



On some features of the shape effect in human dentin under compression

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ABSTRACT

Contribution of inorganic and organic phases of human dentin in the shape effect under uniaxial compression is discussed. Comparison of the deformation behavior under compression of the samples with the different ratios between the diagonal of the compression surface and the height of quartz glass, aluminum oxide and PMMA with dentin samples having similar aspect ratios is carried out. In addition, the comparison of the deformation behavior of these materials under tensile stress is carried out. It has been shown that the shape effect of human dentin under compression is caused by the inorganic phase. The organic phase of dentin is responsible for the lowering of the Young's modulus and the compression strength and the increasing of its plasticity. Plasticity of the dentin can be additionally provided by its porosity, when the d/h ratio of the samples exceeds 1.5.

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1. Introduction

Human dentin is the hard basis of a tooth, which possesses the unique combination of the mechanical properties under uniaxial compression. Dentin samples can exhibit considerable elasticity (up to 40%) and plasticity (up to 17%) at the high compression strength (up to 800 MPa), simultaneously. It was shown that its strength properties strongly depend on the ratio between the diagonal of the compression surface and the height of cuboid sample (d/h ratio) [1]. This type of deformation behavior is determined as the shape effect. Dentin samples with a low aspect ratio behave as an almost brittle solid, whereas the samples with a high aspect ratio exhibit the high elasticity and plasticity [1,2]. The shape effect is inherent for both deformable polymer materials and brittle rock ones [3,4]. This effect can be caused by the parameters of experiment, which rule the stress distribution in the sample, and the intrinsic properties of material [4].

There are two phases (inorganic and organic) in dentin. The contribution of each of them in the deformation behavior of dentin and, hence, in the shape effect cannot be ignored because portion of each phase is considerable: apatite mineral phase is approximately 50% by volume and collagen fibers are approximately 30% by volume [5,6]. It may be supposed that the mineral phase provides the strength of dentin, whereas the organic phase is responsible for its deformability. However, the proportion between the contributions of inorganic and organic phases is still unknown. The comparison of the shape effect under compression of a brittle and deformable materials with human

dentin allow estimating the contribution of each phase in the shape effect in this hard tissue. The comparison of the deformation behavior human dentin with these materials in the field of the tensile stress under diametral compression will be additionally carried out. These findings are able to extend our understanding of the mechanisms of deformation behavior of dentin and can be useful for elaboration of new dental materials. Therefore, the aim of this work is estimation of the contributions of inorganic and organic phases in the shape effect under compression in human dentin.

2. Materials and methods

Commercial quartz glass, plasma spraying aluminum oxide (the mean of porosity is ~10%) and polymethylmethacrylate (PMMA) were taken as the model materials. Forty intact human molars and premolars were used. The teeth were extracted from mature subjects (25–40 years old) according to the medical diagnoses and the Ethics Protocol of the Urals State Medical University at Yekaterinburg, Russia. Samples of the model materials and human dentin were cut off by means of the diamond saw under water irrigation. The samples for diametral compression have been drilled by the diamond core bit with water irrigation. Their shape was cylindrical or tablet with the diameter of 5 mm and 2.5 mm in height for the model materials and 2.5 mm and 1.25 mm for dentin. The surfaces of the samples were abraded by the abrasive paper with the grain size 10 μm for removing the damaged layer on the surfaces of samples, which appeared under cutoff. The dentin samples consist of the intermediate dentin. Detailed description of the dentin sample preparation is presented in refs. [1,2,7]. There were six groups with the different d/h ratios (10, 7, 4, 1.5, 0.8, 0.5) per 10 samples for each model material and eleven groups with the different d/h ratios (11, 10, 8.5, 7, 5.5, 4, 2.5, 1.5, 0.7, 0.5) with 10 pieces of human dentin for

