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Epidemiology of Erosive Tooth Wear, Dental Fluorosis and Molar Incisor Hypomineralization in the American Continent

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Abstract
Non-carious dental lesions such as developmental defects of enamel (DDE) and erosive tooth wear (ETW) are the subject of intensive research. This paper aims to give perspectives on both DDE, including dental fluorosis and molar incisor hypomineralization (MIH), and ETW, presenting epidemiological data from the Americas and associated diagnostic aspects. Besides, it is important to present evidence to guide the clinical assessment process, supporting the clinicians' management decisions towards better oral health of their patients. The overall increase in the worldwide prevalence of non-carious lesions discussed in this this paper may reflect the need of perceptual changes. Although the number of publications related to these conditions has been increasing in the last years, there is still a need for clinical diagnostic and management awareness to include these conditions in routine dental practice. Besides, it is important to provide recommendations for standardized clinical assessment criteria, improving the process and helping clinicians' adherence. In this sense, this paper discusses the most commonly implemented indices for each condition. Thus, despite the wide range of diagnostic indices, BEWE is proposed to be the index recommended for ETW assessment, Dean or Thylstrup & Fejerskov indices for fluorosis and preferably the EAPD criteria (or modified DDE index) for MIH. Overall, non-carious lesions are a growing concern, and it is important to implement preventive measures that control their severity and progression, and accurate diagnosis by the dental clinician.

Introduction

This paper is a product of the Saturday Afternoon Symposium (SAS) that took place last July during the 66th ORCA Congress in Cartagena, Colombia and offers valuable information for recognizing dental conditions (apart from dental caries) that constitute clinical, epidemiological, research and education challenges. Thus, a perspective based on best available evidence, on erosive tooth wear (ETW) and developmental defects of enamel

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(including molar incisal hypomineralization (MIH) and dental fluorosis) (DDE) is given here, emphasizing the American continent epidemiological information in relation to the context of the ORCA meeting held in a Latin American country.

In this sense, non-carious dental conditions such as ETW, MIH and dental fluorosis are subject of extensive research as well as growing concern to dentists around the world. The aim of this symposium paper is to give a perspective on the aforementioned conditions presenting, in addition to the epidemiological data, the most frequently reported indices for each condition and supporting guidance to clinicians regarding the assessment process in order to inform best practice management decisions, thus leading to better oral health outcomes for their patients.

The understanding of these dental conditions is also relevant to increase dental practitioners' awareness and skills regarding differential diagnosis of non-carious lesions for routine practice.

Erosive Tooth Wear

General Aspects

ETW has received increasing attention over the past 15 years [Schlueter and Luka, 2018]. This is in no small part to the data derived from global epidemiological studies, but most has been published in Europe. In 2009 [Van't Spijker et al., 2009] and 2010 [Kreulen et al., 2010] published two systematic reviews reporting higher levels in children and adolescents up to 82% in primary teeth and 5% in permanent teeth and for adults up to 17%. However, comparison between studies was challenging, because different indices were used to assess the severity of wear. In part, to overcome this the Basic Erosive Tooth Wear Examination (BEWE) was devised as part of a consensus meeting [Bartlett et al., 2008]. Although primarily designed for screening in general dental practice it has now been used regularly in prevalence studies and has since its introduction has been used in 58 clinical and epidemiological studies on 36,982 participants in 35 countries. Our team at KCL has reported prevalence rates for over 10,000 adults in 14 developed and developing countries with reported prevalence rates of 30% in adults aged 18–30 years [Bartlett et al., 2013] and up to 60% in developing countries such as Oman [Awad et al., 2019]. Overall, the prevalence rate is reported to be over 30%.

In calculating data, the convention is to accept the highest value from a single tooth or surface in a dentition. This gives an estimation of the impact of the condition, which is different to a patient's perspective, particularly for those with a mouth destroyed by tooth wear. However, using these methods data can be compared between countries with some confidence.

