

Root caries: the intersection between periodontal disease and dental caries in the course of ageing

Nivetha N. Gavriilidou*¹ and Georgios N. Belibasakis¹

Key points

There is a clear correlation between periodontal health status and development of root caries.

Increasing age, associated with both greater prevalence of gingival recession and caries risk, could accelerate root caries among older adults.

Root caries management based on structured diagnostic protocol and active engagement of cross-disciplinary dental professionals are needed.

Abstract

Caries and periodontitis are the primary non-communicable oral diseases among elderly individuals. The burden of the disease increases with ageing, particularly as the elderly are tending to retain more teeth due to improvement of oral health measures and increased life expectancy. Root caries represents itself as an overlapping pathology, but not necessarily a summation of the two diseases. This narrative commentary discusses the cross-boundary nature of root caries, a periodontal-cariological condition, taking into account the multi-morbidities of ageing. The evidence includes epidemiological and pathophysiological features of root caries, and specific influencing factors of ageing, such as xerostomia, polypharmacy, functional and cognitive impairment and oral ecological alterations. Active or previous history of periodontal disease poses a risk for root caries, whereas the systemic co-morbidities of ageing may also increase the susceptibility to this pathology. It is plausible that root caries is the net outcome of coexisting risk for these conditions. There exists no standardised system for risk assessment and diagnosis that takes into account the interactive effect of caries, periodontitis and the constellation of age-specific influencing factors. As restorative treatment is challenging, cost-effective prevention and diagnosis methods are needed for vulnerable elderly populations. These may include improved clinical registration methods and establishment of individualised prevention and treatment protocols.

Background

By 2050, doubling of the 'greying population' will have major health and economic implications.^{1,2} Approximately 900 million individuals are aged over 60 years worldwide, with 125 million of this age group aged over 80 years.¹ The most common causes of mortality among elderly are vascular diseases and associated non-communicable chronic conditions, such as chronic obstructive pulmonary disease, cardiovascular diseases, type-2 diabetes mellitus, cognitive decline, dementia, and cancer.^{3,4,5} Dental caries and periodontal diseases are the commonest of oral health issues and most prevalent among

older age groups. They are closely related to systemic inflammatory comorbidities of older adults, and may affect disease progression and quality of life.^{6,7}

With this current demographic shift, older adults also tend to retain their dentition into old age demanding provision of dental care to prevent disease and promote (oral) health and wellbeing.^{2,8} Maintenance of adequate masticatory function is crucial in the maintenance of a nutritional balance particularly among the sarcopenic and the frail elderly.^{9,10,11} This enables a healthy 'oral ageing', which entails satisfactory and sufficient nutrition, cognitive function and social wellbeing.^{6,11,12,13} To be able to achieve this, it is important to address the most common chronic causes of tooth loss, namely, dental caries and periodontitis, as well as their interconnection in the course of ageing. This narrative review focuses on root surface caries, a common and challenging issue among older adults, and presents the significance and practical implications of the cross-boundary

nature of this periodontal-cariological condition. It was based on reviews and original articles identified on searches in PubMed, Medline and Embase, the Cochrane register and bibliographies of European and World Workshops, considering the periodontal and cariological perspectives of root caries among elderly. The evidence includes the epidemiology and patho-physiology of root caries, and the implications of common factors of ageing such as xerostomia, polypharmacy, functional and cognitive impairment and oral ecological alterations.

Epidemiology of root caries

Dental caries and periodontitis compromise oral health and function in elderly individuals, and root caries is a condition that combines features of these two oral diseases. The prevalence of root caries has been reported to vary widely (25–100%) due to vast clinical heterogeneity of the studies conducted. The annual root caries incidence also presents a

¹Division of Oral Diseases, Department of Dental Medicine, Karolinska Institutet, Alfred Nobels allè 8, 14104, Huddinge, Sweden

*Correspondence to: Nivetha N. Gavriilidou
Email: nivetha.gavriilidou.natarajan@ki.se

Refereed Paper.