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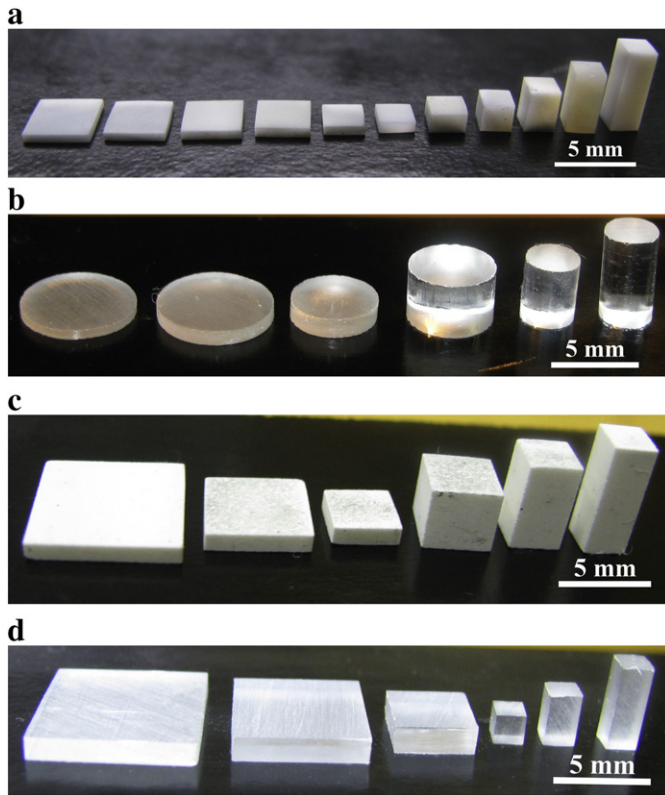


Fig. 1. Samples for compression with different d/h ratios: a – dentin; b – glass quartz; c – aluminum oxide; d – methacrylate.

compression (Fig. 1), and the groups per 10 samples of each material for diametral compression (Fig. 2) in this work. Shimadzu AGX-50kN (Japan) testing machine was used for compression testing (traverse rate 0.1 mm/min). Statistical analysis was carried out by Trapezium XTM standard software for the Shimadzu facilities. Normalized Young's modulus for each group was calculated by $E_{norm} = \frac{E_i}{E_{max}} * 100\%$, where E_{max} is maximal Young's modulus between the groups of the material and E_i is the current Young's modulus of the groups of the material. The diametral tensile stress and the diametral strain were calculated by $\sigma = \frac{2F}{\pi D h}$ and $\varepsilon = \frac{\Delta x}{D}$, respectively, where F – applied force, D – diameter of samples, h – height of sample and Δx – movement of the traverse.

3. Results

Experiments have shown that the shape effect under compression is inherent for all tested materials. Their mechanical properties are stored in Tables 1–4. Shape effect in human dentin and model materials has some common features. Compression strength and elastic and plastic deformations increase with the growth of the aspect ratio of the

Table 1
Mechanical properties of dentin sample with different aspect ratios under compression.

d/h	Young's modulus, GPa	Compressive strength, MPa	Elastic deformation, %	Plastic deformation, %	Total deformation, %
11	2.15 ± 0.01	840.2 ± 56.7	44.0 ± 1.8	19.3 ± 2.9	63.3 ± 2.4
10	2.53 ± 0.04	758.5 ± 45.4	35.7 ± 2.3	20.4 ± 3.4	56.1 ± 2.2
8.5	2.84 ± 0.09	661.8 ± 26.8	27.6 ± 2.9	19.7 ± 2.1	47.2 ± 2.2
7	3.36 ± 0.10	650.4 ± 49.5	24.1 ± 2.0	15.2 ± 5.1	39.3 ± 3.1
5.5	3.64 ± 0.09	575.1 ± 58.1	16.3 ± 2.5	14.3 ± 3.2	30.6 ± 3.3
4	4.42 ± 0.23	527.4 ± 28.9	13.5 ± 1.7	13.5 ± 2.4	27.0 ± 3.4
2.5	6.23 ± 0.31	442.7 ± 22.5	8.4 ± 1.6	12.5 ± 2.7	20.9 ± 2.8
1.5	8.04 ± 0.58	384.9 ± 29.3	5.4 ± 0.7	1.7 ± 0.6	7.1 ± 2.0
1	8.41 ± 0.74	344.9 ± 21.3	4.6 ± 0.5	1.2 ± 0.7	5.8 ± 1.2
0.7	9.00 ± 0.58	360.6 ± 25.6	4.2 ± 0.5	1.8 ± 0.6	6.0 ± 0.5
0.5	9.95 ± 1.29	332.9 ± 25.4	3.3 ± 0.4	1.8 ± 0.5	5.1 ± 0.7