Epidemiology

European data suggests that the condition is common. One study from seven European countries reported BEWE scores of 2 with 29% of 3100 participants and 3% with BEWE 3, the higher score representing more severe wear [Bartlett et al., 2013]. Typically, with large multi-country studies there was variation between countries at different BEWE scores. This might reflect variation in risk factors between countries or differences in assessment processes which are inevitable with large population studies. A similar methodological process was used in an Arab study across 6 countries, which also reported variation between 60% in Oman to 15% in Jordan [Awad et al., 2019]. Training is essential to reduce variation between examiners, but some differences are inevitable. The UK has reported a comparatively large number of studies [Smith et al., 1997; Bartlett et al., 1998; Fares et al., 2009], but many have used the Smith and Knight [Smith and Knight, 1984] index which calculates tooth wear by dentine exposure. These data, based on dentine exposure, give a range between 2–5% in younger adults and up to 10% for older age groups [Van't Spijker et al., 2009]. But direct comparison to the BEWE is not possible as they use different criteria. But overall, the evidence suggests that ETW is common and increases severity with age (Table 1).

A recent paper by Schlueter and Luka [2018] reported prevalence data of 22% in Europe and 21% in America for children and adolescents. The number of studies reported in Europe was far higher than in other countries with 23 in Europe and 9 in the America's. Amongst other countries there were around ten. This paper also reported that the condition was age related, generally more common in males than females and children had higher levels. Their analysis of the data reported that in Europe the condition in adults varied between countries with Germany reporting 6- to 7-year-olds with 72%, the Netherlands 15- to 16-year-olds 30%, Sweden 18–19 years 22%. Very little data is available from South America or the USA.

The clinical finding that dentine is exposed causes some controversy partly due to a study on extracted teeth where dentine was observed to be exposed but on microscopic examination enamel remained visible [Ganss et al., 2006]. However, from a clinical perspective exposed dentine is a useful predictor of the depth of ETW whereas the

Table 1. The prevalence of erosive tooth wear in the Americas

Country	Authors	Year	Age, years	Sample size	ETW prevalence	Criteria
Brazil	Nahás-Pires et al.	2011	2–20	232	25.4	O'Brien index
Brazil	De Carvalho Sales-Peres et al.	2013	4 & 12	2,731	51.7	Erosion wear index (EWI)
Brazil	Moimaz et al.	2013	6–7	2,759	0.6	Tooth Wear Index (TWI)
Brazil	Frazao et al.	2018	6–10	239	11.7	BEWE
Brazil	Mangueira et al.	2009	6–12	983	19.9	O'Sullivan index
Brazil	Salas et al.	2014	8–12	1,211	25.0	O'Sullivan index
Brazil	Vargas-Ferreira et al.	2011	11–14	944	7.2	O'Sullivan index
Brazil	Peres et al.	2005	12	499	13.0	O'Sullivan index
Brazil	Correr et al.	2009	12	389	26.0	O'Sullivan index
Brazil	Alves et al.	2015	12	1,528	15.0	BEWE
Brazil	Gurgel et al.	2011	12 & 16	414	20.0	O'Brien index
Brazil	Auad et al.	2007	13–14	458	34.1	O'Sullivan-Index
Brazil	Pedrão et al.	2018	35–74	207	58.9	BEWE
Chile	Dugmore et al.	2003	12	1,753	56.3	O'Brien index
Chile	Marró et al.	2020	18–46	535	97.9	BEWE
Colombia	Mafla et al.	2017	10–15	384	57.3	O'Sullivan index
Colombia	Avila et al.	2019	12–15	176	73.9	BEWE
Colombia	Martignon et al.	2019	18–25	601	73.0	BEWE
Ecuador	Martínez et al.	2018	8–12	175	53.1	O'Brien index
Mexico	Pineda et al.	2019	11–14	512	63.9	BEWE
México	Pineda et al.	2016	14–19	417	31.7	Lussi index
Peru	Torres-Vargas et al.	2012	Adults	150	30.0	Lussi index
Uruguay	Alvarez Loureiro et al.	2015	12	1,136	52.9	BEWE
USA	Habib M et al.	2013	2–4 & 12	243	12.0	Tooth surface loss
USA	Deery et al.	2000	11–13	129	41.0	O'Brien index
USA	Mungia et al.	2009	12–17	307	5.5	Tooth Wear Index
USA	Okunseri et al.	2011	13–19	1,314	45.0	Smith and Knight tooth wear index
USA	McGuire et al.	2009	13–19	1,962	45.9	Smith and Knight tooth wear index

BEWE is predominantly a screening tool. Dentine exposure is calculated in a similar way to the highest BEWE score with one surface with dentine exposed used to calculate the prevalence. Using this method dentine exposure ranges from 2–45% and mostly on the occlusal and incisal surfaces.