Accepted 22 August 2019

<https://doi.org/10.1038/s41415-019-0973-4>

similar broad variation between 10.1 and to 40.6% and mean root caries index between 9.7 and 38.7. These studies, however, converge on the conclusion that the burden of root caries is high in the older population.¹⁴ Furthermore, evidence indicates that root caries increased over time even among the healthier older adults, demanding closer attention both at an individual level among clinicians and at a community level among policy makers.¹⁵

Periodontal disease – dental caries: a negative mutualism in ageing

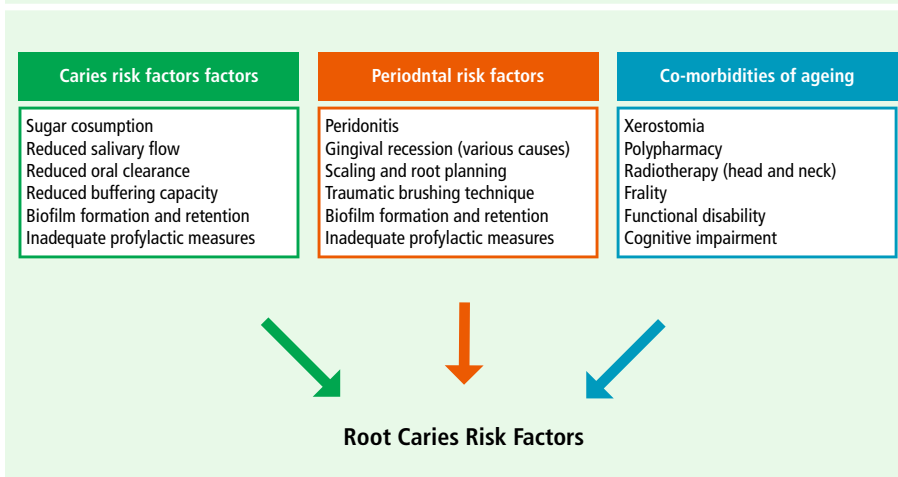
Despite the increased prevalence of chronic medical conditions among the elderly,^{16,17} increasing numbers live independently, are mobile and active in their communities.¹⁸ The vast majority are also healthy in relation to oral structures and function.^{11,19,20}

Despite the extensive scientific work in the field of root caries, consensus is lacking regarding certain aspects. This includes the relationship between periodontal status and predilection for root caries, age-changes as predisposing factors, age-specific risk factors and specified diagnostic criteria. Figure 1 gives a schematic representation of the risk factors for root caries accounting for the correlation between caries and periodontal risk factors and the co-morbidities of ageing. It illustrates the cross-disciplinary nature of root caries pathology.

Advancing age could be an aggravating factor that increases the susceptibility for root caries, particularly with a history of, or ongoing, periodontal disease.^{21,22,23} However, definitive epidemiological evidence in this regard is still missing. Similarly, full awareness of the risk and activity of root caries in patients with periodontal disease or long-term periodontal treatment also appears to be lacking.

There exist several assumptions regarding the interplay between root caries and periodontal status (dormant, active, aggressive or treated disease).^{9,21,24,25,26} They are principally based on the theory that risk factors for 'any-surface' caries exist in an environment where there is an available tooth surface. Here, it is the root surface that is exposed to the oral cavity acting as a substrate, taking into account the role of caries aggravating and resistance factors.^{21,23,25,26} In this way, root caries pathology seems to override two significant predisposing factors: periodontal status and ageing process. Fundamentally, root caries develops on tooth structures that have a clinical attachment loss,

Fig. 1 Illustration of the risk factors for root caries accounting for the correlation between caries and periodontal risk factors and the co-morbidities of ageing



where the latter is evidently not a common parameter in any other smooth surface carious lesion.^{24,27,28} Gingival recession may not indicate periodontal disease but may rather denote a history of anatomical discrepancies in the arrangement of the dental arch. These aspects cannot be disregarded in understanding the process of root caries development.²⁴ Gingival recession may also be related to the ageing process, a manifestation of latent systemic inflammation by itself that could involve the connective tissue of supportive structures with or without periodontal pathology.^{24,28} Other changes related to ageing, discussed in detail in the following section, could also act laterally making it conducive for the development of root caries.

