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Impact of radiation history, gender and age on bone quality in sites for orthodontic skeletal anchorage device placement

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ABSTRACT

Aims: Stability of orthodontic miniscrew implants is prerequisite to their success and durability in orthodontic treatment. As investigations revealed a positive correlation of miniscrew stability to periimplant bone quality, it has been the aim of this study to analyze the bone structure of resection preparations of human mandibles histologically by investigating the samples according to age, gender and exposure to radiotherapy.
Methods: Inflammation- and tumor-free alveolar bone sections from human mandibles ($n = 31$) with previously diagnosed carcinoma, chronic osteomyelitis or cysts were analyzed histomorphologically and histomorphometrically as to the dimension of trabeculae in cancellous areas. Group A investigated the impact of a history of radiation therapy, group B of gender and group C contrasted biopsies from individuals aging under 60 or over 60 years. Statistics were performed using the Kruskal–Wallis-test.
Results: Radiation, gender and age did not significantly influence bone density. The mean bone density averaged $40.7 \pm 15.0\%$ of spongiosa for the total collective with a median age of 58.4 years ± 14.7 years.
Conclusions: Our findings provide new information on bone quality, thus contributing to a more precise evaluation of the parameters affecting and those not affecting miniscrew implant stability. On the basis of these results, the formulation of clinical guidelines for risk assessment of therapeutic approaches in patients prior to insertion of orthodontic skeletal anchorage devices seems to be conceivable.

1. Introduction

Orthodontic tooth movement control is decisive to successful treatment outcome and often involves the necessity of maximum anchorage, which is nowadays increasingly realized by the application of temporal skeletal anchorage devices (Janssen et al., 2008). Analoguous to dental implants, primary stability of these orthodontic miniscrew implants is a prerequisite to their success and durability during orthodontic treatment (Friberg et al., 1991). Investigations revealed a positive correlation between implant primary stability and the bone quality of the periimplant hard tissue characterized by the osseous structure and the degree of tissue mineralization (Marquezan et al., 2012). As the clinical performance of miniscrew implants during orthodontic loading, with special regard to stationary maintenance of the insertion site, has not yet been fully investigated, and, as reduced bone quality is related to higher implant failure rates, information on bone structure is crucial to the success of orthodontic treatment in combination with skeletal anchorage devices (Santiago et al., 2009). This knowledge is of particular importance in orthodontic treatment of older patients, as age-related morphological changes in dentofacial structures also entail bone mass reduction ascribed to factors such as hormonal changes, reduced calcium resorption, a decreased mineral content, inhomogeneous mineralization density and thinned bone trabeculae (Chan and Duque, 2002; Khosla, 2013; Macdonald et al., 2011). These alterations especially affect female patients and might be relevant to the stability of skeletal anchorage devices (Santiago et al., 2009). The physiological signs of bone aging can be further modulated by pathological processes like generalized osteoporosis or external factors like radiation-induced tissue injury (Hopewell, 2003; Lin and Lane, 2004). Radiation induces intraosseous inflammation attended by a reduced blood supply, which, in consequence, manifests radiologically as low bone mineral density, trabecular fracture, destruction of cortical structures, and loss of cancellous

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trabeculae (Jereczek-Fossa and Orecchia, 2002). Up to date, there is no data available on the use of temporal skeletal anchorage devices in patients requiring orthodontic therapy subsequent to radiotherapy. However, orthodontic treatment of adult patients more frequently requires application of skeletal anchorage devices than therapy in younger patients, e.g. for the non-surgical treatment of class III malocclusions with retraction of the lower dentition or for preprosthetic molar uprighting using miniscrew implants (Jing et al., 2013; Nienkemper et al., 2013). Histomorphometrical analyses of bone biopsies represent a valid method for the evaluation of bone quality, whereas clinical assessments comprise methods like digital image analysis of dental radiographs, ultrasound or computerized tomography (CT) scans (Hans et al., 1996; Jäger et al., 1990; Norton and Gamble, 2001; Trisi and Rao, 1999). The latter quantifies bone mineral density in Hounsfield units (HU) and has provided data from former investigations on jawbone density with mean values for cortical bone density of 929.27 ± 322.12 HU in the maxilla and 1116.2 ± 298.33 HU in the mandible, and for cancellous bone 450.09 ± 205.66 HU in the maxilla and 561.87 ± 170.83 HU in the mandible (Samrit et al., 2012). Regarding conventional oral implants for prosthetic rehabilitation, the determination of bone mineral density via CT imaging methods previous to implant placement represents a standard procedure, but, in miniimplant placement, this assessment is not routinely conducted (Santiago et al., 2009). Additionally, this technique entails several disadvantages, e.g. exposure to radiation and manipulation by metal components (Nkenke et al., 2003). For the prediction of miniimplant stability in orthodontically treated patients, a noninvasive valid estimation method would be useful. However, an ideal evaluation method, also accommodating the fact that miniscrew implants do not have to provide the same long term stability as conventional implants, and thus, do not fully justify radiation exposure, does not exist up to date. Clinical guidelines elucidating factors which do impact bone quality and parameters which do not compromise osseous structures, and thus, miniscrew implant stability would be beneficial in a precise estimation of skeletal anchorage device stability. Therefore, it has been the aim of the present study to analyze the bone structure of resection preparations of human mandibles histologically by dichotomizing the samples according to age, gender and exposure to radiotherapy. These findings might provide the orthodontic practitioner with novel data concerning potential risk factors impeding both successful miniscrew implant placement and therapeutic use during orthodontic tooth movement due to impaired bone quality especially in older patients.

