Dental Traumatology

Dental Traumatology 2011; **27**: 179–183; doi: 10.1111/j.1600-9657.2011.00977.x

Biomechanical properties of the body and angle of the sheep mandible under bending loads

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Accepted 23 December, 2010

Abstract – *Aim:* The aim of the study was to compare the body and angle of the sheep mandible in terms of bone density and biomechanical competence under bending load conditions. *Material and Methods:* Nineteen sheep mandibles were used in this study. The mandibles were separated at the symphysis into two halves. Three regions of interest on the body and angle of the hemi-mandibles were selected for measurements of bone mineral density (g cm^{-2}) by dual energy X-ray absorbtiometry. Biomechanical properties of the left mandibular body and right mandibular angle were measured by three-point bending test using a material testing machine. The load and deformation were recorded, and the load–deformation curves were obtained. The values of failure load (FL), yield load (YL), yield deformation (YD), postyield deformation (PD), stiffness, energy to yield point (EY) and energy to failure point (EF) were calculated with the analysis of load–deformation curves. Groups were compared using independent samples Student's *t*-test. *Results:* The mandibular angle exhibited the lower bone density (−64%) and biomechanical properties (FL; −45%, YL; −40%, PD; −7% stiffness, −40% EY; −48% and EF; −34%) than the mandibular body under bending loads, and there was no significant difference in values of YD between the two regions. *Conclusion:* Our results show that the mandibular angle is weaker than the mandibular body under bending loads.

The mandible is the largest and strongest bone of the face, but mandibular fractures are among the most common facial injuries (1, 2). Two main factors contribute to the mandible's high incidence of fracture. First, its incomplete ring configuration is less rigid than a complete ring, and second, its unique location makes it susceptible to inferior as well as lateral forces (3, 4). Studies have shown varying frequencies of mandibular fracture by location, but body and angle of the mandible are generally the most common fracture sites (5, 6). Mandibular fractures are commonly caused by many human activities, motor vehicle accidents, assaults, sports, falls and other causes (7, 8) and can have long-term bad consequences on patient's quality of life, both functionally and aesthetically. Therefore, it is important to know the biomechanical behaviour of the human mandible in various situations to understand the mechanism of fractures.

Bone strength and fracture resistance are determined by bone mineral density (BMD) and bone structural, mechanical and geometric properties, collectively termed bone quality (9, 10).

Direct biomechanical testing of bone provides more information about mechanical integrity (11). Fractures occur when the load on a bone exceeds the ability of the bone to carry that load (12, 13). Bone characteristics under load in vitro depend on type, rate and direction of load applied on the whole bone (14, 15). The biomechanical behaviour of the mandible under impact loads has been examined in a few studies. It was found that the mandibular regions have different biomechanical behaviour depending on the direction of load (16) and that some of them are weaker than others (16, 17).

The sheep mandible has been used for experimental studies mainly because of the similarities in format, size and structure to the human mandible (18). The purpose of this study is to compare the body and angle of the sheep mandible in terms of BMD and biomechanical competence under bending loads.

Materials and methods

Nineteen fresh mandibles obtained from domestic sheep (ovis aries) approximately 2 year old and average body weight of 40 (SD ± 5) kg from the same local abattoir were used in this study. The mandibles were cleared of all soft tissues and were separated at the symphysis into two halves. BMD measurements were performed in the body and angle of the mandible with a Hologic QDR-4500 scanner (Hologic, Waltham, MA, USA) (in the Department of Nuclear Medicine, Faculty of Medicine, Istanbul University) underneath a soft-tissue phantom solution of sodium chloride. Each hemi-mandible was positioned with the buccal side up. Analyses of the areas were carried out with the image of the bone on the screen using the regions of interest (ROIs). A region of interest was placed in approximately 10 cm^2 area over the mandibular angle between the distal aspect of the last molar and the line that passes from mandibular foramen and is parallel to occlusal plane (ROI_A). An approximately 10 cm^2 area between the distal aspect of last molar and the mesial aspect of the first premolar over the mandibular body was selected as another region of interest (ROI_B). BMD of the area (2.5 cm^2) free of tooth elements and their roots close to the inferior edge of the mandible at the bottom of the ROI_B were also measured (ROI_C). BMD were recorded in grams per square centimetre. The shape and size of ROIs were altered according to the shape of the bone images of each hemi-mandible. BMD values were calculated with vertebral software of the Hologic QDR–4500 scanner by a single operator using standardized procedures.