Diagnostic criteria & management of root caries

Based on the International Caries Detection and Assessment System (ICDAS)²⁹ and as a serial refinement of the existing caries management protocols, the International Caries Classification and Management System (ICCMS) has been proposed.³⁰ It suggests a comprehensive set of clinical protocols that address all diagnostic, preventive and restorative decisions necessary 'to preserve tooth structure and restore only when indicated'.³⁰ Despite these well-validated systems, there is still no consensus on a universal standard for root caries identification and management.^{30,31,32,33}

Root caries clinically presents as discolouration and loss of surface continuity or cavitation below the cement-enamel junction (Fig. 2). The ICCMS Diagnostic

Criteria for Detection and assessment of Root Caries proposed root caries staging and activity assessment.³⁰ The staging was based on cavitation and activity of the lesions and the root surfaces were classified as 'none' or in the 'initial and moderate/extensive' stages. The activity of root caries was determined based on the characteristics of the observed discolouration on the root surface. This included texture (smooth, rough), appearance (shiny or glossy, matte or non-glossy), location in a plaque-stagnation area, and perception of texture on gentle probing (soft, leathery, hard). This system has, however, not been further evaluated nor were the proposed criteria designed to be standardised guidelines for identification and diagnosis of root caries.

Furthermore, efforts have been made in the identification of a caries risk assessment tool to effectively capture (at least) the high-risk individuals in clinical settings aiming to maximise the effectiveness of preventive procedures.^{34,35} Cariogram, an interactive computer-based caries risk assessment program, developed in Malmö, Sweden proved to be a reliable tool in predicting root caries risk in older adults.³⁴ However, this was studied among a specific, self-selected population and setting, and needs further validation with respect to its broader health economic benefits. Caries Management by Risk Assessment (CAMBRA) developed in California is another caries risk assessment tool that has demonstrated the relationship between the assessed risk levels (low, moderate, high, and extreme) with radiological evidence of dentine caries established with time.³⁶ Studies have investigated the predictability of CAMBRA among children (0–5 years, 6 years and above)



Fig. 2 A patient presenting with clinical signs of generalised gingival recession and root caries lesions on the exposed root surfaces (here evidenced particularly on the lower dentition as a discoloration below the cemento-enamel junction)

and among adults taking into account the relevant caries risk and protective factors.³⁶ Nevertheless, the applicability of CAMBRA in the elderly population, exposed to a unique array of risk factors, is debatable.³⁷

The treatment of root caries lesions is challenging, and traditional restorative treatment is not offered, given also the physical and functional restrictions common to the vulnerable elderly group. Consequently, there is a great need for cost-effective prevention. A study conducted within the German healthcare setting, assessed and compared the cost-effectiveness of root caries prevention using fluoride rinses, chlorhexidine varnishes, silver diamine fluoride varnishes and no treatment. They found that application of silver diamine fluorides was the most effective strategy in patients with high risk of root caries.³⁵ A study among disabled elderly nursing home residents showed that toothpastes with higher fluoride concentration (5,000 ppm F⁻) could be effective in arresting root caries lesions and promoting remineralisation.³⁸ Accordingly, dentifrices containing similarly high fluoride doses are shown to be effective against root caries and promote a higher degree of mineralisation^{38,39,40}

