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Stress–relaxation and microscopic dynamics of rabbit periodontal ligament

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Abstract

The aim of the present study was to examine the structural basis for the stress–relaxation behaviour of the periodontal ligament (PDL). Seventeen 4-month-old rabbits were used. A tooth–PDL–bone segment was cut in a rectangular prism from the incisor of a dissected mandible. The specimen was mounted in a testing machine built on a video stereomicroscope. Following preconditioning, each specimen was stretched to a deformation of 35 μm and then the deformation was kept constant for 300 s to obtain a stress–relaxation curve. Thereafter, stress–relaxation tests were repeated sequentially at deformations of 55, 75, and 95 μm. Polarised-light video–stereomicroscopic images of the specimens were simultaneously recorded and analysed with the stress–relaxation curves. The image analysis revealed that during stress–relaxation, the brightness of the birefringent fibres tended to initially increase rapidly and then do so gradually. There were negative correlations between the brightness and relaxation modulus at the four deformations. The decreases of normalised relaxation modulus for 300 s were less at greater deformation levels. The stress–relaxation process was well described by a function with three exponential decay terms and a constant. These findings suggest that during stress–relaxation of the PDL, the alignment of the collagen molecules and fibrils within the stretched fibres may occur, which could be driven by the strain energy imparted to the specimen on initial stretching.

Keywords: Periodontal ligament; Stress–relaxation; Collagen fibres; Polarised-light microscopy; Video recording

1. Introduction

Biomechanical analyses of not only the stress–strain responses, but also viscoelastic responses such as hysteresis, creep, and stress–relaxation of the periodontal ligament (PDL) help elucidate the tooth support function of the tissue (Moxham and Berkovitz, 1995). When a tooth is subjected to an excessive force, the PDL may dissipate the strain energy stored in the tissues to some extent. Viscoelastic responses are principal causes of energy dissipation. Without the dissipation of strain energy, excessive strain energy may cause tissue breakage (Fung, 1980; Provenzano et al., 2001; Sanctuary et al., 2005, 2006; Shibata et al., 2006). Thus, viscoelasticity is probably quite important for the tooth support function of the PDL.

However, little is known about the relation between the viscoelastic response and the structure of the PDL (Komatsu et al., 2004a). We previously devised an experimental set-up for continuous video recording of stereomicroscopic images during tensile loading of a PDL specimen (Komatsu and Chiba, 2001). The simultaneous recording of the mechanical response coupled with polarised–light stereomicroscopic images effectively revealed that the birefringent characteristics of collagen bundles are intimately related to the stress–strain behaviour of the PDL.

The aims of the present study were to simultaneously record stress–relaxation measurements and the

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corresponding polarised-light microscopic images on video of the rabbit PDL, and to elucidate the relation between the viscoelastic response and the structure of the load-bearing periodontal collagen fibres. Quantitative polarised-light microscopy is a useful method for investigating the macromolecular orientation and organisation of collagen fibres in living connective tissues without dyes or fluorescent labels (Diamant et al., 1972; Wolman and Kasten, 1986; Whittaker et al., 1988; Vilarta and Vidal, 1989; Gathercole and Keller, 1991). Here we applied this method to help elucidate the mechanisms of viscoelastic response in the PDL.

2. Materials and methods

The experiment was approved by the Animal Care Committee of Tsurumi University School of Dental Medicine. Seventeen 4-month-old male rabbits of the Japanese white strain, with a mean body weight of 3.5 ± 0.4 (SD) kg were used. The animals were killed by intravenous injection of an overdose of thiopental sodium. Immediately after death, the left mandibles were dissected free and the adhering soft tissues removed (Fig. 1a).