The most common tooth surfaces are consistently the occlusal surfaces of the lower molars and the buccal surfaces of the upper central incisors [Schlueter and Luka, 2018]. This could be considered key teeth and may in large population studies reduce the time needed to screen for the condition. There has not been any comprehensive epidemiological study to analyze the prevalence across large populations. Most studies are based on convenience studies but even with this proviso the indication from multiple studies across different countries is that ETW is a common clinical finding.

The clinical management of ETW is wide ranging and complex depending on its associated origin and severity, emphasizing on its regular routine examination and recording using the BEWE [Bartlett et al., 2008] and involving from avoiding acidic foods and drinks, to self- and professionally application of fluoride to restorative care [O'Toole et al., 2015, 2017, 2018].

Developmental Defects of Enamel

There are two major types of DDE – hypoplasia and hypomineralization. Hypoplasia occurs when the ameloblast's secretion of enamel matrix is interrupted, creating a quantitative defect – thin enamel. This normally occurs as pits or horizontal lines in the enamel – indicating the age at which the insult to the ameloblast occurred. Hypomineralization is a qualitative defect – lower mineral density occurs due to an insult to the ameloblast during the calcification or maturation phase, however the enamel is usually full thickness, although hypoplasia and hypomin-

Table 2. The prevalence of fluorosis in the Americas national reports

Country	Authors	Year	Age, years	Sample size	Defect prevalence	Criteria
Bolivia	Ministry of Health and Social Welfare	1997	6–15	2,707	40.8	Dean
Canada	Canadian Health Measures Survey (CHMS)	2010	<12	5,604	37.1	Dean
Colombia	Ministry of Health and Social Protection	2014	5, 12 & 15	2,276 2,183 2,046	8.4 65.1 56.1	Dean
Costa Rica	Ministry of Health	2002	6–8, 12 & 15	3,780	5.7 31.9 24.4	Dean
Ecuador	Ministry of Public Health	2009	12 & 15	700	5.0	Dean
El Salvador	Ministry of Public Health and Social Assistance	2000	12–15	2,000	5.2	Dean
Mexico	Secretary of Health	2017	>6	307,993	2.6	Not reported
Nicaragua	Pan American Health Organization – a	1999	12–15	292	16.7	Dean
Paraguay	Ministry of Public Health and Social Welfare	2017	12 & 15	1,340	14.4	Dean
USA	National Center for Health Statistics	2019	6–19	7,158	85.7	Dean
Venezuela	Pan American Health Organization – b	1998	6–8, 12 & 15	4,462	15.0	Dean

eralization can occur in the same lesion. Hypomineralized lesions can be diffuse (such as fluorosis) or demarcated (such as MIH). Both primary and permanent dentitions can be affected [Wright et al., 2015].

Dental Fluorosis

General Aspects

At appropriate levels, fluoride has been established as an effective agent in the prevention of dental caries [ADA, 2019]. However, excessive intake of fluoride during tooth formation may result in the development of fluorosis. Histologically, enamel fluorosis presents as a subsurface hypomineralization with various degrees of subsurface porosity. There is contradictory evidence on the relationship between the concentration of fluoride in enamel and fluorosis severity [Richards et al., 1989, 1992; Vieira et al., 2004, 2005]. However, more recent research has indicated that a positive linear relationship does exist [Martinez-Mier et al., 2016].

Clinically, the first signs of enamel fluorosis present as thin white striae across teeth surfaces, which follow the perikymata pattern. In mild fluorosis, the cusps, tips, incisal edges, and marginal ridges may be completely opaque, a sign called "snow capping." In moderate cases, the white lines appear more pronounced and may merge to produce cloudy areas scattered over the surface. As severity increases, the entire tooth surface exhibits opaque cloudy areas mixed with areas of brownish discoloration and there may be pitting [Thylstrup and Fejerskov, 1978].