Role of the dental biofilm

The ICCMS system takes into consideration the location and thickness of the biofilm on the tooth surface, as increased caries risk has been traditionally associated with plaque/biofilm accumulation. Yet, the current concepts on the development of dental caries infection implicate shifts in the microbial ecology within the different micro-niches of the oral

cavity, rather than considering volumetric or 'geographic' criteria.⁴¹

Root caries development has been hypothetically explained by the ecological phenomenon of acid production by bacteria in the associated biofilm. As a result of 'aciduric' microbiota there is hard tissue demineralisation, exposure of organic matrix, and activation of host-derived proteases in saliva and dentine (matrix metalloproteinases, cathepsins) initiating degradation of demineralised organic matrix in root surfaces.⁴² The acidic microenvironment instilled by saccharolytic bacteria that ferment dietary sugars (such as mutans streptococci) favour their further growth and metabolic activities, as well as the mineral dissolution of the dental hard tissues. Exposure of cementum/dentine due to recession may provide a new substrate for bacterial adhesion, and favour colonisation of Gram-negative proteolytic species that can degrade the endogenous collagen and other organic components of these tissues. Hence, a mixed flora may act in concert to catabolise both the inorganic and the organic components of the hard dental tissues.⁴³ *Actinomyces* spp. show increased prevalence of colonisation by increasing age, and potentially as a result of the affinity of this species with the dental hard tissues.⁴⁴ Indeed, *Actinomyces* spp. are typically more predominant than mutans streptococci in root caries, although variations may exist depending on the stage (initial vs advanced) or activity of the carious lesion.^{45,46} Therefore, measurements of biological changes within the biofilm could be useful in the future in monitoring the risk for establishment or the activity of established carious lesions.

Risk factors for oral disease in the elderly populations

A number of physiological and pathological changes associated with ageing, or the inflammatory process in senility, may be detrimental to oral health, including increased susceptibility to root caries.^{23,25,26,37,47} Local risk factors may include decreased salivary flow (or xerostomia), root surface exposure due to periodontal disease, previous caries experience and inability to perform sufficient oral hygiene. Systemic risk factors may include, chronic medical conditions, such as diabetes mellitus, cardiovascular diseases, rheumatoid arthritis, mental illness, depression, Alzheimer's disease or dementia and Sjögren's syndrome. These may not only increase the systemic inflammatory burden, but also increase the need for medication and pose physical and functional limitations that necessitate dependence in daily life activities, and impact dietary habits and oral hygiene practice. Multiple medications or radiation treatment are also indirect risk factors due to their negative influence on salivary flow or a high sugar content in the drug carrier. The roles of oral hygiene, polypharmacy, saliva and quality of life, in relation to root caries are discussed further in the following sections.

Oral hygiene

Mechanical plaque control and fluoride use are essential caries management measures that address microbial colonisation.⁴⁸ Highly fluoridated (5,000 ppm) toothpastes provide better protection against root caries lesions by achieving a significant increase in fluoride concentration in saliva and plaque after tooth brushing.^{38,39,40,49} An important recommendation is that such toothpastes are used in conjunction with mechanical cleaning procedures, including interdental cleaning, in susceptible elderly patients.

Specific predilection sites for caries, such as interdental surfaces, pits and fissures, challenge optimal hygiene measures.³² This applies also to the root surfaces. Poor plaque control is rather evidently associated with root caries because sub-gingival plaque not only challenges oral hygiene practices but also conceals the consequent progressing tissue degradation on the tooth surface of contact.^{24,43} Such lesions invading the cemental surface may or may not comprise gingival coverage.²⁸ The identification of root caries through visual

inspection is therefore possible only after a preceding gingival recession, which in itself could represent an active/dormant/latent/or previous periodontal disease. Active gingivitis presenting with swelling and bleeding could also pose challenges to the visual identification of root caries and hence cause a delay in management.²⁴ Besides, mechanical plaque removal measures ensure improvement in periodontal health by reducing bleeding and swelling, consequently creating a conducive platform for effective caries management. Older adults, particularly those dependent on assistance for daily life activities for varying reasons, have a relatively greater caries risk and activity than their younger or healthier counterparts.^{10,22,25} Here, effective plaque control and management of periodontitis would be the first line strategy in the management of root caries.

