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Correction of some mechanical characteristics of human dentin under compression considering the shape effect

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ABSTRACT

The paper is aimed to determine the true compression strength and Poisson's ratio of human dentin. The origin of the shape effect in dentin under compression is discussed, too. It was shown that the shape effect is mainly caused by the friction between the surface of the sample and the compression plates. Ratio d/h = 4 is the optimal proportion between the diagonal of compression surface and the height of dentin sample for compression testing. Inhomogeneous deformation takes place in the sample with a low aspect ratio whereas lateral deformation is suppressed in the sample with a high aspect ratio. There is significant difference between the conventional compression strength and the true compression strength. True compression strength of human dentin is 432 ± 16 MPa, the Young's modulus is 4.04 ± 0.12 GPa and Poisson's ratio of human dentin is 0.14 ± 0.04.

1. Introduction

Human dentin is the hard base of a tooth. The main mechanical function of dentin is to support the overlaying enamel, which protects the tooth from external action. Enamel re-distributes the dangerous stresses in homogeneous one into its thickness under mastication. Therefore, the uniaxial compression is the sole scheme of deformation that dentin underwent. Information on the mechanical properties of human dentin is important for the manufacturers of dental restorative materials because their properties should be close to the properties of tooth hard tissues.

Study of the mechanical properties of dentin under compression attracted the interest of many researchers since 1895 [1]. However, the mechanical characteristics of dentin are different and varied in the wide diapason: the Young's modulus 8–19 GPa and the compression strength 250–350 MPa [2–4]. It has been shown that mechanical properties of the cuboid dentin samples under compression strongly depend on the ratio between the diagonal of compression surface of the sample and its height (d/h ratio, Fig. 1a). The samples with low aspect ratio behave like a brittle material while the deformation behavior of samples with high aspect ratio is close to a ductile solid. The Young's modulus of human dentin varied from 2 GPa to 11 GPa and the compression strength is 330–800 MPa [5,6]. This dependence of the mechanical properties from the sample shape explains in most cases the variation of the results given in the literature. In the other cases, the distinction in the results is caused by such experimental factors as environment and temperature of testing.

The origin of the shape effect under compression connects with both intrinsic properties of the material and several experimental factors. One of them is the friction between the surface of the sample and the compression plate when the lateral deformation is hampered (Fig. 1b). The next cause of the shape effect is the difference between conventional and true stresses in the sample. Calculation of the conventional stresses is based on the initial size of sample, however, the sizes of the samples and its area of contact with the compression plates can be changed during loading and hence the level of true stresses in the samples should be distinct from the conventional stress, which was calculated by the testing machine (Fig. 2). It is not significant for a brittle material where the deformation is less than 1%, but it should be taken into account for a deformable material when the deformation can reach several tens of percent. Therefore, this difference in the stresses should be considered for human dentin under compression because its deformation reaches up to 56% for the samples with the highest aspect ratio [5–7].

One of the important mechanical parameters is the Poisson's ratio, which characterizes the competition between the lateral and the axial deformations. It is used for calculating of the Young's modulus at indentation testing. The Poisson's ratio of dentin lies in diapason 0.025–0.45 [4]. Variation of the value appears due to the measurement of Poisson's ratio that is carried out by the different methods such as Resonant Ultrasound Spectroscopy and calculation from the numerical models. No direct measurements of Poisson's ratio of dentin have been done. Besides, it should be noted that measurements of porous and inhomogeneous materials such as human dentin by means of wave transmission look like not quite correct.

