Cumhuriyet Dental Journal, 26(1): 1-7, 2023
DOI: https://doi.org/10.7126/cumudj.1105151

Cumhuriyet Dental Journal

| cdj.cumhuriyet.edu.tr | Founded: 1998 Available online, ISSN: 1302-5805 e-ISSN: 2146-2852 Publisher: Sivas Cumhuriyet Üniversitesi

The Indicators of Molar Coefficients of the Chemical Elements in Dentin and their Correlation with Enamel

Iryna I. Zabolotna[1,a], **Olena S. Genzytska**[1,b*], **Oleksandr S. Zabolotnyi**[2,c]

[1] Department of Internship of Doctors-Dentists, Faculty of Internship and Postgraduate Education, Donetsk national medical university, Liman, Ukraine
[2] Student of Faculty of Computer Sciences and Software Engineering, National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine
*Corresponding author

Research Article

History

Received: 18/04/2022
Accepted: 08/01/2023

ABSTRACT

Objectives: Determination of molar coefficients of the chemical elements in dentin, their possible correlation with tooth enamel.
Material and Methods: There were examined 29 clinically extracted teeth of both jaws and their longitudinal sections (12 clinically intact teeth, 10 teeth with wedge-shaped defects, 7 teeth with cervical caries) of the patients aged 25 to 54 with the help of JSM-6490 LV focused beam electron microscope (scanning) with system of energy-dispersive X-ray microanalysis. We have determined the chemical composition of 290 enamel areas and 235 dentin areas in the incisal region (tubercle), equator, cervical area as a percentage of the weight amounts of carbon, oxygen, calcium, phosphorus, sodium, magnesium, sulfur, chlorine, zinc, potassium, aluminum, we have identified their molar coefficients.
Results: The chemical composition of dentin differed in the values of Na/Mg, Al/Zn, Mg/Ca, K/Na ($p \le 0.05$) in all studied topographical regions of the samples. Higher values of Na/Mg and lower values of Al/Zn were identified in the teeth with cervical caries ($p \le 0.05$). Correlation was found in dentin: inverse - between Ca/P and P/Ca, Mg/Ca and Na/Mg, Ca/Mg and Mg/Ca, Mg/P and Na/Mg, Mg/P and Ca/Mg, direct - between Ca/Mg and Na/Mg, Mg/P and Mg/Ca ($p \le 0.05$). High correlation was determined between molar coefficients in enamel and dentin: Mg/Ca and Mg/P (direct), Ca/P and P/Ca (inverse), $p<0.0001$.
Conclusions: The differences in the indicators of molar coefficients in dentin, their correlation with enamel are probably associated with the peculiarities of the pathological processes in the cervical region and it requires further study.

Key words: Teeth, Enamel, Dentin, Chemical Elements, Cervical Caries.

[a] myhelp200@gmail.com https://orcid.org/0000-0002-3284-0392
[b] blacky3000@ukr.net https://orcid.org/0000-0002-4694-8679
[c] sergzabolotny@gmail.com https://orcid.org/0000-0003-0291-2727

How to Cite: *Zabolotna I.I, Genzytska O.S., Zabolotnyi O. S. (2023) The Indicators of Molar Coefficients of the Chemical Elements in Dentin and their Correlation with Enamel, Cumhuriyet Dental Journal, 26(1):1-7.*

Introduction

The onset of the pathology of dental hard tissues is generally considered that the lesions don't result from a single factor but they may be caused by a combination of some factors.[1] The effectiveness of its prevention depends on understanding the risk factors and how they interact and change in specific patients in course of time.[2] The content of the chemical elements in hard dental tissues is not a constant value but it dynamically changes under the influence of various reasons, one of which is damage of carious and non-carious genesis.[3,4] Dentin permeability can be increased because of the changes to the integrity of enamel and dentin through processes of trauma, decay and toothwear.[5] The amount of calcium has significant differences both in the structure of enamel and dentin in different types of pathology and it determines their development.[6] Dentin also had the characteristics of microwear which were more consistent with wear types than enamel.[7] Chemical dissolution of the components of both organic and inorganic matrix happens during an acidic attack or a typical demineralization regime. It is come about by the water content of enamel and dentin that facilitate acid diffusion in and mineral content out of the tooth. The areas of structural weakness which have been demineralized are also the objectives for the formation of caries. Bacteria can colonize tooth demineralized areas easily and, with a combination of their own acid formation, they can penetrate into dentin.[8] Previous studies confirmed the assumptions about the differences in the inorganic composition of enamel and dentin at various levels.[6,9,10] Significant differences were found in the content of sodium and zinc in dentin of the incisal region (tubercle) (IR), equator (E), cervical area (CA) depending on the presence and type of the pathology.[9] But taking into account the widespread occurrence of the coordinated effects of some chemical elements it is necessary to pay attention not only to their amount but also to the ratios that have a synergistic and antagonistic impact on various physiological parameters.[11] We have hypothesized that molar coefficients in dentin, their possible correlation with enamel may influence the occurrence and progression of cervical defects in hard dental tissues. Therefore, this study is considered to be relevant to determine the integrated parameters under the conditions of the physiology of the oral cavity, establish their critical values in order to prevent the onset of the pathology.