Comorbidities and polypharmacy

The prevalence of systemic diseases increases exponentially with increasing age, challenging the healthy ageing process.^{16,21} Several medical conditions common among older adults, such as cardiovascular diseases, diabetes, chronic renal failure, Alzheimer's disease and depression, have been shown to be tightly linked to oral disease.^{6,7,50}

An inflammatory relationship has also been illustrated between the oral and systemic environment creating ground for periodontal manifestation of the systemic inflammation which could in turn result in gingival attachment loss and risk for root caries.^{7,9,16,44,51} Other related root caries risk events are drug-induced xerostomia (discussed in the next section), high sugar content in the drug delivery system, prescribed food supplements in malnourished individuals and those with percutaneous endoscopic gastrostomy (PEG, provided for dysphagia or sedation), Sjogren's syndrome etc.^{10,22} Frailty, functional constraint and cognitive deterioration, neglected self-care and dependence in daily life activities also pose challenges to self and professional anti-caries measures.^{9,25,52}

Root caries, given the challenges with diagnosis and management, pose a serious threat to the longevity of tooth structure. Occlusal derangement resulting from tooth loss has direct and indirect effects.^{53,54} The loss of sound oral functions, such as mastication and swallowing, could lead to dietary insufficiencies and malnutrition, an

alarming condition among (frail) elderly.^{20,53} Cognitive decline has also shown to be related to deteriorating masticatory efficiency due to tooth loss.¹³

Role of saliva (xerostomia)

Adequate quantity and function of saliva is vital to the maintenance of oral health. Reduction of salivary production not only results in a deterioration in oral health but also has a huge impact on quality of life. Several prescribed drugs used in the management of the common medical conditions among elderly patients have been shown to cause a reduction in salivary flow.¹⁷ Continuous use of xerostomic medications is shown to increase the risk of tooth loss among older adults.⁸ Psychopharmacological substances, antihypertensives, antihistaminics and diuretics have reported xerostomia as a common side effect.^{10,23,25} Awareness and appropriate management by medical professionals is therefore critical. Radiation therapy, which is necessitated in head-and-neck cancers, has also been shown to hamper salivary secretion, hence creating caries-favourable conditions, particularly around the marginal gingiva and sub-gingival areas.⁵⁵ Other consequences include plaque retention due to reduced salivary flow and acidic pH due to reduced salivary buffering. Several oral supplements and medications are also shown to contain high quantities of sugar delivered at a consistency favourable for nutritional intake but with the downside of oral sugar overload.¹¹ All of these factors are collectively contributing to the establishment of a microenvironment, which increases the risk for the development of root caries.

Quality of life

Several parameters influence the quality of life among elderly individuals. Studies have demonstrated oral health-related quality of life as a multidimensional parameter that impacts the overall functionality, well-being or quality of life of individuals.⁵³ Structural degradation of oral tissue, such as dental caries or periodontitis, leads to functional restrictions and symptomatic dysfunction. Root caries, prevalent among older adults could also cause pain, discomfort and deranged function leading to a higher grade of consequences, eg compromised nutrition intake, physical and psychological symptoms, greater dependence

in daily activities and disempowerment resulting from social isolation, social disadvantage and lower health literacy.

Summary and conclusions

Oral health is a critical component of healthy ageing and requires the ability to care for oneself and access to preventive services and treatment. Epidemiological evidence and analysis of trends in risk factors suggest that the burden of periodontal diseases and root caries increase as ageing populations tend to retain more teeth.^{19,26} Root caries is indeed most prevalent among this population. A previous history of periodontal disease or an active condition is a pre-requisite for root surface lesions. It is important to address this pathology not simply as a summation of two discrete diseases but identify their interactive effect, if any, and the potential synergism/antagonism of their interplay. Combining age, a clear risk factor, with other identified risk factors, would facilitate the development of guidelines and protocols for risk assessment, diagnostics and management, customised for the elderly population.