Following the measurements of BMD, bones were wrapped in saline-soaked gauze and stored at −20°C in closed tubes until the day of biomechanical testing. The bones were slowly thawed to room temperature for biomechanical testing. The three-point bending test was performed with a customized material testing machine (Model YKM50 TRI; Yuksel Kaya Makine, Ankara, Turkey) containing a force transducer based upon ASTM Standard D2850 (Fig. 1).

Each hemi-mandible was positioned with the buccal side up. The body of the left hemi-mandibles was placed on two lower supports that were 5 cm apart, and the angle of the right hemi-mandibles was placed in the same way. For mandibular body, the loading point was determined as the mid-point of an imaginary vertical line between premolars and molars. In the mandibular angle, the loading point was determined as the mid-point of an imaginary line that runs from gonion of the mandible to the deepest point of the retromolar fossa. The force was delivered perpendicularly by cross head at a constant deformation rate (5 mm min^{-1}) until the samples were fractured. The bending load and deformation of bone were recorded continuously. The plots of load vs deformation were obtained. These plots recorded both the elastic (linear) and plastic components separated by the yield point. The following parameters were calculated from the analysis of load–deformation curves: Failure load (FL) (N), yield load (YL) (N), yield deformation (YD) (mm), postyield deformation (PD) (mm), stiffness (S) (N mm^{-1}), energy to yield point (EY) (mJ) and energy to failure point (EF) (mJ).

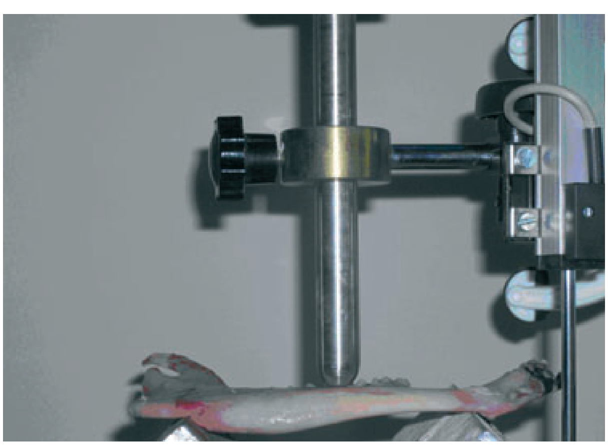

Fig. 1. Three-point bending test.

Frequency tables and statistical analyses were evaluated with SPSS, v. 16.0 (SPSS Inc. Chicago, IL, USA). The results were expressed as mean ± SD. Statistical differences between means of quantitative variables were analysed using independent samples Student's *t*-test. The Pearson correlation analysis test was used to find the correlations between the variables in each group. *P*-value of < 0.05 was regarded as significant.

Results

Bone mineral density and biomechanical measurements revealed the significant differences between the body and angle of the sheep mandible. The mean BMD values and SD of the mandibular regions are shown in Table 1. There were no significant differences in BMD between the same regions of the left and right hemi-mandibles. But significant differences were found between BMD of the different regions (ROI_A, ROI_B, ROI_C) in both hemi-mandibles ($P < 0.001$). The mean BMD of the ROI_A was 64% less than ROI_B in both right ($P < 0.001$) and left mandibles ($P < 0.001$). Also, the mean BMD of the ROI_A was 37% and 41% less than ROI_C in right ($P < 0.001$) and left ($P < 0.001$) mandibles, respectively.

In Table 2, the mean values of the experimentally determined biomechanical parameters for two regions of the mandible and the corresponding SD are shown.

Table 1. Bone mineral density (BMD) of the regions of interest (ROI_B, ROI_A, ROI_C)

BMD (g/cm^2)	ROI_B	ROI_A	ROI_C
Left (*n* = 19)	0.550 ± 0.06[1,2]	0.200 ± 0.04[2,3]	0.320 ± 0.04[1,3]
Right (*n* = 19)	0.560 ± 0.07[1,2]	0.200 ± 0.05[2,3]	0.340 ± 0.05[1,3]

Data are mean ± SD.
Diiference from ROI_A: [1]$P < 0.001$.
Diiference from ROI_c: [2]$P < 0.001$.
Diiference from ROI_B: [3]$P < 0.001$.

Table 2. Biomechanical properties of the body (ROI_B) and angle (ROI_A) of the hemi-mandible

	Body (Left)	Angle (Right)
	n = 19	*n* = 19
Yield load (N)	358 ± 54	214 ± 46*
Yield deformation (mm)	2.00 ± 0.32	1.80 ± 0.32[NS]
Energy to yield point (mJ)	319 ± 49	166 ± 36*
Stiffness (N mm^{-1})	280 ± 31	168 ± 37*
Failure load (N)	631 ± 77	346 ± 55*
Postyield deformation (mm)	3.92 ± 0.32	3.66 ± 0.45**
Energy to failure point (mJ)	622 ± 51	412 ± 51*

Data are mean ± SD, *$P < 0.001$, **$P < 0.05$, NS, not significant.
ROI, regions of interest.

