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CONTEXTUAL DETERMINANTS OF THE OCCURRENCE OF CARIES AND UNTREATED CARIES AMONG ADULTS IN BRAZIL: A MULTILEVEL STUDY

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ABSTRACT

This multilevel cross-sectional study aimed to identify the contextual factors associated with dental cariesamong adults in Brazil. Data from adults who participated in the National Oral Health Research- SBBrazil 2010 project were included. The dependent variables were "caries occurrence" (measured using the decayed, missing, and filled teeth (DMFT) index) and "untreated caries" (decay component of the DMFT index). To adjust the models, individual independent and independent contextual variables were considered. Negative multilevel binomial regression was conducted, and the mean ratio (MR) was estimated. The study included 9,564 individuals. The mean DMFT among the participants was 16.89 (± 7.27), and the mean number of decayed teeth was 1.79 (± 2.90). In the final model, DMFT was higher for residents in municipalities with lower social inequality and without fluoridated water. On the other hand, the average number of decayed teeth was higher among residents of municipalities with higher social inequality and a lower proportion of dentists per capita, even after adjusting for individual variables. Therefore, social inequality is associated with both outcomes. These findings reinforce the need to reduce social inequalities and ensure greater access to dental care.

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INTRODUCTION

Dental caries affect the structure of teeth and are considered the most prevalent oral health problems (Kassebaum, 2015 and Bernabe et al., 2017). The decayed, missing, and filled teeth (DMFT) index, formulated by Klein & Palmer (1937), measures the lifetime occurrence of caries (past and present) by considering the total number of decayed, lost, and/or restored teeth, giving equal importance to all components. The DMFT index has been widely used worldwide and is recommended by the World Health Organization (WHO) as an indicator of oral health conditions (WHO, 1997 and WHO, 2013).

However, some studies have only adopted the "decay component" of the DMFT index when focusing on dental caries, as this component reflects the current stateand the presence of cavitated lesions that require treatment (untreated caries) (Celeste et al., 2009 and Celeste et al., 2017). Although both forms have been adopted in the literature to measure dental caries, there have been no previous studies aiming to establish a parallel between these two measurement methods. Social inequalities are strong determinants of population health (Organização Mundial de Saúde, 2011). Individuals embody the world in which they live, producing patterns of health, disease, disability, and even death (Barata, 2005). Most diseases and inequities in health occur due to"social health determinants," a term that includes social, economic, political, cultural, and environmental issues related to health (Organização Mundial de Saúde, 2011). Dental caries are recognized as a multifactorial diseases linked to unfavorable behavioral and social factors, such as low levels of education, income, and access to information and health services (Boing et al., 2010). Study models aimedatunderstanding health phenomena by recognizing explanatory elements from different levels have been proposed to overcome the theoretical limitations of classical multicausality (Kreft, 1998). This is because not all determinants of the health-disease process can be conceptualized as attributes at the individual level (Diez-rouxe et al., 2004). The use of "multilevel" models enables the understanding and achievement of results close to reality, since the differentiated effects of variables related to individuals and the different social contexts where such individuals reside are considered (Puente-Palacios and Laros, 2009). Some studies have examinedthe impact of sociodemographic factors on oral health. Contextual-level indicators, such as the human development index (HDI) and Gini coefficient on periodontal disease (Vettore et al., 2013) and dental caries (Celeste et al., 2009; Celeste, 2011 and Bernabé et al., 2009), have already been verified (Celeste et al., 2009; Celeste, 2011 and Bernabé et al., 2009). However, studies evaluating the relationship between contextual indicators, considering the occurrence of caries and untreated caries simultaneously, are scarce.In addition, the WHO hasasserted that the study of socioeconomic inequalities in relation to oral diseases needs to be a research priority in the 21st century (Petersen et al., 2005). Therefore, this study aimed to identify the contextual factors associated with the occurrenceof caries (measured by the DMFT index) and untreated caries (the decayed component of the DMFT index) among adults in Brazil, using a multilevel approach to build a parallel between these two outcomes.