The purpose of the study is to determine molar coefficients of the chemical elements in the dentin of clinically intact teeth, teeth with a wedge-shaped defect and cervical caries in IR, E, CA, identify their possible correlation with enamel.

Material and Methods

Written informed consent was obtained from all subjects in compliance with Helsinki Declaration of the World Medical Association – Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects (1964-2008) as well as the order of the Ministry of Health of Ukraine No. 690 dated September 23, 2009. The work was approved by Bioethics Commission of Donetsk National Medical University (No 43, dated January 21, 2021).

We examined 29 teeth that were extracted from both jaws for some orthodontic indications and their longitudinal sections (12 clinically intact teeth, 10 teeth with wedge-shaped defects, 7 teeth with cervical caries) of the patients aged 25 to 54 with the help of a JSM-6490 LV focused beam electron microscope (scanning) with system of energy-dispersive X-ray microanalysis INCA Penta FETx3 (OXFORD Instruments, England) based on the previously described method.[9] Using the method of the peak to background ratio local mass fractions of chemical elements were calculated taking into consideration the corrections for atomic number, fluorescence and absorption, measured in normal mass percentage (normal mass %). The mineral composition of 290 enamel and 235 dentine areas in IR, E, CA has been identified as a percentage of the weight amounts of calcium, phosphorus, sodium, magnesium, sulfur, chlorine, zinc, potassium, and aluminum. The molar coefficients were calculated as the ratio of the amounts of chemical elements. We examined dentin at approximately the same distance from the enamel-dentin border.

To determine possible relationships between the chemical composition of enamel and dentin the correlation was identified in the following groups: Group I – teeth with a wedge-shaped defect and clinically intact hard tissues, Group II –teeth with cervical caries and clinically intact hard tissues, Group III – teeth with cervical pathology. The research was carried out at the base of Donetsk Institute of Physics and Technology of the National Academy of Sciences of Ukraine.

Statistical analysis

Using the Statistica 12.0 computer program (3BA94C4ED07A) we carried out statistical analysis. We used the G*Power program to calculate the sample size. Replication measurements were averaged in one sample before statistical analysis. To check the presence of the relationship between the variables, the correlation analysis was performed (Pearson's parametric correlation method) based on the determination of the parametric Brave-Pearson coefficient (r) with the confidence level of 95%. Using Student's T-test we assessed the reliability of obtained results as well as the correlation between the indicators – based on Student's T-test using Z-test (Fisher's Z-test). The differences were thought to be statistically significant at $p \le 0.05$. The significance of the differences between the groups was evaluated based on the analysis of variance.

Results

The chemical composition of dentin in the area of IR samples was determined at the first stage (Table 1). Clinically intact teeth were characterized by higher molar coefficients of P/Ca, Al/Zn, K/Na and lower ones of Na/K ($p \le 0.05$). The values of Al/Zn molar coefficient in dentin of intact samples were 4.5 and 1.5 times higher than in the samples with cervical caries and a wedge-shaped defect, respectively. Its indicators differed by 2 times depending on the type of the pathology of hard dental tissues ($p \le 0.05$). The chemical composition of dentin of the samples with a carious process was characterized by higher values of the coefficients of Na/Mg, Ca/P, Ca/Mg ($p \le 0.05$). The indicators of Na/Mg in the teeth with cervical caries were 10.7 and 4.7 times higher than in the teeth with a wedge-shaped defect and intact teeth, respectively. Na/Mg molar coefficient was 2.3 times higher in the group of clinically intact samples compared to the samples with non-carious cervical pathology (NCCL). The indicators of C/Mg in dentin of the teeth with caries were 2.7 and 2.2 times higher than those ones with a wedge-shaped defect and intact hard tissues, respectively.