The FL of the angle was 45% lower than the body ($P < 0.001$). At failure point, the mandibular angle had 7% less deformation ($P < 0.05$) and 34% less absorbed energy ($P < 0.001$) than body. These differences between the biomechanical integrity of mandibular angle and body at the failure point were similar when corresponding data were collected at the yield point. At yield point, mandibular angle had 40% less load ($P < 0.001$) and 48% less absorbed energy ($P < 0.001$) than body. No significant difference was found in YD values (Figs 2–4). Stiffness of the mandibular angle was 40% ($P < 0.001$) lower than mandibular body (Fig. 5).

Discussion

Bone mineral density and structural biomechanical properties (FL, YL, YD, PD, S, EY and EF) were assessed in two anatomically distinct regions of the sheep mandible. The BMD and biomechanical measurements revealed the significant differences between the two regions. Mandibular angle exhibited the lower bone density and biomechanical properties (FL, YL, PD, S, EY and EF) compared to the mandibular body. The sheep mandible was chosen because of similarities in size and thickness to the human mandible. The use of cadaver bone appears to be valid for extrapolation to comparable properties and behaviour of bone in the living animal, especially with fresh or deep-frozen bone (19).

Bone mineral density is the major factor for determining bone strength (20). There were no significant differences between BMD of the same regions of the right and left hemi-mandibles, but BMD of the mandibular angle (ROI_A) was significantly lower than BMD of the same and opposite side of the mandibular body (ROI_B). The difference between these regions is the presence of crowns and roots of premolars and molars which occupy a large area in the mandibular body. The lower BMD of the angle (ROI_A) may have been caused by the absense of the mineral content of the teeth, but BMD of the mandibular angle (ROI_A) was also significantly lower than BMD of the rootless region (ROI_C).

Using the three-point bending tests on both angle and body of the same hemi-mandibles were not appropriate, because bone microfractures that occur in the first test could affect the reliability of the second test on the other region of the same hemi-mandible. Therefore, we prefered the mandibular body of the left hemi-mandibles and the mandibular angle of the right hemi-mandibles for biomechanical tests. The biomechanical definition of bone fragility includes at least three components: Strength (FL), ductility (PD) and EF (10). In this study, the lower FL, PD (higher brittleness) and EF of the

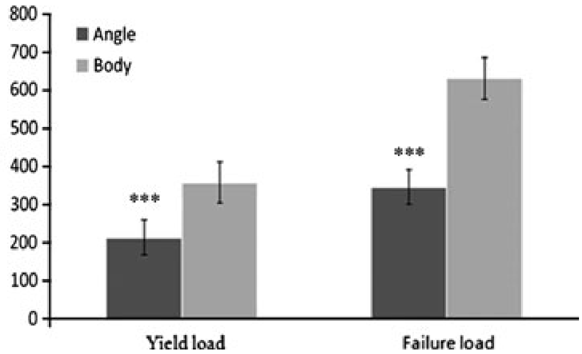

Fig. 2. The yield and failure loads of the mandibular angle and body. ***$P < 0.001$.

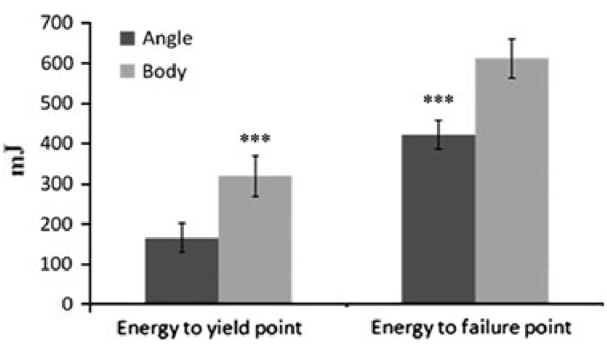

Fig. 4. Energy to yield point and energy to failure point. ***$P < 0.001$.