2.1. Preparation of specimens

The preparation of the rabbit PDL specimens for the uniaxial tests was as described elsewhere (Komatsu and Chiba, 2001). In brief, from each dissected mandible (Fig. 1a), a transverse section (0.23 ± 0.01 [SD] mm in thickness) of the middle region of the incisor (Komatsu et al., 1998) with its surrounding PDL and alveolar bone was cut through an axis

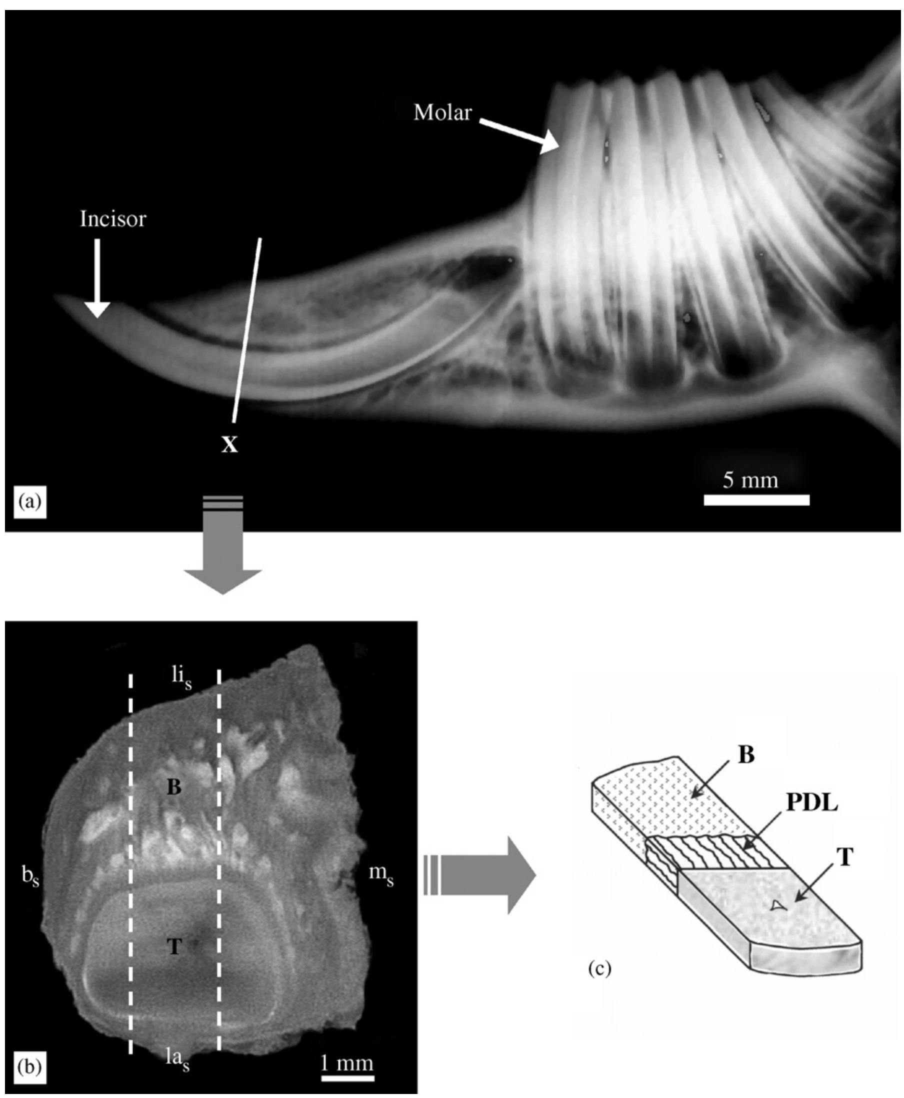

Fig. 1. (a) Radiograph of a dissected rabbit left mandible. (b) Photograph of a transverse section of the incisor (T) cut through an axis (X) perpendicular to the tangent of the labial surface of the incisor. The buccal (b_s) and mesial (m_s) sides of the section were trimmed to prepare a mechanical specimen. B, bone; li_s, lingual; la_s, labial. (c) Schematic diagram of a specimen consisting of bone, periodontal ligament (PDL), and tooth.