The chemical composition of dentin of the samples in E region was studied at the next stage (Table 2). Dentin of clinically intact teeth was distinguished by higher values of molar coefficients of Al/Zn, Mg/Ca, Mg/P and lower values of Na/Mg, Ca/Mg, K/Na ($p \le 0.05$). The indicators of Al/Zn in intact samples were 4 and 2 times higher than in the samples with cervical caries and a wedge-shaped defect, respectively. The indicators of Al/Zn differed 2 times depending on the type of cervical pathology ($p \le 0.05$). Significant differences were identified in terms of the indicators of Na/Mg molar coefficient. Its values were 2.5 and 4.5 times higher in dentin of the samples with cervical caries than in the samples with a wedge-shaped defect and clinically intact hard tissues, respectively ($p \le 0.05$). The teeth with a carious process had higher indicators of Ca/Mg molar coefficient: almost 2 times higher when compared with the teeth with NCCL and 3.8 times higher when compared with intact teeth. The molar coefficient of K/Na was 2.4 and 5 times higher in dentin of the samples of the teeth with a wedge-shaped defect when compared with the samples damaged by caries and intact teeth, respectively.

The results of determining the chemical composition of dentin in CA region are presented in Table 3. Examined parts of dentin in CA are presented in Figure 1.

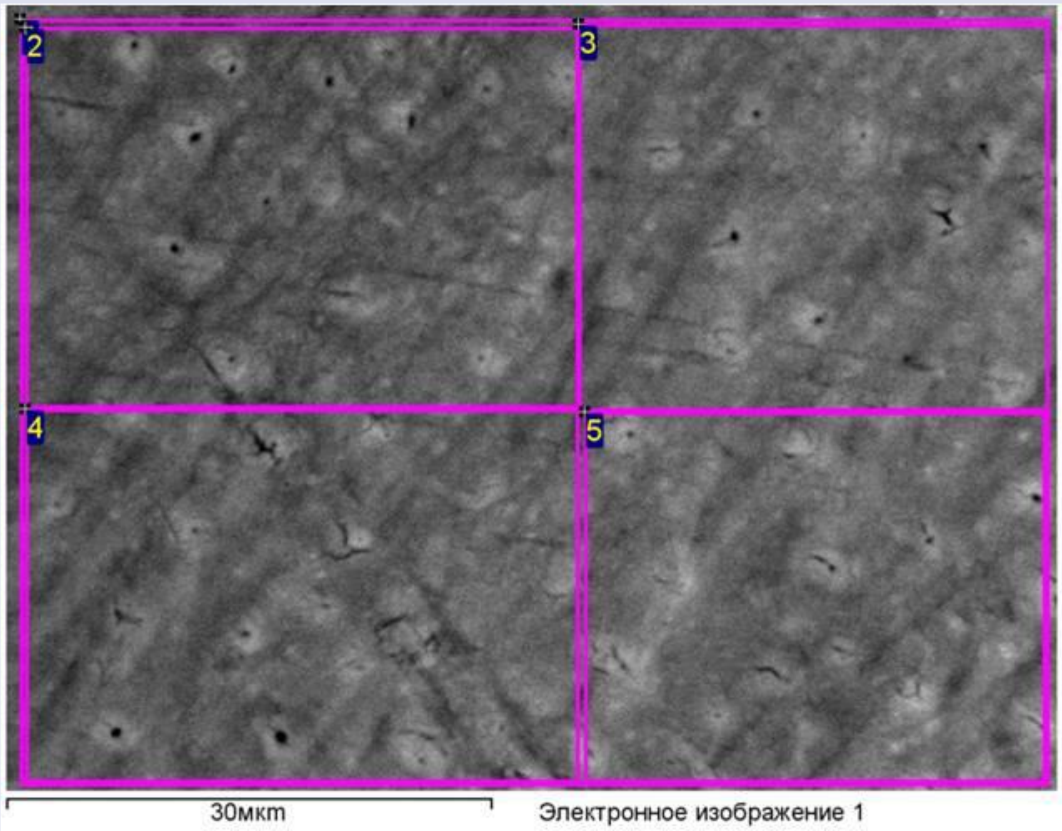

Figure 1-A. The sample with a wedge-shaped defect (magnification x30).