In conclusion, we hypothesise that root caries is an outcome of coexisting risk for caries and periodontal disease, which is age-wise dependent on the progression of the latter. To investigate this epidemiological assumption, large dental registry databases should be screened, assessing whether root caries lesions are registered as individual pathologies, or inclusive of enamel caries. This may raise a future need to differentiate the clinical registration of root caries *versus* enamel caries for earlier risk assessment, and establish individualised protocols for their prevention or treatment. The treatment of root caries lesions is challenging, as the traditional restorative treatment may often not be offered. Consequently, there is a great need for clinical validation of cost-effective preventive and diagnostic strategies, such as customised oral hygiene practices and routine monitoring, that may promote timely arrest of progression and thereby minimise the need for extensive restorations. Personalised prevention strategies may eventually involve microbiological and other biological parameters, a perspective that needs to be more closely considered in the future.⁵⁶

Acknowledgements

This work was supported by Institutional funds.

References

- World Health Organisation. Speed of population ageing. 2017.
- Ronald L. The demographic transition: Three centuries of fundamental change. *J Econ Perspect* 2003; **17**: 167–190.
- World Health Organisation. Preventing chronic diseases: a vital investment. Geneva (Switzerland): WHO Publications, 2005. Report No.: 92 4 156300 1.
- World Health Organisation. World report on Health and Aging. 2015. Geneva (Switzerland): WHO Publications, 2015
- Government Offices of Sweden. Future Challenges for Sweden – Final Report of the Commission on the Future of Sweden. Available online at <https://www.government.se/legal-documents/2013/03/ds-201319/> (accessed 31 October 2019).
- Ahmed T, Haboubi N. Assessment and management of nutrition in older people and its importance to health. *Clin Interv Aging* 2010; **5**: 207–216.
- Joseph B K, Kullman L, Sharma P N. The oral-systemic disease connection: a retrospective study. *Clin Oral Investig* 2016; **20**: 2267–2273.
- Edman K, Ohrn K, Nordstrom B, Holmlund A. Prevalence of dental caries and influencing factors, time trends over a 30-year period in an adult population. Epidemiological studies between 1983 and 2013 in the county of Dalarna, Sweden. *Acta Odontol Scand* 2016; **74**: 385–392.
- Tonetti M S, Bottenberg P, Conrads G *et al*. Dental caries and periodontal diseases in the ageing population: call to action to protect and enhance oral health and well-being as an essential component of healthy ageing – Consensus report of group 4 of the joint EFP/ ORCA workshop on the boundaries between caries and periodontal diseases. *J Clin Periodontol* 2017; **44** (Suppl 18): S135–S44.
- de Mata C, McKenna G, Burke F M. Caries and the older patient. *Dent Update*. 2011; **386**: 376–378: 81.
- Hujoel P P, Lingstrom P. Nutrition, dental caries and periodontal disease: a narrative review. *J Clin Periodontol* 2017; **44** (Suppl 18): S79–S84.
- Shlisky J, Bloom D E, Beaudreault A R *et al*. Nutritional considerations for healthy aging and reduction in age-related chronic disease. *Adv Nutr* 2017; **8**: 17–26.
- Elsig F, Schimmel M, Duverney E *et al*. Tooth loss, chewing efficiency and cognitive impairment in geriatric patients. *Gerodontology* 2015; **32**: 149–156.
- Hayes M, Burke F, Allen P F. Incidence, prevalence and global distribution of root caries. *Monogr Oral Sci* 2017; **26**: 1–8.