samples, whereas the Young's modulus decreases. The samples of quartz glass and aluminum oxide having d/h ratios 7 and 10 did not fail under loading in spite of the highest stress (>1500 MPa) and deformation (>40%), but the Young's modulus can be calculated (Tables 2,3). PMMA samples of all d/h ratios never failed due to their high plasticity up to 65% and therefore the value of compression strength of PMMA samples cannot be obtained. However, the Young's modulus and the elastic deformation were calculated in this case (Table 4). One-way ANOVA of the different (significantly different – p) dentin samples and model material samples with the same d/h ratio is shown in Table 5.

Dependences of the normalized Young's modulus from d/h ratio for the samples of quartz glass, aluminum oxide and human dentin were similar. The trend of their curves was nonlinear, while the curve of PMMA samples was linear (Fig. 3a). The “the compression strength–d/h ratio” curves can be approximated by a straight line for quartz glass, aluminum oxide and human dentin (Fig. 3b). However, the compression strength of human dentin was grown not so intensively as the compression strength of quartz glass and aluminum oxide. Dependences of the elastic deformation from the aspect ratio of the samples were nonlinear for all groups of samples, but the trend of dentin curve was more close to PMMA in comparison with quartz glass and aluminum oxide (Fig. 3c). There was no plasticity in the quartz glass samples at all range of stresses. Plastic deformation of PMMA samples was always more than 30% for all d/h-ratios, but its value could not be calculated because the samples never failed under loading. The profile of the “plastic deformation–d/h ratio” curves of human dentin and aluminum oxide was similar, however, the values of plastic deformation of human dentin were higher than for aluminum oxide (Fig. 3d). It should be noted that the plasticity in the aluminum oxide samples appears when their d/h ratio exceeds 1.5, whereas human dentin samples possess plasticity at all range of d/h-ratios.

The diametral compression testing has shown that the response of dentin samples contains both elastic (3.6%) and plastic (1.1%) contributions at the diametral compression strength 63.6 MPa, which is the highest among the tested materials (Fig. 4). Quartz glass and alumina samples exhibited the elastic response only. Their diametral

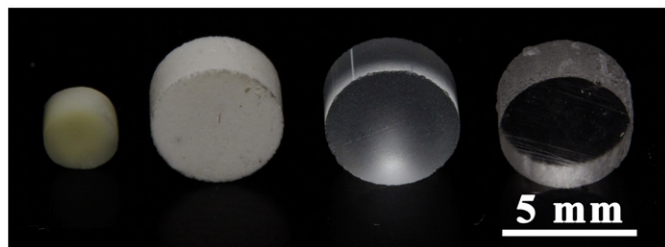


Fig. 2. Samples for diametral compression: human dentin, alumina, quartz glass and PMMA (left to right).

Table 2
Mechanical properties of quartz glass sample with different aspect ratios under compression.

d/h	Young's modulus, GPa	Compressive strength, MPa	Elastic deformation, %	Plastic deformation, %	Total deformation, %
10	1.34 ± 0.03	–	–	–	–
7	1.95 ± 0.05	–	–	–	–
4	4.17 ± 0.10	1565.0 ± 66.7	42.8 ± 4.3	0.0 ± 0.1	42.8 ± 4.3
1.5	9.63 ± 0.09	1019.1 ± 97.5	10.9 ± 1.2	0.0 ± 0.1	10.9 ± 1.2
0.8	14.12 ± 1.39	379.4 ± 27.3	3.0 ± 0.3	0.0 ± 0.1	3.0 ± 0.3
0.5	18.14 ± 2.27	223.1 ± 22.0	1.7 ± 0.1	0.0 ± 0.1	1.7 ± 0.1

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