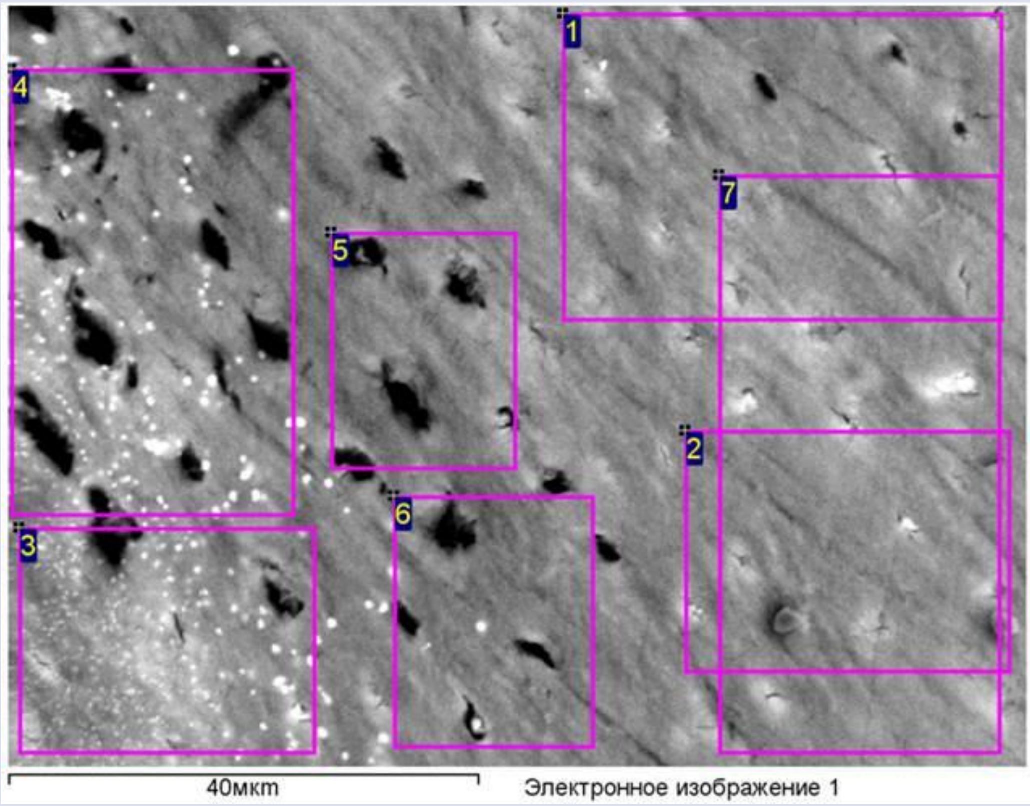

Figure 1-B. The sample with cervical caries (magnification x40).

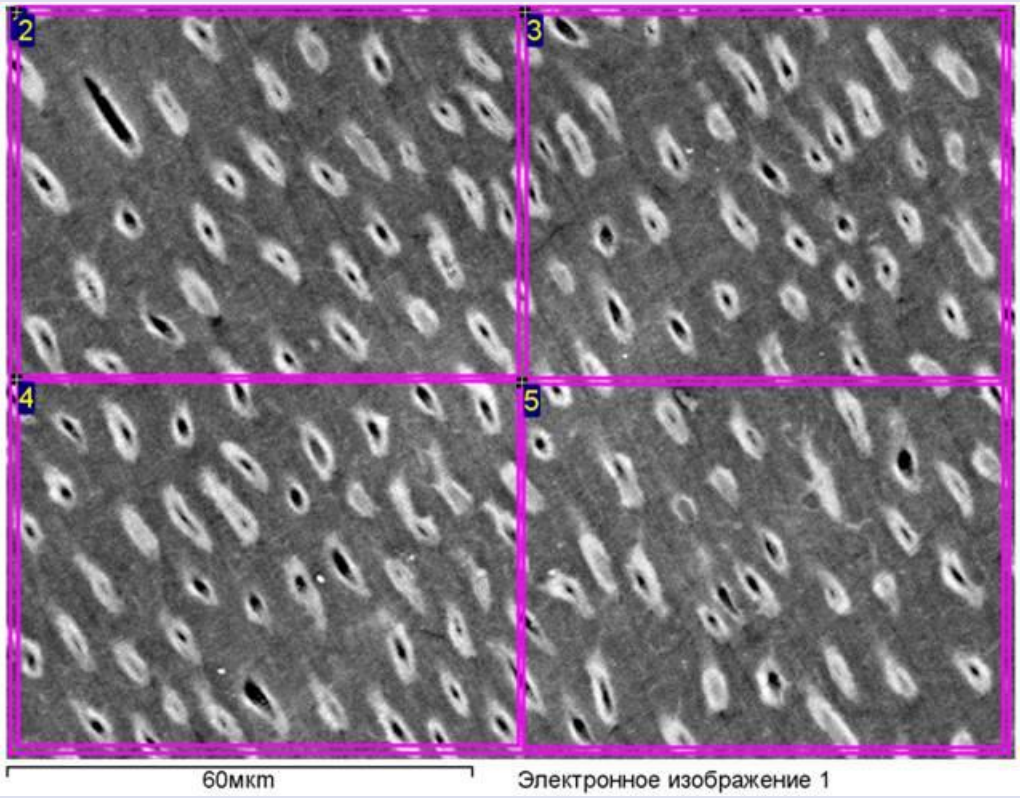

Figure 1-C. The sample of clinically intact teeth (magnification x60).