METHODS

This multilevel cross-sectional study included individual variables and contextual variables to explain outcomes measured at the individual level. The individual variables were derived from the National Oral Health Research (SBBrasil 2010), and the contextual variables were obtained at a municipal level from official public databases. SBBrasil 2010 was a national population-based survey that was coordinated and funded by the Ministry of Health. It included individuals aged 5 and 12 years and those aged 15-19, 35-44, and 65-74 years, as recommended by the WHO, to assess oral health at a population level (WHO, 1997), with the assurance of national representativeness for each age group. The sample plan consisted of domains related to the capitals of the Brazilian states and the Federal District, and municipalities in the countryside of each of the country's natural regions (north, northeast, center-west, southeast, and south). A total of 177 municipalities in Brazil were considered. The conglomerates were selected by probabilistic sampling in multiple stages with a design effect (*deff*) equal to two. The primary sampling units were: (a) municipality for the countryside regions and (b) the census sector for the capitals. Intraoral examinations were conducted in the participants' homes under natural light by trained and regulateddental surgeons (Kappa ≥ 0.65), using an electronic device and specific software to record the information. The field teams consisted of one examiner and one annotator. The capitals had 10 field teams, and inland cities had two to six teams, depending on the population size. Regarding the calibration technique, the weighted kappa coefficient was calculated for each examiner, age group, and condition studied, with a minimum acceptable value limit of 0.65.The diagnostic criteria in the 4th edition of the *Oral Health Surveys: Basic Methods* published bythe WHOwere adopted (WHO, 1997). In addition,a questionnaire was used to ask the participants about their socioeconomic status, use of dental services, oral morbidity (self-reported), and self-perception of oral health. Additional information on the methodology used in SBBrasil 2010 can be obtained from a previous publication[18].The present study used the data of individuals 35-44 years from the SBBrasil 2010 project to represent the Brazilian adult population. The 35-44 year age group represents the standard group to assess oral health in adults (WHO, 1997).

The contextual-level variables were collected from public and official databases for each of the 177 municipalities participating in the SBBrasil 2010: 2010 Demographic Census of the Brazilian Institute of Geography and Statistics (IBGE) (Instituto Brasileiro de Geografia e Estatística, 2011), Atlas Brazil of the United Nations Development Program (UNDP) (Atlas do Desenvolvimento Humano no Brasil, 2020), IBGE's National Basic Sanitation Survey (2019), and the Department of Information Technology of the Brazilian Unified Health System (DATASUS) (BRASIL, 2019). The databases referring to the Atlas Braziland the National Basic Sanitation Survey (Instituto Brasileiro de Geografia e Estatística, 2019) were generated from the 2010 demographic census, the data of which were collected between August 1 and October 30, 2010, using the territorial base, which consisted of 316,574 census sectors (Instituto Brasileiro de Geografia e Estatística, 2011). Two dependent variables were adopted: "caries occurrence" (measured by the DMFT index) and "untreated caries" (decay component of the DMFT index). The DMFT index was obtained by summing the permanent teeth with decay, loss, and/or restoration.This measure quantifies the occurrence of cariesin boththe past and present. The decayed component refers to the total number of decayed teeth, which results from the sum of the decayed teeth and decayed teeth restored (codes 1 and 3 of the DMFT index). This measure represents current disease. Information was obtained for each of the 32 teeth examined per individual (WHO, 1997). These variables were determined based on their discrete numerical nature.

The independent contextual variables considered in this study were the geographical location of the municipality (capital; countryside) (BRASIL, 2012), the municipal human development index (HDI), (Atlas do Desenvolvimento Humano no Brasil, 2010), Gini coefficient (Atlas do Desenvolvimento Humano no Brasil, 2010), oral health team coverage (BRASIL, 2019), the proportion of dentists per 1000 inhabitants (BRASIL, 2019), and fluoridation of the public water supply (yes; no) (Instituto Brasileiro de Geografia e Estatística, 2019). The HDI is an indicator that aggregates information on income, level of education, and longevity in each municipality, ranging from zero to one, where higher values reflect a higher level of human development. The Gini coefficient aims to measure inequality in income distribution, varying from zero (absolute equality) to one (absolute inequality) [20]. The coverage of oral health teams refers to the proportion of the municipalities' populationreceiving primary health care coverage from oral health teams (BRASIL, 2019). Except for the "geographical location of the municipality"and "fluoridation of public water supply"variables, all of the other contextual variables were analyzed in a continuous numerical manner.