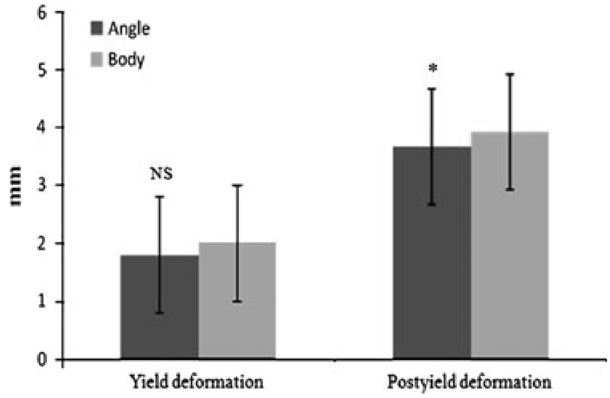

Fig. 3. The yield and postyield deformations of the mandibular angle and body. NS: not significant, *$P < 0.05$.

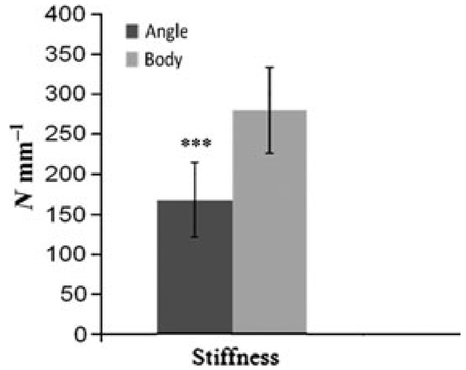

Fig. 5. Stiffness of the mandibular angle and body. ***$P < 0.001$.

mandibular angle together with the lower BMD may show that the mandibular angle is more brittle compared to the mandibular body and suggest that these regions were different from each other in terms of extrinsic biomechanical properties under bending loads.

The amount of PD that occurs in a material before fracture is a measure of the ductilty of the material (21). In this study, it suggests from the results of PD measurements that the mandibular body can accommodate permanent deformation without losing the ability to resist load, whereas the ability of the mandibular angle to resist load decreases with permanent deformation.

There were no significant differences between the YD measurements of the angle and body, but the YL of the mandibular angle that cause the same level of deformation was much lower than the mandibular body. The angle region demonstrated less absorbed energy (EY and EF) than the body region at both yield and failure point and majority of energy absorption of the angle has occurred in the postyield region. Energy absorption capacity of the mandibular angle (EY) was 40% of total energy absorption capacity (EF). But this rate was 51% in the mandibular body. These results demonstrated that the mandibular angle could absorb less energy without damaging than the mandibular body. The other biomechanical measure, stiffness, is also used to assess mechanical integrity of bones, but is not a direct measure of fragility. The bending stiffness is deduced from the elastic portion of the load–deformation curve and is known to be a measure of the mineral fraction of the bone (22, 23). The results from bending stiffness measurements in the mandibular angle, similarly to other biomechanical indices, were significantly lower than those of the mandibular body. These results suggested that the intrinsic properties of the mandibular angle may be different from the mandibular body. Other intrinsic biomechanical properties of these regions are needed to be explored in future studies.

Similar results were noted in a study that evaluated the regions of the sheep mandible under two different (lateral and ventral) impact loading directions: Under lateral loading conditions, the mandibular angle had been determined to be the weakest region of the mandible, and molar and premolar regions were found more stronger than the angle region (16). In a finite element study, the mandibular angles and condylar necks were found to be the weak areas in the mandibular geometry (17). Our results may be supported by the most common sites of mandibular fracture in human. The body (premolar region) and angle of the mandibular bone are found to be the most common fracture sites (5, 6, 24). Moreover, it has been suggested that the angle shows the higher incidence of fracture than the mandibular body (6, 25–27).

Stresses and strains are produced in the mandible as a result of external loading. Resisting forces, bending and torsional moments applied to the mandible depend not only on the nature of the external loading but also on the material properties and geometrical design of the mandible (28).

The cross-sectional geometry of the mandible has an important bearing on the understanding of its biomechanics. Knowledge about the amount and distribution of bone tissue can provide insights into the rigidity of a cross section subjected to a variety of loads. It was found that the ability of the mandible to resist stresses and strains greatly depends on the distribution of cortical bone throughout the mandibular cross section (29, 30). The cortical index and polar moments vary slightly in going from the posterior to the anterior region along the corpus. This implies that the resistance to axial loads and to shear and torsion hardly differs in the antero-posterior direction (31). In addition, a contribution to explain the difference between the two regions may be also the effects of the presence of the teeth and periodontal ligament on biomechanical behaviour of the body. The presence of teeth has a role in the rigidity of the mandibular body, and the periodontal ligament also appears to influence the stress-bearing capabilities (32).