Table 1. The molar coefficients of chemical elements in dentin of IR

Molar coefficients	Teeth with wedge-shaped defect mean±SD (*n*=21)	Teeth with cervical caries mean±SD (*n*=26)	Clinically intact teeth mean±SD (*n*=20)	*P-value*
Na/K	53.103±44.934	74.014±38.785#	43.749±42.338**	0.048*
Na/Mg	0.846±0.225#**	9.035±10.951#	1.938±0.498**	<0.001*
Ca/P	1.802±0.030#**	1.947±0.113	1.934±0,135	<0.001*
P/Ca	0.055±0.009#**	0.515±0.030	0.520±0.038	<0.001*
Ca/Mg	52.717±12.024#**	143.134±149.484#	64.267±22.035**	0.003*
Ca/Cl	294.962±126.626**	189.292±263.410	214.443±129.909	0.188
Al/Zn	40.525±50.661**	20.266±41.199#	62.591±50.172**	0.014*
Mg/Ca	0.020±0.004**	0.015±0.009	0.017±0.006	0.043*
Mg/P	0.036±0.008**	0.028±0.018	0.034±0.013	0.144
K/Na	0.054±0.063**	0.020±0.032#	0.058±0.051**	0.018*

p – the statistical significance of differences; *n* – number of dentin areas; * ($p \leq 0.05$); # – the difference of intact teeth from dentin is statistically significant, $p \leq 0.05$; ** – the difference of teeth with cervical caries from dentin is statistically significant, $p \leq 0.05$.

Table 2. The molar coefficients of chemical elements in dentin of E

Molar coefficients	Teeth with wedge-shaped defect mean±SD (*n*=26)	Teeth with cervical caries mean±SD (*n*=41)	Clinically intact teeth mean±SD (*n*=26)	*P-value*
Na/K	49.020±45.688	59.222±43.116	69.530±37.311	0.315
Na/Mg	2.539±3.568**	6.255±7.5126#	1.385±0.386**	0.005*
Ca/P	1.992±0.138#	2.051±0.138	2.072±0.061	0.091
P/Ca	0.504±0.035#	0.490±0.034	0.483±0.014	0.078
Ca/Mg	84.479±29.760#**	165.158±160.578#	43.774±8.171**	<0.001*
Ca/Cl	234.088±161.405**	353.009±462.075	290.075±283.613	0.430
Al/Zn	35.145±48.867#**	17.281±38.459#	69.554±48.174**	<0,001*
Mg/Ca	0.013±0.003#	0.015±0.012#	0.024±0.004**	<0.001*
Mg/P	0.026±0.007#	0.029±0.023#	0.049±0.007**	<0.001*
K/Na	0.091±0.115#**	0.038±0.043	0.018±0.025	0.003*

*p – the statistical significance of differences; n – number of dentin areas; * ($p \leq 0.05$); # – the difference of intact teeth from dentin is statistically significant, $p \leq 0.05$; ** – the difference of teeth with cervical caries from dentin is statistically significant, $p \leq 0.05$.*

Table 3. The molar coefficients of chemical elements in dentin of CA

Molar coefficients	Teeth with wedge-shaped defect mean±SD (*n*=26)	Teeth with cervical caries mean±SD (*n*=20)	Clinically intact teeth mean±SD (*n*=29)	*P-value*
Na/K	50.0378±44.467$^{\#**}$	69.095±43.137	82.969±31.480	0.019*
Na/Mg	2.638±4.672$^{\#**}$	10.177±6.390	9.811±23.608	0.13*
Ca/P	1.791±0,143$^{\#**}$	1.945±0.161$^{\#}$	2.0599±0.065**	<0.001*
P/Ca	0.562±0.044$^{\#**}$	0.518±0.047$^{\#}$	0.486±0.016**	<0.001*
Ca/Mg	120.728±201.365**	186.690±90.962	163.451±264.068	0.411
Ca/Cl	218.106±148.323**	108.515±67.421	160.866±127.932	0.007*
Al/Zn	35.200±48.358**	0.970±1.018$^{\#}$	31.690±48.262**	0.011*
Mg/Ca	0.014±0.005**	0.008±0.008	0.013±0.009	0.006*
Mg/P	0.024±0.009**	0.016±0.014$^{\#}$	0.027±0.017**	0.009*
K/Na	0.421±0.137$^{\#**}$	0.975±0.374	1.011±0.410	<0.001*