- Hariyani N, Setyowati D, Spencer A J, Luzzi L, Do L G. Root caries incidence and increment in the population – A systematic review, meta-analysis and meta-regression of longitudinal studies. *J Dent* 2018; **77**: 1–7.
- Hsu H C. Trajectories of multimorbidity and impacts on successful aging. *Exp Gerontol* 2015; **66**: 32–38.
- Yang D C, Lee J D, Huang C C, Shih H I, Chang C M. Association between multiple geriatric syndromes and life satisfaction in community-dwelling older adults: A nationwide study in Taiwan. *Arch Gerontol Geriatr* 2015; **60**: 437–442.
- Tucker K L, Buranapin S. Nutrition and aging in developing countries. *J Nutr* 2001; **131**: 2417S2423S.
- Frencken J E, Sharma P, Stenhouse L, Green D, Laverty D, Dietrich T. Global epidemiology of dental caries and severe periodontitis – a comprehensive review. *J Clin Periodontol* 2017; **44** (Suppl 18): S94–S105.
- Thorstensson H, Johansson B. Why do some people lose teeth across their lifespan whereas others retain a functional dentition into very old age? *Gerodontology* 2010; **27**: 19–25.
- Lopez R, Smith P C, Gostemeyer G, Schwendicke F. Ageing, dental caries and periodontal diseases. *J Clin Periodontol* 2017; **44** (Suppl 18): S145–S52.
- Carvalho J C, Schiffner U. Dental caries in European adults and senior citizens 1996–2016: ORCA Saturday Afternoon Symposium in Greifswald, Germany – Part II. *Caries Res* 2018; **53**: 242–252.
- Gati D, Vieira A R. Elderly at greater risk for root caries: a look at the multifactorial risks with emphasis on genetics susceptibility. *Int J Dent* 2011; **2011**: 647, 168.
- Heasman P A, Ritchie M, Asuni A, Gavillet E, Simonsen J L, Nyvad B. Gingival recession and root caries in the ageing population: a critical evaluation of treatments. *J Clin Periodontol* 2017; **44** (Suppl 18): S178–S193.
- Hayes M, Da Mata C, Cole M, McKenna G, Burke F, Allen P F. Risk indicators associated with root caries in independently living older adults. *J Dent* 2016; **51**: 8–14.
- Ritter A V, Shugars D A, Bader J D. Root caries risk indicators: a systematic review of risk models. *Community Dent Oral Epidemiol* 2010; **38**: 383–397.
- Zenthofer A, Schroder J, Cabrera T, Rammelsberg P, Hassel A J. Comparison of oral health among older people with and without dementia. *Community Dent Health* 2014; **31**: 27–31.
- Tugnait A, Clerehugh V. Gingival recession – its significance and management. *J Dent* 2001; **29**: 381–394.
- Pitts N B, Ekstrand K R, Foundation I. International Caries Detection and Assessment System (ICDAS) and its International Caries Classification and Management System (ICCMS) – methods for staging of the caries process and enabling dentists to manage caries. *Community Dent Oral Epidemiol* 2013; **41**: e41–52.
- Ismail A I, Pitts N B, Tellez M *et al*. The International Caries Classification and Management System (ICCMS) An Example of a Caries Management Pathway. *BMC Oral Health* 2015; **15** (Suppl 1): S9.
- Kamppi A, Tanner T, Pakkila J, Patinen P, Tjaderhane L, Anttonen V. Comparison of simple screening criteria with the International Caries Detection and Assessment System classification in determining restorative treatment need. *Int Dent J* 2016; **66**: 63–70.
- Ismail A I, Tellez M, Pitts N B *et al*. Caries management pathways preserve dental tissues and promote oral health. *Community Dent Oral Epidemiol* 2013; **41**: e12–40.
- Tellez M, Gomez J, Pretty I, Ellwood R, Ismail A I. Evidence on existing caries risk assessment systems: are they predictive of future caries? *Community Dent Oral Epidemiol* 2013; **41**: 67–78.
- Hayes M, Da Mata C, McKenna G, Burke F M, Allen P F. Evaluation of the Cariogram for root caries prediction. *J Dent* 2017; **62**: 25–30.
- Schwendicke F, Gostemeyer G. Cost-effectiveness of root caries preventive treatments. *J Dent* 2017; **56**: 58–64.