The differential diagnosis of enamel fluorosis is complex and includes caries, MIH, and other non-fluoride opacities. Multiple indices have been developed for the visual examination of enamel fluorosis. In 1934, Dean developed the first index to describe the condition [Dean, 1934]. In 1978, the Thylstrup and Fejerskov Index (TFI) was introduced; and, in 1984, the Tooth Surface Index of Fluorosis was developed [Thylstrup and Fejerskov, 1978; Horowitz et al., 1984]. Since then, multiple efforts have been focused on the development of methods to identify and quantify fluorosis using imaging technology [Pretty et al., 2012; Cuevas-Espinoza et al., 2017].

Epidemiology

Table 2 summarizes selected national reports made in American countries. In the United States, assessments of changes in the prevalence of enamel fluorosis have generally found increases at all levels of severity over time [Clark, 1994; Beltrán-Aguilar et al., 2010; Wiener et al., 2018]. Larger increases in severity and prevalence have been found in the most recent national surveys. Total fluorosis prevalence increased from 22 to 41 to 65% in the 1986–1987, 1999–2004, and 2011–2012 National Health and Nutrition Examination Survey (NHANES) surveys, respectively [Neurath et al., 2019]. However, a quality assessment of the enamel fluorosis clinical data concluded that factors other than a true change in prevalence may explain the observed differences, including potential examiner subjectivity [National Center for Health Statistics, 2019]. In Mexico, clinical examinations for enamel fluorosis are not included in national health surveys; however, two review articles presented prevalence data. These reviews included data from naturally fluoridated areas where water fluoride was above optimal levels as well as areas where water has negligible, unknown or optimal fluoride levels and where fluoridated salt was distributed [Soto et al., 2004; Aguilar-Díaz et al., 2017]. Studies span over two decades and the prevalence ranged from 40 to 100%. These studies point towards a potential increase in both the prevalence and severity of fluorosis over time.

In Colombia, the Community Fluorosis Index (CFI) has been used to measure the burden of dental fluorosis in more than 70 communities as part of a sentinel monitoring program for the national salt fluoridation program. The reported CFIs have ranged from 0.60 to 3.0 [Tovar & Misnaza, 2016]. A scoping review of fluorosis prevalence in Colombia reported a range in prevalence from 0% to 98% [Agudelo-Suárez et al., 2013] and an epidemiological study conducted in a fluorosis endemic Colombian region included besides dental fluorosis with the TFI the assessment of caries lesions with the ICDAS criteria [Tellez et al., 2012].

Enamel fluorosis development has been linked to prolonged, excessive ingestion from varied sources of fluoride [Bronckers et al., 2009]. Potential sources of fluoride include water for drinking and cooking, fluoridated milk and salt, dentifrice ingestion, environmental pollution, pesticides, and professionally applied fluoride products, among others. In the United States, Health and Human Services (HHS) and the Environmental Protection Agency (EPA) conducted a review of standards and guidelines on fluoride in drinking water. As part of this review, the EPA completed and peer-reviewed a study on environmental exposure to fluoride and the relative source contribution of known sources of fluoride [EPA, 2010]. Water, food, beverages, sulfuryl fluoride, toothpaste and soils were identified as major sources of fluoride. In Mexico and Colombia, no national reviews on relative source contribution have been conducted thus far. Selected studies on fluoride intake have identified diet and dental products as major sources of fluoride. Toothpaste ingestion in young children has been identified as a major source of fluoride in both countries [Martinez-Mier et al., 2003; Franco et al., 2005].

The clinical management of fluorosis depends on its severity [Alhawij et al., 2015; Marín et al., 2016], the individual's caries risk and the esthetic patient's perspective. While mild cases do not require treatment, more severe forms of fluorosis would, including preventive, microinvasive and operative care [Shahroom et al., 2019].

A dental epidemiological transition is underway at the global level and research is needed to describe it. There is a need to characterize the prevalence of enamel fluorosis and to identify current sources of fluoride intake and their relative source contributions in the Americas.

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Molar-Incisor Hypomineralization

General Aspects

In the past 20 years, increased interest has been engendered in the dental research community regarding the DDE termed molar incisor hypomineralization (MIH) and defined as a demarcated hypomineralized defect on at least one first permanent molar, often also affecting the permanent incisors [Weerheijm et al., 2001]. Other less-used terms with respect to MIH include cheesy molars, idiopathic enamel hypomineralization and non-endemic mottling [Weerheijm et al., 2001].