*p – the statistical significance of differences; n – number of dentin areas; * (p≤0.05);$^{\#}$ – the difference of intact teeth from dentin is statistically significant, p≤0.05; ** – the difference of teeth with cervical caries from dentin is statistically significant, p≤0.05.*

Intact teeth had higher values of Na/K, Ca/P, Mg/P and K/Na (p≤0.05). The indicators of K/Na in their dentin were 2.4 times higher than in the samples with NCCL. Its indicators differed by 2.3 times in the groups of the teeth with a cervical pathology. Na/Mg coefficient was 3.9 times lower in the samples with a wedge-shaped defect than in the samples with cervical caries, and it was 3.7 times lower when compared with intact samples. Dentin of the teeth with NCCL differed from the teeth with carious process by 1.5 times lower values of Ca/Mg and 2 times higher values of Ca/Cl (p≤0.05). Significant differences were determined in Al/Zn-coefficient: its indicators in the group of the teeth with cervical caries were 36 and 32.7 times lower than in the groups of the teeth with NCCL and intact hard tissues, respectively.

Thus, the chemical composition of dentin in clinically intact specimens and with cervical pathology in all studied anatomical areas differed in the values of molar coefficients of Na/Mg, Al/Zn, Mg/Ca, K/Na (p≤0.05). There have been determined higher values of Na/Mg and lower values of Al/Zn (p≤0.05) in teeth with cervical caries.

The revealed correlations between the molar coefficients in dentin of the studied topographical areas, their nature are presented in Table 4. Correlation was determined: inverse - between Ca/P and P/Ca, Mg/Ca and Na/Mg, Ca/Mg and Mg/Ca, Mg/P and Na/Mg, Mg/P and Ca/Mg, direct - between Ca/Mg and Na/Mg, Mg/P and Mg/Ca (p≤0.05). High correlation was found between the molar coefficients in dentin and enamel: direct -Mg/Ca and Mg/P, inverse - Ca/P and P/Ca, p<0.0001 (Table 5).

Table 4. Correlation between the molar coefficients of dentin, r

Molar coefficients	Area	Molar coefficients											
		Na/Mg			Mg/P			Mg/Ca			Ca/P		
		group											
		I	II	III	I	II	III	I	II	III	I	II	III
Ca/Mg	IR	0.551*	0.910*	0.916*	-0.922*	-0.735*	-0.788*	-0.994*	-0.760*	-0.803*		-	
	E	0.672*	0.943*	0.913*	-0.878*	-0.776*	-0.685*	-0.889*	-0.774*	-0.687*			
	CA	0.810*	0.977*	0.817*	-0.598*	-0.585*	-0.615*	-0.637*	-0.581*	-0.625*			
Mg/Ca	IR	-0.503 *p*=0.010	-0.758*	-0.837*	0.979*	0.992*	0.993*		-			-	
	E	-0.408 *p*=0.008	-0.684*	-0.586*	0.992*	0.996*	0.995*						
	CA	-0.484*	-0.470 *p*=0.004	-0.765*	0.978*	0.994*	0.993*						
Mg/P	IR	-0.358*	-0.726*	-0.819*		-			-			-	
	E	-0.388 *p*=0.012	-0.686*	-0.582*									
	CA	-0.452*	-0.476 *p*=0.003	-0.751*									
P/Ca	IR		-			-			-		-0.999*	-0.998*	-0.999*
	E										-0.999*	-0.996*	-0.997*
	CA										-0.996*	-0.994*	-0.995*

p – the statistical significance of differences; r -Pearson correlation coefficient; * (p<0.001); Group: I – teeth with a wedge-shaped defect and clinically intact hard tissues, II –teeth with cervical caries and clinically intact hard tissues, III –teeth with cervical pathology; Area: IR - incisal region (tubercle), E - equator, CA - cervical area

Table 5. Correlation between molar coefficients of enamel and dentin, r ($p<0.0001$)