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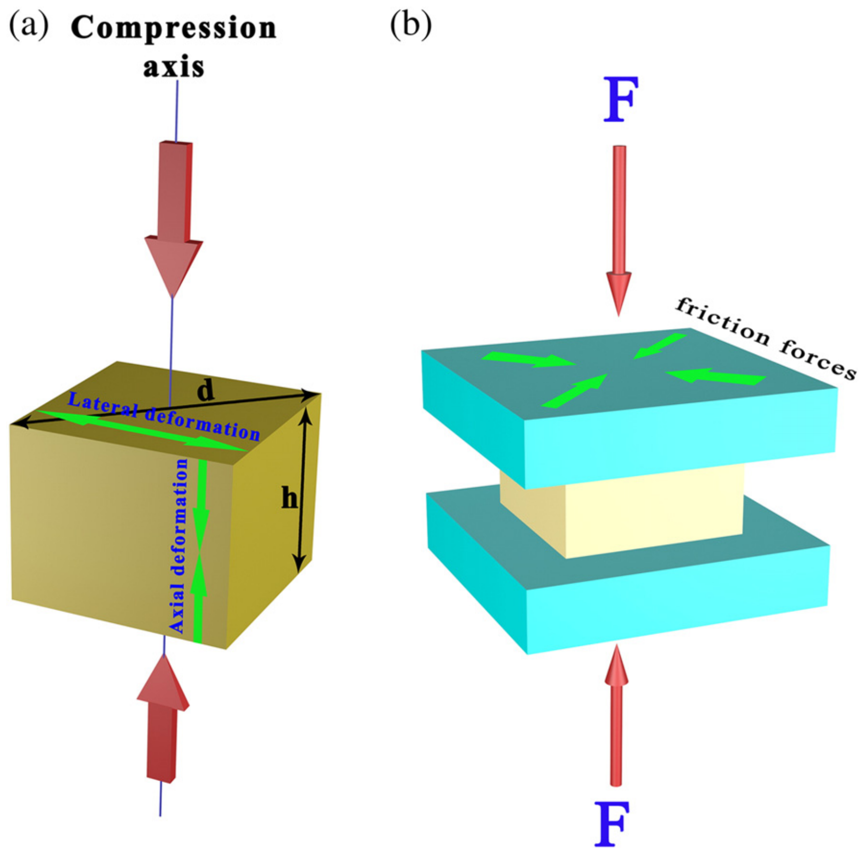

Fig. 1. Schemes: a — dimensions parameters of the sample; b — direction of friction forces.

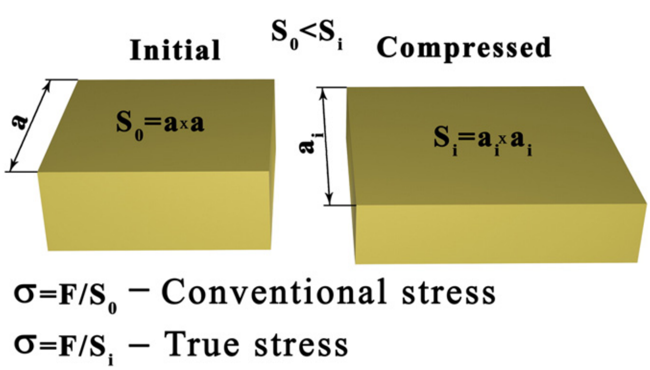

Fig. 2. Calculation of stress in the sample at compression test.

Recording of the lateral and the axial deformations of the sample during compression test allows estimating the influence of friction between the surface of the sample and the compression plate on the deformation behavior of dentin, and calculating the true mechanical values that reflect its intrinsic properties. The aim of this work is the correction of the compression strength, the Young's modulus and the Poisson's ratio of human dentin under compression testing.

2. Experimental procedure

Fifty intact human molars and premolars were used in this work. They did not contain damages and were extracted from mature subjects according to the medical diagnosis and the Ethic Protocol of the Urals State Medical University at Yekaterinburg, Russia. Detailed description of the methods of sample preparation was given in Ref. [5]. The samples were cut from the teeth by means of a diamond saw with water irrigation and, further, their surfaces were abraded using the abrasive papers. Seven groups with different d/h ratios per 10 cuboid samples each were prepared. Sizes of the samples are given in Table 1. Uniaxial compression was carried out by means of a Shimadzu AGX-50 kN (Japan) testing machine at room condition. Rate of loading was 0.1 mm/min for all tests. Processing of the results including statistical analysis was carried out by Trapezium-X software. The lateral deformation of the sample was calculated by means of a Canon photo microsystem (Japan), where the width of the sample compared in situ with the etalon

Table 1
Mechanical properties of the sample of human dentin in dependence on the d/h ratio under compression.

Sizes, mm	1.7 × 1.8 × 1.8	1.2 × 2.1 × 2.1	0.7 × 2.0 × 2.0	0.6 × 2.3 × 2.3	0.6 × 3.0 × 3.0	0.55 × 3.3 × 3.3	0.5 × 3.5 × 3.5
d/h ratio	1.5	2.5	4	5.5	7	8.5	10
Conventional compression strength, MPa	405 ± 23	404 ± 13	525 ± 34	615 ± 30	625 ± 12	667 ± 61	749 ± 46
True compression strength, MPa	372 ± 23	359 ± 16	432 ± 16	454 ± 5	476 ± 12	513 ± 22	518 ± 35
Young's modulus, GPa	8.80 ± 0.71	5.32 ± 0.13	4.36 ± 0.23	3.76 ± 0.13	2.82 ± 0.20	2.29 ± 0.13	2.13 ± 0.08
Lateral deformation / axial deformation	0.37 ± 0.06	0.34 ± 0.05	0.49 ± 0.07	0.38 ± 0.07	0.29 ± 0.04	0.26 ± 0.01	0.31 ± 0.04