There is variability in the number of teeth affected in MIH, with a tendency for incisors to be affected more frequently when the molars are more severely affected [Jälevik et al., 2001]. Severity can vary both within the individual but also within the tooth. This feature is confusing with respect to the pathogenesis of the lesion. It has been hypothesized that MIH is influenced by multiple genes and the environment within a developmental system that can be affected in various ways which allows the variable phenotype to occur [Vieira and Manton, 2019].

Although MIH is the most prevalent presentation of demarcated hypomineralized defects, all teeth in both primary and permanent dentitions can be affected by similar lesions [Kühnisch et al., 2014], highlighting the

Table 3. The prevalence of molar incisor hypomineralization and demarcated opacities in the Americas

Country	Authors	Year	Age, years	Sample size	Defect prevalence, %	Criteria
Argentina	López et al.	2014	7–17	1,090	16.1	DDE
Argentina	Biondi et al.	2011	11.3	1,098	15.9	DDE
Argentina	Biondi et al.	2012	11.6	512	6.4	DDE
Brazil	da Silva Junior et al.	2015	5–17	260	8.8	EAPD
Brazil	Sé	2017	6–11	858	14.7	EAPD
Brazil	da Costa-Silva et al.	2010	6–12	918	19.8	EAPD
Brazil	Souza et al.	2012	6–12	903	19.8	EAPD
Brazil	Jeremias et al.	2013	6–12	1,157	12.3	EAPD
Brazil	Souza et al.	2013	7–12	1,151	12.3	EAPD
Brazil	Soviero et al.	2009	7–13	249	40.2	EAPD
Brazil	Rodrigues et al.	2015	7–14	1,179	2.5	mDDE*
Brazil	Portella et al.	2019	8	728	12.1	EAPD
Brazil	Tourino et al.	2016	8–9	1,181	20.4	EAPD
Brazil	Dantas-Neta et al.	2018	8–10	744	25.0	EAPD
Brazil	Vargas-Ferreira et al.	2018	8–12	1,206	26.4	mDDE
Brazil	De Lima et al.	2015	11–14	594	18.4	EAPD
Canada	Sidhu et al.	2019	0–17	233	12.4	EAPD
Chile	Corral-Núñez et al.	2016	6–12	851	12.7	EAPD
Chile	Gambetta et al.	2019	6–12	577	15.8	EAPD
Chile	Jans-Muñoz et al.	2011	6–13	334	16.8	Weerheijm
Colombia	Mejía et al.	2019	6–15	1,075	11.2	EAPD
Colombia	Beltran et al.	2019	12–15	176	13.6	EAPD
Mexico	Gurrusquieta et al.	2017	6–12	1,156	15.8	EAPD
Mexico	Villanueva-Gutiérrez et al.	2019	7–12	686	35.4	EAPD
Peru	Vásquez-Muñoz & Aguilar-Gálvez.	2014	6–13	970	10.0	EAPD
USA	Davenport et al.	2019	6–14	375	9.6	EAPD
USA	Tagelsir et al.	2019	6–15	266	12.0	EAPD
Uruguay	López et al.	2014	7–17	626	12.3	Mathu-Muju and Wright
Uruguay	Biondi et al.	2012	11	463	7.1	Mathu-Muju and Wright

* mDDE will have demarcated opacities on first permanent molars and/or incisors.

importance of hypomineralized second primary molars (HSPM) [Elfrink et al., 2012].

Hypomineralized enamel can have markedly altered physical characteristics, with up to 70% mineral density deficit, increased protein content (mainly serum albumin), decreased hardness and lower fracture resistance, more carbonate, and an altered elemental profile [Robinson et al., 1992; Mangum et al., 2010; Crombie et al., 2013; Elhennawy et al., 2017].

Approximately one third of MIH lesions are severe, with increasing severity being associated with increased caries experience and burden, as well as rapid lesion breakdown, especially in high-caries risk individuals [Jälevik et al., 2001; Kuhnisch et al., 2018; Paixão-Gonçalves et al., 2019].