The following independent variables at the individual level were also considered: sex (female; male), age (in years), self-identified skin color (white; yellow/black/mixed/indigenous), education (years of study), and family income in USD (≤ 284;285-852; 853-2556; ≥2557); and the minimum wage at the time of data collection was USD 290.0.Individual variables regarding the health system were also used (previous use of the dental service: yes/no; time since the last appointment: ≤1 year/>1 year/ never been to the dentist; type of dental service used: public/private/never been to the dentist). Regarding the type of dental service used, any services delivered by the Single Health System (SUS) were consideredpublic. The data regarding the contextual and individual variables were initially organized in the statistical *Predictive Analytics Software* (PASW/SPSS®) *software (*version 18.0) for *Windows®*. For the descriptive analysis of contextual variables, we used the overall data from the municipalities. The descriptive analysis of the individual variables was conducted with respect to the need for correction by sample design since they came from samples per conglomerate. The "*Complex Samples*" module was used, which considers the weights from the sampling process. Measures of central tendency and variability were estimated for the independent numeric variables and simple (n) and relative (%) frequencies for categorical independent variables. The bivariate association between the dependent variables (caries occurrence anduntreated caries) and individual characteristics was verified using Pearson's correlation (r) for the independent numerical variables, the Student's *t*-test for dichotomies, and an analysis of variance (ANOVA) for polytomies. To obtain multiple models, the data were exported to STATA® version 14.0. Themultilevel negative binomial regression model (stepwise backward method) was used with contextual and individual data. The negative binomial regression model is appropriate when the dependent variable is quantitative,has whole values, is not negative (counting data), and has overdispersion in the data (the variance of the dependent variable should be greater than the mean), (Fávero, 2015). Before starting the modeling, the adequacy of the dependent variables for this regressionmodality was verified and confirmed. To estimate the adjustment between the outcome ("caries occurrence" and "untreated caries") and the explanatory variables inthe first (contextual) and second (individual) levels of the analysis, the mixed effect scheme (fixed effect and random intercept) was used (Snijders, 2011).

A priori, an empty model was considered (only with a random intercept and the dependent variable, without the other variables). Subsequently, the first-level variables were included, followed by the variables of the second level. The menbregirr function was used to obtain the mean ratio (MR) and 95% confidence interval (CI 95%).Only the variables with a significance level less than or equal to 0.05 ($p \leq 0.05$) were maintained in the final models. The analysis of the adjustment of the models was carried out through deviance, obtained through log-likelihood multiplied by (-2), where it was expected that there would be significant differences between the models (difference greater than 3.84) (Carle, 2009). Multicollinearity was also tested, checking the correlations between the independent variables using Pearson's correlation (r), with values above 0.7. In addition, a multilevel negative binomial regression analysis was conducted regarding the effect of the Gini coefficient on the DMFT index and its components (dependent variables) tobetter understand the role of social inequality in dental caries. The results of this analysis are presented in Supplementary Material. The SBBrasil 2010 met the ethical principles of the National Health Council (CNS) Resolution (No. 196/96) on research on human beings. This study was approved by the Research Ethics Committee of the Ministry of Health and was registered in the National Committee on Ethics in Research (CONEP) of the CNS (15,498/2009). The participants were informed about the study and signedafree and informed consent form (Roncalli, 2012).

RESULTS

In total, 9,779 individuals were included in SBBrasil 2010. However, 215 (2.2%) participants were excluded because they did not have any information related to the dependent variables under analysis. Thus, 9,564 individuals were included in the study. The mean DMFT was 16.89 (± 7.27), and the mean number of decayed teeth was 1.79 (± 2.90). The descriptive analysis of the contextual variables, considering the 177 municipalities included in this study, is presented in Table 1. About one-third of these municipalities did not have fluoridated water. In the descriptive analysis of the individual variables, a predominance of females (62.3%) and those that declared themselves to be yellow/black/mixed/indigenous (52.4%). The participants' mean age was 39.35 years (±3.08). On average, participants had studied for 8.86 years (±3.93). The majority of participants (57.2%) used public dental services (Table 2). The results of the bivariate analysis are summarized in Table 2. Table 3 presents the results of the multilevel negative binomial regression analysis relative to the occurrence of caries.