- Featherstone J D B, Chaffee B W. The Evidence for Caries Management by Risk Assessment (CAMBRA). *Adv Dent Res* 2018; **29**: 9–14.
- Chi D L, Berg J H, Kim A S *et al*. Correlates of root caries experience in middle-aged and older adults in the Northwest Practice-based REsearch Collaborative in Evidence-based DENTistry research network. *J Am Dent Assoc* 2013; **144**: 507–516.
- Ekstrand K R, Poulsen J E, Hede B, Twetman S, Qvist V, Ellwood R P A. A randomized clinical trial of the anti-caries efficacy of 5000 compared to 1450 ppm fluoridated toothpaste on root caries lesions in elderly disabled nursing home residents. *Caries Res* 2013; **47**: 391–398.
- Heijnsbroek M, Paraskevas S, Van der Weijden G A. Fluoride interventions for root caries: a review. *Oral Health Prev Dent* 2007; **5**: 145–152.
- Lynch E, Baysan A, Ellwood R, Davies R, Petersson L, Borsboom P. Effectiveness of two fluoride dentifrices to arrest root carious lesions. *Am J Dent* 2000; **13**: 218–220.
- Marsh P D. In Sickness and in health what does the oral microbiome mean to us? An ecological perspective. *Adv Dent Res* 2018; **29**: 60–65.
- Takahashi N, Nyvad B. Ecological hypothesis of dentin and root caries. *Caries Res* 2016; **50**: 422–431.
- Do T, Dame-Teixeira N, Naginyte M, Marsh P D. Root surface biofilms and caries. *Monogr Oral Sci* 2017; **26**: 26–34.
- Belibasakis G N. Microbiological changes of the ageing oral cavity. *Arch Oral Biol* 2018; **96**: 230–232.
- Schubach P, Osterwalder V, Guggenheim B. Human root caries: microbiota in plaque covering sound, carious and arrested carious root surfaces. *Caries Res* 1995; **29**: 382–395.
- Schubach P, Osterwalder V, Guggenheim B. Human root caries: microbiota of a limited number of root caries lesions. *Caries Res* 1996; **30**: 52–64.
- Sanchez-Garcia S, Reyes-Morales H, Juarez-Cedillo T, Espinel-Bermudez C, Solorzano-Santos F, Garcia-Pena C. A prediction model for root caries in an elderly population. *Community Dent Oral Epidemiol* 2011; **39**: 44–52.
- Mira A, Simon-Soro A, Curtis M A. Role of microbial communities in the pathogenesis of periodontal diseases and caries. *J Clin Periodontol* 2017; **44** (Suppl 18): S23–S38.
- Ekstrand K, Martignon S, Holm-Paedersen P. Development and evaluation of two root caries controlling programmes for home-based frail people older than 75 years. *Gerodontology* 2008; **25**: 67–75.
- Wu B, Fillenbaum G G, Plassman B L, Guo L. Association Between Oral Health and Cognitive Status: A Systematic Review. *J Am Geriatr Soc* 2016; **64**: 739–751.
- Bischoff S C, Boirie Y, Cederholm T *et al*. Towards a multidisciplinary approach to understand and manage obesity and related diseases. *Clin Nutr* 2017; **36**: 917–938.
- Gronbeck-Linden I, Hagglin C, Petersson A, Linander P O, Gahnberg L. Discontinued dental attendance among elderly people in Sweden. *J Int Soc Prev Community Dent* 2016; **6**: 224–229.
- Naka O, Anastasiadou V, Pissiotis A. Association between functional tooth units and chewing ability in older adults: a systematic review. *Gerodontology* 2014; **31**: 166–177.
- Nakanishi N, Hino Y, Ida O, Fukuda H, Shinsho F, Tataru K. Associations between self-assessed masticatory disability and health of community-residing elderly people. *Community Dent Oral Epidemiol* 1999; **27**: 366–371.
- Bertl K, Loidl S, Kotowski U *et al*. Oral health status and dental care behaviours of head and neck cancer patients: a cross-sectional study in an Austrian tertiary hospital. *Clin Oral Investig* 2016; **20**: 1317–1327.
- Belibasakis G N, Bostanci N, Marsh P D, Zaura E. Applications of the oral microbiome in personalized dentistry. *Arch Oral Biol* 2019; **104**: 7–12.