DENTAL-2962; No. of Pages 11
ARTICLE IN PRESS
dental materials xxx (2017) xxx.e1–xxx.e11
Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.intl.elsevierhealth.com/journals/dema

Biomechanical behaviour of craniofacial sutures during distraction: An evaluation all over the entire craniofacial skeleton

Fabio Savoldi[a,b], James K.H. Tsoi[a,*], Corrado Paganelli[b], Jukka P. Matinlinna[a]

[a] *Dental Materials Science, Faculty of Dentistry, The University of Hong Kong, Prince Philip Dental Hospital, 34 Hospital Road, Sai Ying Pun, Hong Kong SAR, PR China*
[b] *Department of Orthodontics, Dental School, University of Brescia, P.le Spedali Civili, 25123 Brescia, Italy*

ARTICLE INFO

Article history:
Received 2 December 2016
Received in revised form
15 April 2017
Accepted 28 April 2017
Available online xxx

Keywords:
Craniofacial sutures
Ligament
Biomechanics
Tension
Acoustic emission
Sutural distraction osteogenesis

ABSTRACT

Objective. Sutures are fibrous joints connecting the bones of the head. Despite the fundamental role played by sutures in dentofacial orthopaedics, their biomechanical properties are not completely understood. This study evaluated anatomy, biomechanics, and acoustic emission (AE) during distraction of the sutural ligament (SL).

Methods. Seventy-two suture samples were removed from a twelve-months-old swine (*Sus scrofa*) head. Each volume was acquired using micro-computed tomography (μCT), and the linear interdigitation index was calculated on both planes (LII_{COR} and LII_{SAG}). Mechanical testing till failure was carried at 1 mm/min, and four piezoelectric sensors were used for recording of amplitude (*A*), duration (*D*), and energy (*E*) of AE. The relationships between interdigitation, fracture types, tensile stress (σ_0), and AE were statistically analysed with non-parametric tests ($\alpha = 0.05$).

Results. σ_0 of the SL had median values of 4.0 MPa, and AE were characterised by *A* of 49.3 dB (IQR = 2.2), *D* of 826.3 μs (IQR = 533.4), and *E* of 57,715.8 eu (IQR = 439,613.5). Most of the fractures happened in the SL (46%), some within the bone (34%), and fewer were combined (19%). LII_{COR} had correlation with *A* (0.383, p = 0.028), *D* (0.348, p = 0.048), and *E* (0.437, p = 0.011) of the AE, and σ_0 had similar relationship with *A* (0.500, p = 0.003), *D* (0.495, p = 0.003), and *E* (0.579, p < 0.001). Maximum energy values were different between fractures within the bone and within the SL (p = 0.021).

Significance. Biomechanical properties under tension of most of the sutures of the craniofacial skeleton were reported. AE provided information about the sequence of events during SL distraction, and had significant relationship with its mechanical properties. Further studies are necessary to confirm these preliminary findings, and to identify their relationship with biological processes and dentofacial treatments.

* Corresponding author.
E-mail addresses: fabiosavoldi@live.com (F. Savoldi), jkhtsoi@hku.hk (J.K.H. Tsoi), corrado.paganelli@unibs.it (C. Paganelli), jpmat@hku.hk (J.P. Matinlinna).

http://dx.doi.org/10.1016/j.dental.2017.04.025
0109-5641/

Please cite this article in press as: Savoldi F, et al. Biomechanical behaviour of craniofacial sutures during distraction: An evaluation all over the entire craniofacial skeleton. Dent Mater (2017), http://dx.doi.org/10.1016/j.dental.2017.04.025

1. Introduction

Cranial sutures are articulations joining bones of the head through a sutural ligament (SL). Two main approaches may exist to the biomechanics of the sutures: the first one considering their function in the sutural system of the craniofacial skeleton as a whole *e.g.*, suture system biomechanics, the second one isolating them as single entity *e.g.*, suture biomechanics. Studies in both humans and mammalian animals have evaluated the suture system biomechanics mainly in shock absorption during impacts [1,2], in presence of pathologies affecting sutural growth [3,4], during rapid maxillary expansion (RME) [5–7] or during mastication [8,9]. In this context, the suture is not interpreted as a single functional unit, and thus its extraction from the suture is required to test the mechanical properties of its SL *per se*.