Molar coefficients	Area	Molar coefficients					
		Mg/P			Ca/P		
		group					
		I	II	III	I	II	III
P/Ca	IR	-			-0.9568	-0.9646	-0.9979
	E				-0.9773	-0.9968	-0.9782
	CA				-0.9316	-0.9857	-0.9219
Mg/Ca	IR	0.9945	0.9949	0.9965	-		
	E	0.9974	0.9973	0.9964			
	CA	0.9844	0.9947	0.9879			

p – the statistical significance of differences; r -Pearson correlation coefficient; Group: I – teeth with a wedge-shaped defect and clinically intact hard tissues, II –teeth with cervical caries and clinically intact hard tissues, III –teeth with cervical pathology; Area: IR - incisal region (tubercle), E - equator, CA - cervical area

Discussion

As a result of the study, the values of the molar coefficient of Ca/P were determined in the range of 1.79-2.07. According to other authors' data the coefficient of Ca/P ranged within 1.58[12] that may be due to the heterogeneity of the distribution of the chemical elements in dental hard tissues[13] and the associated difference in obtained results.[14] Compared with clinically intact teeth at the level of 5% smaller values of the coefficient of Ca/Mg in IR region and CA of dentin of the teeth with a wedge-shaped defect is probably due to tooth wear.[15] In all studied areas of the samples with cervical caries the molar coefficient of Ca/Mg was higher than in clinically intact ones that is explained by a higher concentration of magnesium in the hard tissues of healthy teeth according to the of data *Klimuszko E. et al.*[16] According to *Meisel P.et al.* (2016) the coefficient of Mg/Ca is serum that predicts periodontitis and tooth loss in a 5-year follow-up.[17]

Higher values of Na/Mg and lower values of Al/Zn were determined in all investigated areas of dentin of the samples with cervical caries. The tendency in the indicators of Na/Mg molar coefficient in the teeth with a carious process can be explained by the revealed significantly large amount of sodium in this group.[9] The lower values of Al/Zn coefficient in the samples with cervical caries are probably associated with a certain reliably high amount of zinc in all studied anatomical regions: from 3.8 times (at the E) to 23 times (in the IR) when comparing with dentin of the patients' teeth with a wedge-shaped defect and intact hard tissues, respectively.[9] *Shishniashvili T. et al.*[18] (2018) determined the increase in the content of zinc in the teeth with caries by 28.4% that they explained by its ability to reduce the permeability of enamel and, consequently, the transition of the chemical elements from saliva to hard dental tissues. *Zohoori FV.et al.*[19] (2020) found an inverse relationship between the incidence of tooth decay and aluminum levels in drinking water, food and soil. Other researchers confirmed the accumulation of aluminum and zinc in teeth dentin from the environment.[20] It was not possible to compare certain indicators of the molar coefficient of K/Na in dentin due to the lack of the information on its study in the available literary sources.

Correlation between the chemical composition of enamel and dentin (magnesium and calcium, magnesium and phosphorus) that was described in a previously published work[10] probably explains the revealed strong direct correlation between the molar coefficients of Mg/P and Mg/Ca in enamel and dentin. Obtained results confirm a certain role of Mg concentrations not only in the dental-enamel junction (according to *Kuczumow A. et al.* (2021))[21] but also in the entire thickness of hard tissues. In our opinion, the conducted research has confirmed the opinion of *Fernández-Escudero AC.et al.* (2020) that dentin presents physiological exchanges of in trace elements after a period of mineralization and some factors can influence its concentration[22], one of which is cervical pathology.

In our opinion, the limitation of the study is the insufficient number of the samples that is associated with the difficulties in obtaining them taking into account the patients' age. We believe that the further search for etiopathogenetic factors of the development of cervical pathology and the development of the methods for its prevention are promising.

Conclusions

Revealed differences in the values of molar coefficients of chemical elements in dentin, depending on the topographical region and the state of the hard tissues of the teeth, their correlation with the indicators in enamel are probably associated with the peculiarities of the pathogenesis of a wedge-shaped defect and cervical caries and they are one of the risk factors for their occurrence which requires further study.

