CA, Junquera LM, Cobo J, Vega JA. Molecular basis of dental sensitivity: The odontoblasts are multisensory cells and express multifunctional ion channels. Ann Anat. 2018; 215:20-9.

35. Cury MS, Silva CB, Nogueira RD, Campos MGD, Palma-Dibb RG, Geraldo-Martins VR. Surface roughness and bacterial adhesion on root dentin treated with diode laser and conventional desensitizing agents. Lasers Med Sci. 2018;33(2):257-62.

36. Elovikova TM, Ermishina EY, Uvarova LV, Koshcheev AS. The increased sensitivity of dentin: the mechanisms of remineralization using toothpaste with tin fluoride. Stomatologiia (Mosk). 2019;98(5):66-71.

37. Joao-Souza SH, Machado AC, Lopes RM, Zezell DM, Scaramucci T, Aranha ACC. Effectiveness and acid/tooth brushing resistance of in-office desensitizing treatments-A hydraulic conductance study. Arch Oral Biol. 2018;96:130-6.

38. Nassar HM, Lippert F, Eckert GJ, Hara AT. Impact of toothbrushing frequency and toothpaste fluoride/abrasivity levels on incipient artificial caries lesion abrasion. J Dent. 2018;76: 89-92.

39. Bignozzi I, Littarru C, Crea A, Vittorini Orgeas G, Landi L. Surgical treatment options for grafting areas of gingival recession association with cervical lesions: a review. J Esthet Restor Dent. 2013;25(6):371-82.

40. Teixeira DNR, Zeola LF, Machado AC, Gomes RR, Souza PG, Mendes DC, et al. Relationship between noncarious cervical lesions, cervical dentin hypersensitivity, gingival recession, and associated risk factors: A cross-sectional study. J Dent. 2018;76:93-7.

41. Ibbetson R, Eder A. Tooth surface loss: Editors' introduction. Br Dent J. 1999;186(2): 60.

42. Addy M, Absi EG, Adams D. Dentine hypersensitivity. The effects in vitro of acids and dietary substances on root-planed and burred dentine. J Clin Periodontol. 1987;14(5):274-9.

43. Curtis DA, Jayanetti J, Chu R, Staninec M. Managing dental erosion. Todays FDA. 2012; 24(4):44-5.

44. Grippo JO, Simring M. Dental 'erosion' revisited. J Am Dent Assoc. 1995;126(5):619-20.

45. Grippo JO. Abfractions: a new classification of hard tissue lesions of teeth. J Esthet Dent. 1991;3(1):14-9.

46. Edwards M, Creanor SL, Foye RH, Gilmour WH. Buffering capacities of soft drinks: the potential influence on dental erosion. J Oral Rehabil. 1999;26(12):923-7.

47. Lussi A. Dental erosion clinical diagnosis and case history taking. Eur J Oral Sci. 1996;104(2):91-8.

48. Watson ML, Burke FJ. Investigation and treatment of patients with teeth affected by tooth substance loss: a review. Dent Update. 2000;27(4):175-83.

49. Nascimento MM, Dilbone DA, Pereira PN, Duarte WR, Geraldeli S, Delgado AJ. Abfraction lesions: etiology, diagnosis, and treatment options. Clin Cosmet Investig Dent. 2016;8:79-87.

50. Rees JS, Somi S. A guide to the clinical management of attrition. Br Dent J. 2018;224(5): 319-23.

51. Albayrak Y, Ekinci O. Duloxetine-induced nocturnal bruxism resolved by buspirone: case report. Clin Neuropharmacol. 2011;34(4):137-8.

52. West NX, Lussi A, Seong J, Hellwig E. Dentin hypersensitivity: pain mechanisms and aetiology of exposed cervical dentin. Clin Oral Investig. 2013;17(Suppl 1):9–19.

53. Sharma K, Mangat S, Kichorchandra MS, Handa A, Bindhumadhav S, Meena M. Correlation of Orthodontic Treatment by Fixed or Myofunctional Appliances and Periodontitis: A Retrospective Study. J Contemp Dent Pract. 2017;18(4):322-5.

54. Jin YZ, Zhang P, Hao T, Wang LM, Guo MD, Gan YH. Connexin 43 contributes to temporomandibular joint inflammation induced-hypernociception via sodium channel 1.7 in trigeminal ganglion. Neurosci Lett. 2019;707: 134301.

55. Aras I, Olmez S, Akay MC, Ozturk VO, Aras A. Treatment of lateral open bite with vertical dentoalveolar distraction osteogenesis. Am J Orthod Dentofacial Orthop. 2015;148(2):321-31.

56. Juloski J, Glisic B, Vandevska-Radunovic V. Long-term influence of fixed lingual retainers on the development of gingival recession: A retrospective, longitudinal cohort study. Angle Orthod. 2017;87(5):658-64.

57. Bleicher F. Odontoblast physiology. Exp Cell Res. 2014;325(2):65-71.

58. Carda C, Peydro A. Ultrastructural patterns of human dentinal tubules, odontoblasts processes and nerve fibres. Tissue Cell. 2006; 38(2):141-50.

59. Yumoto H HK, Hosokawa Y. The roles of odontoblasts in dental pulp innate immunity. Jpn Dent Sci Rev. 2018;54(3):105-17.

60. Allard B, Magloire H, Couble ML, Maurin JC, Bleicher F. Voltage-gated sodium channels confer excitability to human odontoblasts: possible role in tooth pain transmission. J Biol Chem. 2006;281(39):29002-10.

61. Martin-de-Llano JJ, Mata M, Peydro S, Peydro A, Carda C. Dentin tubule orientation determines odontoblastic differentiation in vitro: A morphological study. PLoS One. 2019;14(5): e0215780.

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