2. Materials and methods

2.1. Material

The study was conducted in full accordance with ethical principles regarding human experimentation including the World Medical Association Declaration of Helsinki.

Bone specimens ($n = 31$) were obtained from human mandibles undergoing partial resection and subsequent histopathological investigation upon diagnosis of carcinoma, chronic osteomyelitis or cyst at the Department of Oral and Maxillofacial Surgery, University of Bonn. The patients comprised 18 irradiated and 13 non-radiated individuals, 12 female and 19 male, 16 subjects younger than 60 years and 15 aged over 60 years. Corresponding clinical data are listed in Table 1. The biopsies investigated were taken from tumor- and inflammation-free alveolar bone sections and divided into three groups for the investigation, defined as group A for the comparison of radiation versus absence of radiation, group B differentiated by gender and group C by age under 60 years or over 60 years, respectively. Individuals with a positive history for radiation had been subjected to a radiation dose of 36 Gy 2 weeks before surgical resection.

2.2. Methods

Paraffin-embedded sagittal sections of human biopsies of tumor- and inflammation-free alveolar bone from sections of the mandible were subjected to hematoxylin eosin (HE) and Masson's trichrome staining for histological evaluation as previously described (Goldner, 1938; Fischer et al., 2008).

Each biopsy was histomorphologically evaluated using a light microscope (Axioskop 2; Zeiss, Jena, Germany). For histomorphometric analysis, stained sections were transferred to a PC via microscope (Leica DMLB, Solms, Germany) and digital camera (3CCD; JVC, Friedberg, Germany) in a 1.6 fold magnification and cancellous areas were analyzed in accordance with the terms by Dempster et al. (2013). The ratio was determined with the program AxioVision Rel. 4.5® (Zeiss, Jena, Germany). Three sections of each sample and three pictures of each section were analyzed and the mean value determined.Cancellous bone density was evaluated based on the following formula (Dempster et al., 2013):

$$\text{cancellous trabeculae related to the total area of the picture } (\%) = \frac{\text{template area (pixel}^2)}{(\text{total area (pixel}^2) : 100)}$$

2.3. Statistical analysis

Statistical evaluation was performed using the Kruskal–Wallis one-way analysis of variance comparing mean values of different groups. Due to the low number of samples, calculations on statistical significance were omitted. Results are presented as arithmetic mean values with corresponding standard deviations (SD). Analytic tests were performed using Graphpad Prism Software (version 4, MacKiev Software).

3. Results

3.1. Histology

Histomorphological evaluation of the specimens showed regular cortical structures in all specimens investigated. Cancellous trabeculae were regularly structured in many cases as representatively shown in Fig. 1A, but partially also rarified, shortened to hypoplastic or coarse, which is shown for example in Fig. 1B. Histomorphological investigations evidenced explicitly higher variances in the morphology of cancellous trabeculae of irradiated individuals, appearing from hyperplastic, coarse and strongly ramified up to hypoplastic. Here, only a few sections exhibited regular trabeculae as to size, morphology and structure.

In some individuals, processes of new bone formation with overlying unmineralized osteoid on trabecular surfaces and appearance of osteoblasts could be observed (Fig. 1C), whereas only one specimen exhibited characteristics of bone resorption with resorption lacunae (Fig. 1D).

Occasionally, bone marrow, which persistently occurred as fatty bone marrow, was penetrated by hematopoietic areas with small vessels. Some samples also featured signs of fibrosis with fibrous connective tissue and infiltrating immune cells (Fig. 1E). Bone marrow emerged as sound fatty bone marrow in the subgroup without radiation, as opposed to the radiation subgroup, showing fibrous areas partly enriched with cells or even with complete fibrosis of the medullary space.