Acknowledgements

None to declare

Conflicts of Interest Statement

The author declares no conflict of interest in this study

Funding

None to declare

References

1. Peumans M, Politano G, Van Meerbeek B. Treatment of noncarious cervical lesions: when, why, and how. Int J Esthet Dent 2020;15(1):6-42.
2. Nascimento M, Dilbone D, Pereira P, Duarte W, Geraldeli S, Delgado A. Abfraction lesions: etiology, diagnosis, and treatment options. Clin Cosmet Investig Dent 2016;3(8):79-87.
3. Duruk G, Acar B, Temelli Ö. Effect of different doses of radiation on morphogical, mechanical and chemical properties of primary and permanent teeth-an in vitro study. BMC Oral Health 2020;20(1):242.
4. Tkachenko IM, Brailko NN, Kovalenko VV, Nazarenko ZJ, Sheshukova OV. Morphological study of enamel and dentin teeth with carious process and non-carous lesions. Wiadomosci Lekarskie 2018;71(5):1002-1005.
5. Longridge NN, Youngson CC. Dental pain: dentine sensitivity, hypersensitivity and cracked tooth syndrome. Prim Dent J 2019;20;8(1):44-51.
6. Tkachenko IM, Kovalenko VV. Research of microelement composition of enamel and dentine of teeth at caries and increased tooth erosion. Visnyk problem biolohii i medytsyny 2017;2(140),4:248-252.
7. Ranjitkar S, Turan A, Mann C, Gully GA, Marsman M, Edwards S, Kaidonis JA, Hall C, Lekkas D, Wetselaar P, Brook AH, Lobbezoo F, Townsend GC. Surface-sensitive microwear texture analysis of attrition and erosion. J Dent Res 2017;96(3):300-307.
8. Abou Neel EA, Aljabo A, Strange A, Ibrahim S, Coathup M, Young AM, Bozec L, Mudera V. Demineralization–remineralization dynamics in teeth and bone. Int J Nanomedicine 2016;11:4743–4763.
9. Yarova S, Zabolotna I, Genzytska O. Study of the morphological structure and chemical composition of the dentin of intact teeth and teeth with cervical pathology. Medical Studies/Studia Medyczne 2021;37(1):1–6.
10. Zabolotna I. Study of the morphological structure of enamel and correlation of its chemical composition with dentin in intact teeth and with a cervical pathology. J Stoma 2021;74(1):9-15.
11. Kurov IP, Skalnaya MG. Non-invasive study of indicators of mineral metabolism in young men with caries, chronic periodontitis and sanified mouth. Galician medical journal 2013;20(4):130-135.
12. Tytyuk SYu, Iordanishvili AK, Romanenko IG. Features of the morphological structure and chemical composition of hard tissues of teeth in Crohn's disease and chronic ulcerative colitis. Bulletin of the Medical Institute "REAVIZ" 2019;1:88-92.
13. de Souza-Guerra C, Barroso RC, de Almeida AP, Peixoto ITA, Moreira S, de Sousa FB, Gerlach RF. Anatomical variations in primary teeth microelements with known differences in lead content by micro-Synchrotron Radiation X-Ray Fluorescence (μ-SRXRF) – a preliminary study. J Trace Elem Med Biol 2014;28(2):186-193.
14. Srot V, Bussmann B, Salzberger U, Koch CT, van Aken PA. Linking microstructure and nanochemistry in human dental tissues. Microsc Microanal 2012;18(30):509-523.
15. Ey-Chmielewska H, Janiszewska-Olszowska J, Noceń I, Stępień P, Czajkowska A, Frączak B, Opalko K. Effect of pathological tooth wear on the content of calcium, magnesium, zinc and phosphate in human dentin. Magnes Res 2011;24(1):13-16.
16. Klimuszko E, Orywal K, Sierpinska T, Sidun J, Golebiewska M. Evaluation of calcium and magnesium contents in tooth enamel without any pathological changes: in vitro preliminary study. Odontology 2018;106(4):369-376.
17. Meisel P, Pink C, Nauck M, Jablonowski L, Voelzke H, Kocher T. Magnesium/calcium ratio in serum predicts periodontitis and tooth loss in a 5-year follow-up. JDR Clin Trans Res 2016; 1(3):266-274.
18. Shishniashvili T, Suladze N, Beridze M, Manjavidze N. Biosubstrates as dental health indicators in school-age children. Georgian Med News 2018;3(276):51-55.
19. Zohoori FV, Duckworth RM. Chapter 5: Microelements: Part II: F, Al, Mo and Co. Monogr Oral Sci 2020;28:48-58.
20. Asaduzzaman K, Khandaker MU, Binti Baharudin NA, Amin YBM, Farook MS, Bradley DA, Mahmoud O. Heavy metals in human teeth dentine: a bio-indicator of metals exposure and environmental pollution. Chemosphere 2017;176:221-230.
21. Kuczumow A, Chałas R, Nowak J, Lekki J, Sarna-Boś K, Smułek W, Jarzębski W. Novel approach to tooth chemistry. Quantification of the dental-enamel junction. Int J Mol Sci 2021;22(11):6003.
22. Fernández-Escudero AC, Legaz I, Prieto-Bonete G, López-Nicolás M, Maurandi-López A, Pérez-Cárceles MD. Aging and trace elements in human coronal tooth dentine. Sci Rep 2020;10(1):9964.