Table 1. Characterization of the Brazilian municipalities (n=177) regarding the contextual variables. Brazil, 2010

CONTEXTUAL VARIABLES	n	%
Geographical location of the municipality		
Capital	27	15.3
Countryside	150	84.7
HDI§	$\bar{x}$ (SD) = 0.75 (0.06)	
Gini coefficient§	$\bar{x}$ (SD) = 0.62 (0.12)	
Coverage of oral health teams§*	$\bar{x}$ (SD) = 31.0 (27.55)	
Proportion of dentists per 1000 inhabitants§	$\bar{x}$ (SD) = 0.90 (0.45)	
Fluoridation of public water supply		
Yes	118	66.7
No	59	33.3

*Source: SBBrasil 2010, UNDP, DATASUS and IBGE. § Numeric variables * Variation in n=177. Data were unavailable*

Table 2. Characterization of Brazilian adults (n=9,564) regarding individual variables. Brazil, 2010

INDIVIDUAL VARIABLES			DMFT	p-value	Decayed teeth	p-value
	n	%	$\bar{x}$ (SD)		$\bar{x}$ (SD)	
Sex						
Female	6287	62.3	17.42 (7.19)	<0.001**	1.63 (2.72)	<0.001**
Male	3277	37.7	15.87 (7.32)		2.09 (3.19)	
Age (in years)§	$\bar{x}$ (SD) = 39.35 (3.08)			<0.001#		<0.001#
Self-identified skin color						
White	4049	47.6	16.81 (7.23)	0.339**	1.32 (2.47)	<0.001**
Yellow/Black/Mixed/Indigenous	5515	52.4	16.95 (7.30)		2.13 (3.14)	
Education (in years)§*	$\bar{x}$ (SD) = 8.86 (3.93)			<0.001#		<0.001#
Family income (in US dollars)*						
≤ 284	1404	13.8	17.43 (7.82)	<0.001†	2.86 (3.67)	<0.001†
285-852	4687	53.4	17.26 (7.35)		2.01 (2.95)	
853-2556	2741	29.3	16.51 (6.82)		1.08 (2.09)	
≥ 2557	505	3.5	14.53 (6.61)		0.40 (1.34)	
Previous use of the dentalservice*						
Yes	8837	92.2	16.93 (7.13)	0.071**	1.71 (2.79)	<0.001**
No	672	7.8	16.30 (8.86)		2.78 (3.98)	
Time since the last appointment*						
≤ 1 year	4446	46.8	16.77 (6.71)	0.012†	1.28 (2.34)	<0.001†
> 1 year	4293	45.4	17.09 (7.51)		2.11 (3.08)	
Never been to the dentist	672	7.8	16.30 (8.86)		2.78 (3.98)	
Type of dental service used*						
Public	5288	57.2	16.66 (6.96)	<0.001†	1.22 (2.31)	<0.001†
Private	3524	35.0	17.33 (7.36)		2.41 (3.22)	
Never been to the dentist	672	7.8	16.30 (8.86)		2.78 (3.98)	

*Source: SBBrasil, 2010; § Numeric variables. * Change in total n due to loss of information.** Student's t-test # Pearson's correlation, †Analysis of variance*

Table 3. Multilevel negative binomial regression analysis of the occurrence of caries (n=9,244). Brazil, 2010

CONTEXTUAL VARIABLES	Model 1		Model 2*	
	MR (IC 95%)	p-value	MR (IC 95%)	p-value
Gini coefficient	0.71 (0.58-0.87)	0.001	0.73 (0.61-0.89)	0.002
Fluoridation of public water supply				
Yes	Ref.	0.067	Ref.	0.038
No	1.05 (0.99-1.11)		1.06 (1.01-1.12)	

*Source: SBBrasil 2010, UNDP and IBGE; MR = mean ratio; Ref. = Reference Category; Empty model: Deviance = 65805,168; Model 1: Deviance = 65793.67 Model 2: Deviance =62696.21; *Model adjusted by individual variables: sex, age, self-identified skin color, education, family income range, previous use of dental service, time since last appointment, and type of dental service used.*

Table 4. Multilevel negative binomial regression analysis for untreated caries (n= 8,937). Brazil, 2010