The etiological factors involved in MIH (and HSPM) are environmental and genetic in nature, including infantile illnesses, especially hyper-pyrexia, asthma and pneumonia [Crombie et al., 2009; Alaluusua, 2010]. In a recent twins study, after potential confounding factors were controlled for, vitamin D levels at birth, in vitro fertilization, infantile eczema, socioeconomic position, dizygosity and maternal smoking beyond the first trimester of pregnancy demonstrated the strongest associations with HSPM [Silva et al., 2019].

Epidemiology

The prevalence of MIH in the Americas varies from 2.5% to 40.2%, with most studies finding between 10 and 20% prevalence; however, as different indices have been used, direct comparison of data must be done with caution (Table 3). The majority of data come from Brazil, and until recently, no USA data was published, however, several studies are currently underway. The more prevalent indices being the modified DDE index and the EAPD MIH index [Clarkson and O'Mullane, 1992; Ghanim et al., 2019]. Worldwide prevalence figures of 13.1% and 14.2% have been recently reported [Schwendicke et al., 2018; Zhao et al., 2018].

MIH affected teeth place a great burden on individuals, requiring nearly 10 times as much intervention than teeth in non-affected individuals by the age of 9 years [Jälevik and Klingberg, 2002] and by 18 years, affected molars had been treated 4.2 times as often as the controls [Jalevik and Klingberg, 2012]. There is a direct association between MIH presence and increased caries experience and treatment burden [Elhennawy and Schwendicke, 2016; Americano et al., 2017; Kuhnisch et al., 2018]. Hypomineralized teeth can be increasingly sensitive with increased severity, also leading to poor oral hygiene and increased risk of breakdown [Raposo et al., 2019].

Finally, we can hope for early identification of MIH/HSPM, possibly through genetic means – even pre-eruptive diagnosis, which could allow support of affected ameloblasts to minimize the mineral deficit; and development of remineralizing techniques to prevent lesion breakdown after eruption.

Clinical management options for MIH-affected teeth vary considerably, depending on severity and whether they are molars or incisors. Treatment options include from non-operative to operative care and extraction [Baroni et al., 2014; Crombie et al., 2014].

Conclusion

The growing worldwide interest in non-carious lesions such as dental fluorosis, MIH and ETW leads to changes in their approach, both at the clinical and at the community level. Although the number of studies related to these conditions in the American continent has been increasing lately, there is still a need to increase awareness of their accurate diagnosis and management in order to include non-carious lesions in routine dental practice to ensure the maintenance of oral health. Additionally, correct diagnosis is crucial for systematic data collection favoring epidemiological surveillance reliability. Recommendations regarding diagnostic indices to be used during assessment are given, improving this process and helping clinicians' adherence. The most commonly used indices are – BEWE for ETW assessment and quantification, Dean or Thylstrup & Fejerskov indices for dental fluorosis and the EAPD criteria for MIH. Besides, since a wider range of indices has been used, this per se can lead to variation of prevalence data. Thus, a consensus for diagnostic criteria in these three conditions is needed, as already proposed by international groups such as the Erosive Tooth Wear Foundation [Erosive Tooth Wear Foundation, 2020] or the D3 Group [The D3 Group, 2020]. Finally, it is important for dental practitioners to develop skills and knowledge in the diagnosis, quantification and management of non-caries dental disorders, taking into account that their clinical management should be focused on prevention and mitigation of associated consequences as well as control of progression, in order to preserve tooth structure.

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Conflict of Interest Statement

No potential conflicts of interest exist for any author regarding this symposium paper.

Author Contributions

Stefania Martignon: Conception and planning, analysis and interpretation of the epidemiological data, drafting the article, revising critically the article, approval of the version to be published.

David Bartlett: Analysis and interpretation of the Erosive Tooth Wear data, drafting the article, revising critically the article, approval of the version to be published.

David J. Manton: Analysis and interpretation of the Molar Incisor Hypomineralization data, drafting the article, revising critically the article, approval of the version to be published.

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Christian Splieth: Revising critically the article, approval of the version to be published.

Viviana Avila: Conception and planning, analysis and interpretation of the epidemiological data, drafting the article, revising critically the article, approval of the version to be published.

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