The morbidity of suture alterations include severe function impairment and even mortality [10,11], and SL mechanical characterisation is of primary importance to optimise treatments such as sutural distraction osteogenesis (SDO) [12], which relies on the application of tensile stress on the SL to promote bone generation. Despite the first report of SDO through RME could be traced back to 1860 [13], and it has become a routinely treatment since the 60s [14], performing distraction of suture other than the maxillo-maxillary one only came in a rather late stage and has been less frequently applied [15–18]. However, mechanical studies on single suture samples in humans were focused on impacts [19], nano-indentation [20], or bending [21–25], whereas all domains sparsely oriented to SDO. In animals, interest was primary towards impact [26] or bending [26–28] as well, and the few studies on tension at low velocities involved only the parieto-parietal [29,30], fronto-parietal [30], and fronto-frontal suture [30]. However, SDO is based on tensional forces, and each suture may have specific requirements for optimal mechanically-induced osteogenesis [31]. As a consequence, a comprehensive mechanical assessment of all the sutures is probably the first move towards a more calibrated application of forces in clinical treatments.

Nevertheless, classical mechanical investigations or even sub-cutaneous strain gages [32], traction callipers [33], X-rays [5], magnetic resonance [34] and ultrasounds [35], may have limitations in providing stress-related information. The acoustic emission (AE) technique is a non-destructive test (NDT) based on the detection of energy release in the form of sound waves during deformation of materials (Fig. 1). One of the first report in the literature of AE applied on bone is attributed to Hanagud et al. in the 70s [36]. Then, AE has also demonstrated to find useful application in joints [37] and tendons [38], providing additional information beyond the load-displacement evaluation. Later, Cormier et al. extended the application of AE analysis to facial bones [39–41], but neglected to consider any relationship with the sutures. Very recently, Savoldi et al. attempted the use of AE sensors to detect the stress distribution in the craniofacial skeleton of a swine model during RME [7]. However, no prior art seems to be available in the published literature relatively to AE technique application to evaluate mechanical properties of a single suture unit.

2. Materials and methods

2.1. Specimen preparation and experimental setup

One swine head of a just-suppressed twelve-months-old domestic pig (*Sus scrofa*) was studied in agreement with the local regulation concerning the use of animals for research purposes. Mandible and soft tissues were removed with scalpel blade. Two specimens (A and B) were removed from each suture either on the rostral and caudal region of single sutures, or on the left and right side for sutures present on both sides of the skull. Seventy-two testing specimens were extracted using a hand-piece air-turbine (PrestoAcqua© II, Nakanishi Inc., Japan) with saline water supply. The orientation of the long side of the specimen was almost perpendicular to the suture main axis, the thickness was determined by the natural anatomy of each region, the width was ≈5 mm, and the length was subsequently standardised at ≈20 mm. The extremities of the specimens were embedded into acrylic resin (Orthoresin©, Dentsply, US) using a custom-made mould, giving to the non-embedded central part a fixed length of 10 mm, and providing connections for mechanical testing (Fig. 2). Specimens were stored at −20 °C and defrosted at room temperature (25 °C) for 8 h in saline solution before the experiment.

2.2. Acquisition of anatomical data

Each specimen's volume was acquired with micro-computed tomography (μCT) (SkyScan© 1172, Bruker, US). The length of the suture (l, mm) and the width of the specimen (w, mm) were measured on the coronal plane parallel to the external surface (COR, l_{COR} and w_{COR}), and on the sagittal plane perpendicular to the external surface and to the suture main axis (SAG, l_{SAG} and w_{SAG}). For measurements, both planes were centred in the middle of the specimen and images were captured using a graphical software (ImageJ [42]) calibrated on the scale of the μCT acquisition. Respective linear interdigitation index (LII_{COR} and LII_{SAG}, mm/mm) was calculated, expressed as

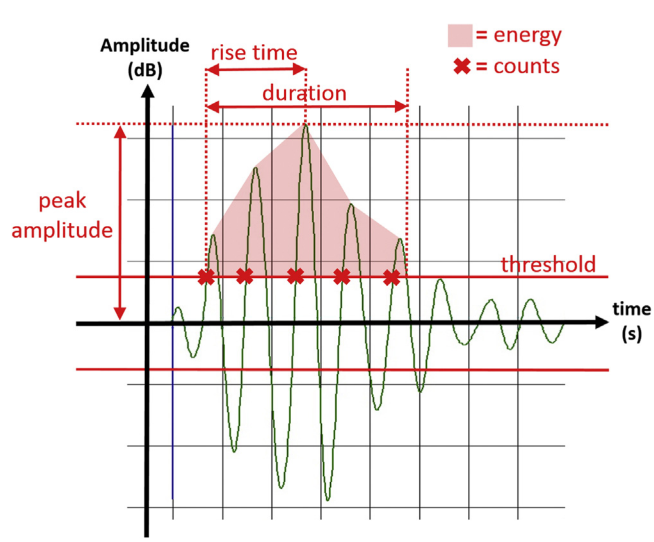

Fig. 1 – Example of AE wave with respective parameters.

Please cite this article in press as: Savoldi F, et al. Biomechanical behaviour of craniofacial sutures during distraction: An evaluation all over the entire craniofacial skeleton. Dent Mater (2017), http://dx.doi.org/10.1016/j.dental.2017.04.025