CONTEXTUAL VARIABLES	Model 1		Model 2*	
	MR (IC 95%)	p-value	MR (IC 95%)	p-value
HDI	0.11 (0.03-0.41)	0.001	----	---
Gini coefficient	2.47 (1.34-4.56)	0.004	2.37 (1.31-4.31)	0.004
Proportion of dentists per 1000 inhabitants	0.74 (0.58-0.93)	0.012	0.67 (0.56-0.80)	<0.001

*Source: SBBrasil 2010, UNDP and DATASUS; MR = mean ratio; Empty model: deviance = 33175,834; Model 1: deviance = 33132,404; Model 2: deviance = 28926.84; *Model adjusted by individual variables: sex, age, self-identified skin color, education, family income range, previous dental service use, time since last appointment, and type of dental service used.*

Adults from municipalities with a higher Gini coefficient had a lower DMFT (MR=0.73). In contrast, residents in municipalitieswith fluoridated water presented a higher DMFT (MR=1.06). Table 4 presents the results of the multilevel negative binomial regression analysis of the untreated caries. The mean number of decayed teeth was higher among residents of municipalities with a higher Gini coefficient (MR=2.37). Living in municipalities with a higher proportion of dentists per capita was associated with a lower mean number of decayed teeth (MR = 0.67). Individual independent variables were maintained in the final model for adjustment purposes. A significant reduction in deviance with the adjustment of the models was observed.

DISCUSSION

This study showed that contextual factors associated with the occurrence of caries and untreated caries differed according to how the dental caries outcome was considered (DMFT index or decayed component). However, both outcomes were related to social inequalities at the contextual level. While a lower Gini coefficient (a measure of social inequality) and the lack of public water supply fluoridation increased the occurrence of caries, a higher Gini coefficient and a lower proportion of dentists per capita resulted in a higher number of untreated caries. Since its publication by Klein & Palmer (1937), theDMFT index has been widely used in epidemiological studies. However, it has some important limitations. The DMFT index does not measure the presence of disease (current caries activity), loses discriminatory power with age due to its cumulative character, and gives equal weight to its components. These factorslimit the ability of the DMFT index to accurately reflect the oral health of a population. Therefore, a useful way to interpret the DMFTindex is to evaluate its components in isolation. For example, by considering only the decayed component, it is possible to assess the current disease stage and indirectly the need for dental treatment (Martins, 2012). The different oral health conditions that can be observed when considering the DMFT index or the decayed component separatelycould explain why the contextual determinants differ according to how the dental caries outcome is considered (caries occurrence or untreated caries).

The DMFT index, either through its components or gross value, can help detect social inequalities (Roncalli, 2022). In the present study, the variable “Gini coefficient,” which measures inequality in income distribution (Atlas do Desenvolvimento Humano no Brasil, 2019), was significantly associated with both dependent variables. However, these associations were different. For example, greater social equality (lower Gini coefficient) was associated with a higher number of caries but fewer teeth with untreated caries. It should be noted that these findings were identified considering the same individuals and municipalities in both analyses.

Therefore, the greatest occurrence of caries was related to a greater representation of the restored component of the DMFT index. Adults residing in cities with a lower Gini coefficient presented a higher number of restored teeth (Table S1), suggesting greateraccess to dental treatment. Previous studies conducted among adults have already verified the effect of the Gini coefficient on both the occurrence of caries (Bernabé et al., 2009) and untreated caries (Celeste et al., 2000 and Celeste et al., 2011). Research conducted among 18 of the 50 richest countries in the world observed that income inequality was inversely related to DMFT, and the number of teeth restored (Bernabé, 2009). In contrast, higher levels of income inequality are directly associated with untreated caries (Celeste, 2009 and Celeste et al., 2011). All the cited studies (Celeste et al., 2009; Celeste, 2011 and Bernabé, 2009), are in agreement with the findings of the present study.A systematic review conducted to assess the associations between socioeconomic indicators and dental caries in adults found that worse socioeconomic indicators, including the Gini coefficient, are associated with greater severity of dental caries in adults (Costa, 2012). However, the outcomes of dental caries were not differentiated. Municipalities with high income inequality may offer fewer opportunities to adopt healthy behaviors in oral health (Celeste, 2009), invest less in public health policies, and provide less access to dental services, which predominately affects the poorer part of the population, resulting inhealth inequalities. Regarding the other contextual variables presented in the final models, the occurrence of caries was associated with the absence of fluoridation of the public water supply. In contrast, untreated caries are related to the lowest proportion of dentists per 1000 inhabitants. Individuals probably benefit from access to fluoridated water throughout their lives, not transversally. The longitudinal character of this variable could explain why it is only associated with the occurrence of caries, not untreated caries, since the occurrence of caries reflects the accumulation of disease throughout life. In contrast, untreated caries represent current disease [26], which is more affected by the supply of dental services (dentist/inhabitant ratio).

