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Time-dependent behavior of porcine periodontal ligament: A combined experimental, numeric in-vitro study

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Introduction: The aim of this study was to analyze the time-dependent in-vitro behavior of the periodontal ligament (PDL) by determining the material parameters using specimens of porcine jawbone. Time-dependent material parameters to be determined were expected to complement the results from earlier biomechanical studies. **Methods:** Five mandibular deciduous porcine premolars were analyzed in a combined experimental-numeric study. After selecting suitable specimens (excluding root resorption) and preparing the measurement system, the specimens were deflected by a distance of 0.2 mm at loading times of 0.2, 0.5, 1, 2, 5, 10, and 60 seconds. The deflection of the teeth was determined via a laser optical system, and the resulting forces and torques were measured. To create the finite element models, a microcomputed tomography scanner was used to create 3-dimensional x-ray images of the samples. The individual structures (tooth, PDL, bone) of the jaw segments were reconstructed using a self-developed reconstruction program. A comparison between experiment and simulation was conducted using the results from finite element simulations. Via iterative parameter adjustments, the material parameters (Young's modulus and Poisson's ratio) of the PDL were assessed at different loading velocities. **Results:** The clinically observed effect of a distinct increase in force during very short periods of loading was confirmed. Thus, a force of 2.6 N ($\pm$1.5 N) was measured at the shortest stress duration of 0.2 seconds, and a force of 1.0 N ($\pm$0.5 N) was measured at the longest stress duration of 60 seconds. The numeric determination of the material parameters showed bilinear behavior with a median value of the first Young's modulus between 0.06 MPa (2 seconds) and 0.04 MPa (60 seconds), and the second Young's modulus between 0.30 MPa (10 seconds) and 0.20 MPa (60 seconds). The ultimate strain marking the transition from the first to the second Young's modulus remained almost unchanged with a median value of 6.0% for all loading times. **Conclusion:** A combined experimental-numeric analysis is suitable for determining the material properties of the PDL. Microcomputed tomography allows high-precision recordings with only minimum effort. This study confirms the assumption of time dependency and nonlinearity of previous studies. (Am J Orthod Dentofacial Orthop 2018;153:97-107)

The periodontal ligament (PDL), a complex, fibrous biologic connective tissue, is responsible for cushioning and transmitting all forces that affect the teeth and their surrounding bones. Consequently, it has an important influence on tooth movement. In the stomatognathic system, the PDL transfers the forces into the alveolar bone that act on the teeth. The resulting change in position of the tooth in the alveolus generates pressure as well as tensile areas. In the pressure areas, the periodontal fibers are compressed, resulting in bone resorption; in the tensile areas, the fibers are outstretched, finally resulting in bone apposition. Reitan[1] and Reitan and Kvam[2] divided tooth movement into 3 phases (initial phase, hyalinization, and resorption). According to them, tooth movement starts with an initial cushioning that deflects the tooth and compresses the PDL.

The initial cushioning that occurs with subliminal forces can be reduced to a variety of mechanisms: the elasticity of dental hard tissue, the elastic deformation

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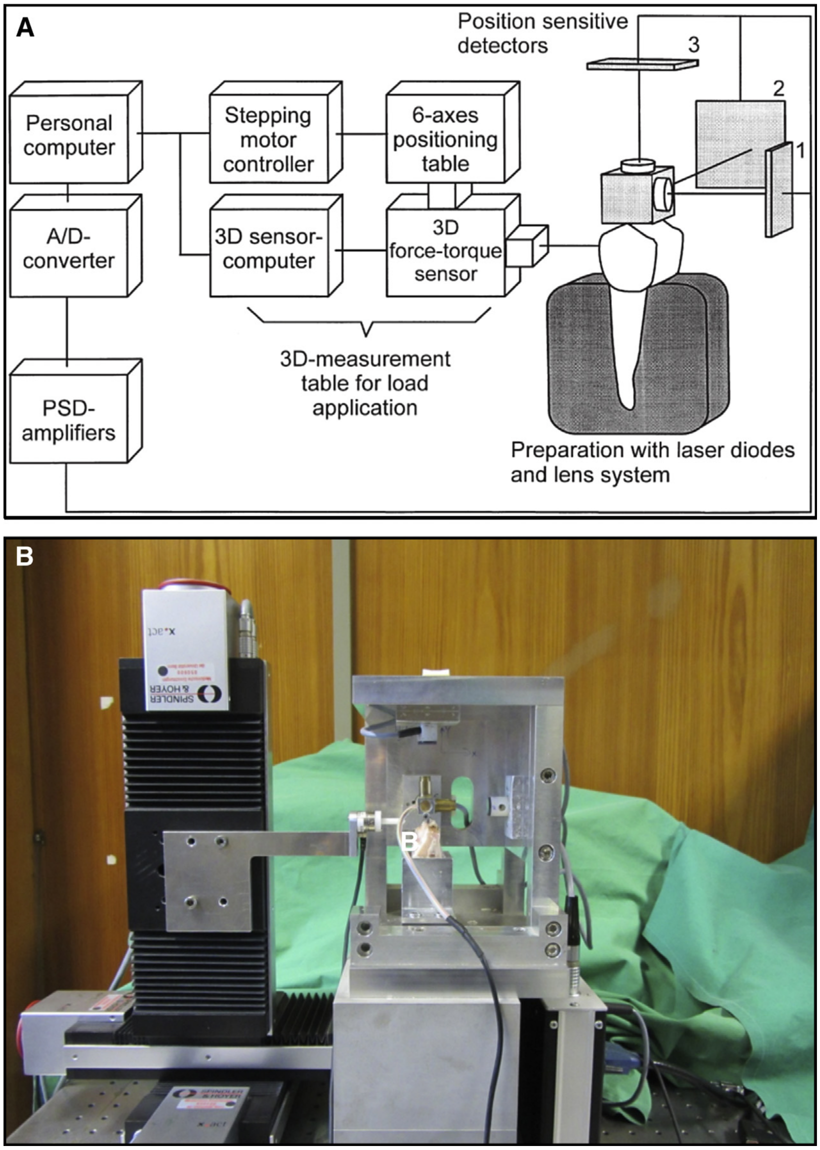

Fig 1. **A,** Schematic diagram of the mobility measurement system. The sample (tooth and surrounding bone) is loaded with a force/torque sensor, and the resulting deflection is measured with 3 surface sensors (position sensitive detectors 1, 2, and 3).[7] **B,** Photo of the optoelectronic and mechanical part of the measurement system with the installed pig specimen immediately before loading of the sample.

of the alveolar bone, the initial extension of desmodontal fibers, and the hydrodynamic cushioning through desmodontal tissue fluid (with the desmodont as the connective part of the PDL between bone and tooth).[3,4] During this phase, the desmodontal circulation stays intact, and the reactions of the periodontium are reversible.

Due to its complex multiphase structure, the PDL shows distinct time-dependency, nonlinearity, and anisotropy. The inconsistent results of previous studies concerning biomechanical behavior can be explained by a number of factors, including differing experimental setups with varying loading velocities, the complexity of involved tissues, and different assumptions about the mechanical properties of the PDL. This led to values for Young's modulus ranging from 0.07 MPa[5] to 1379 MPa.[6]

In this study, a combined experimental and numeric approach was used to analyze the time-dependent behavior of the PDL using samples of