A population-based cohort study conducted in southern Brazil found thatindividuals who had access to fluoridated water for more than 75% of their lives had fewer caries [29]. One meta-analysishas reported the observed effectiveness of fluoride in preventing adult dental caries. Its results identified that exposure to fluoridated water was responsible for a 27% reduction in adult caries [30], and such results have also been observed in other age groups [31, 32]. In an investigation conducted among adults in Australia, a longer time of exposure to fluoridated water was associated with a lower DMFT, but no significant association was observed with the decayed component[33], which corroborates the findings of the current study. Thesefindingshighlight the need to emphasize the importance of water fluoridation as a public health measure. It should be noted that the impact of adding fluoride to the public water supply is greater for municipalities with worse indicators of social inequality [34], which reinforces the importance of this measure as a way to compensate for oral health inequities[35]. Thedentist/population ratio is known to be a determining factor for dental caries [15].This study found a higher number of teeth with untreated caries in residents of municipalities with a lower proportion of dentists per 1000 inhabitants. The proportion of dentists per capita was used to assess theease ofaccess to dental care. Even if individuals may have the financial means and incentive to use dental services regularly, they may not obtain dental care if there is a low number of qualified professionals[33]. It was previously reported that each additional dentist per thousand inhabitants would reducethe chance of a Brazilian having never consulted a dentist by 46.6% [36]. A study conducted to identify the influence of social indicators on the supply of dental services found a higher number of professionals in regions with better socio-economic indicators [37].This highlightsthe importance ofpromoting people to work in other regions, resulting in greater equity in the supply of dental services and possibly better oral health. It should be noted that the data used in this study were from 2010, because the national survey scheduled for 2020 could not yet be carried out due to the COVID-19 pandemic. More recent national data regarding dental caries are not available in Brazil. Despite this time limitation, the associations found are consistent and plausible, although the specific measurement of dental caries prevalence might have changed in the last decade. This study has other limitations.First, in cross-sectional studies, it is not possible to establish a temporal relationship between the outcome investigated and the other independent variables. Second, secondary data were analyzed, and consequently, some risk factors for dental caries, such as habits and lifestyle, were not evaluated, since SBBrazil2010 did not address these characteristics. However, this study included a representative sample of the entire adult Brazilian population. Furthermore, few epidemiological studies haveevaluated dental caries among adults from a contextual perspective.

CONCLUSION

This study identified important contextual factors associated with caries and untreated caries among adults in Brazil, even after adjusting for individual variables. Contextual factors differed according to how the caries outcome was considered (DMFT index or decayed component). While the occurrence of caries was associated with lower social inequality (Gini coefficient) and the absence of public water fluoridation, untreated caries wereassociated with higher social inequality (Gini coefficient) and a lower proportion of dentists per 1000 inhabitants. Thus, this study highlights the role of social inequalities in dental caries at the contextual level. This scenario reinforces the importance of adopting measures to compensate for inequalities in oral health, such as the expansion and better organization of dental services.

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Supplementary material

Table S1. Multilevel negative binomial regression analysis relative to the Gini coefficient (n=9,564). Brazil, 2010

CONTEXTUAL VARIABLE	DMFT MR (IC 95%)	p-value	Decayed teeth MR (IC 95%)	p-value	Missing teeth MR (IC 95%)	p-value	Filled teeth MR (IC 95%)	p-value
Gini coefficient	0.74 (0.61-0.91)	0.003	2.05 (1.01-4.19)	0.047	0.97 (0.59-1.59)	0.902	0.29 (0.13-0.64)	0.002

Source: SBBrasil 2010 and UNDP.
MR = mean ratio

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