Our data should be considered in the context of limitations: The use of sheep bones may limit the translation of these results to human mandible, and we limited our measurements with structural tests that measure how well the whole bone can bear loads. The mechanical properties of a structure depend on both its geometry and the properties of material inside. To determine the properties of the material, it is necessary to normalize out the geometric affects. In this study, it should be noted that the raw data were in terms of load vs deformation curves, as it was not possible to convert the force precisely into stress units (Nm^{-2}) as the cross-sectional area of the material varied. Similarly, EY and EF (toughness) values were not obtained in the normal units of Jm^{-3}, but in (milli) Joules.

In conclusion, this study suggests that the angle of the sheep mandible is weak and brittle when compared to the mandibular body under bending load conditions. These results outline the existence of potentially weak areas in the mandibular geometry but do cannot specifically address which region is more inclined to fracture without detailed studies will be carried out in the future. This research also may provide a useful starting point for further studies on human mandible.

Acknowledgements

We thank Dr Suleyman Dalgic and Dr Ibrahim Kusku, Department of Geological Engineering, University of Istanbul, for helpful engineering consultation. The special thank goes to technician Mr Bilal, Department of Nuclear Medicine, University of Istanbul, for technical support.

References

1. Haug RH, Prather J, Indresano AT. An epidemiologic survey of facial fractures and concomitant injuries. J Oral Maxillofac Surg 1990;48:926–32.
2. Vetter JD, Topazian RG, Goldberg MH, Smith DG. Facial fractures occurring in a medium sized metropolitan area: recent trends. Int J Oral Maxillofac Surg 1991;20:214–6.
3. Fedok FG, Van Kooten DW, DeJoseph LM, McGinn JD, Sobota B, Levin RJ et al. Plating techniques and plate orientation in repair of mandibular angle fractures: an in vitro study. Laryngoscope 1998;108:1218–24.

4. Champy M, Lodde JP, Scmitt R, Jaeger JH, Muster D. Mandibular osteosynthesis by miniature screwed plates via a buccal approach. J Oral Maxillofac Surg 1978;6:14–21.
5. Busuito MJ, Smith DJ Jr, Robson MC. Mandibular fractures in an urban trauma center. J Trauma 1986;26:826–9.
6. Ogundare BO, Bonnick A, Bayley N. Pattern of mandibular fractures in an urban major trauma center. J Oral Maxillofac Surg 2003;61:713–8.
7. Cabrini Gabrielli MA, Real Gabrielli MF, Marcantonio E, Hochuli-Vieira E. Fixation of mandibular fractures with 2.0-mm miniplates: review of 191 cases. J Oral Maxillofac Surg 2003;61:430–6.
8. El-Degwi A, Mathog RH. Mandible fractures: medical and ecenomic considerations. Otolaryngol Head Neck Surg 1993;108:213–9.
9. Hernandez CJ, Keaveny TM. A biomechanical perspective on bone quality. Bone 2006;39:1173–81.
10. Turner CH. Biomechanics of bone: determinants of skeletal fragility and bone quality. Osteoporos Int 2002;13:97–104.
11. Turner CH, Burr DB. Basic biomechanical measurements of bone: a tutorial. Bone (New York, NY) 1993;14:595–608.
12. Bouxsein ML. Mechanisms of osteoporosis therapy: a bone strength perspective. Clin Cornerstone 2003;2:13–21.
13. Bouxsein ML. Bone quality: where do we go from here? Osteoporos Int 2003;14:118–27.
14. van der Meulen MC, Jepsen KJ, Mikić B. Understanding bone strength: size isn't everything. Bone 2001;29:101–4.
15. Black J, Hastings G. Handbook of biomaterial properties, 1st edn. London: Chapman & Hall; 1998. 3–23 pp.
16. Kovan V. An assessment of impact strength of the mandible. J Biomech 2008;41:3488–91.
17. Gallas TM, Fernandez JR. A three-dimensional computer model of the human mandible in two simulated standard trauma situations. J Craniomaxillofac Surg 2004;32:303–7.
18. Uckan S, Schwimmer A, Kummer F, Greenberg AM. Effect of the angle of the screw on the stability of the mandibular sagittal split ramus osteotomy: a study in sheep mandibles. Br J Oral Maxillofac Surg 2001;39:266–8.
19. Sedlin ED. A rheological model for cortical bone. A study of the physical properties of human femoral samples. Acta Orthop Scand Suppl 1965;83(Suppl.):1–77. In: Evans FG, ed.: Mechanical properties of bone. Publication 881 American Lecture Series. Springfield, IL: Thomas, 1973.
20. Ammann P, Rizzoli R. Bone strength and its determinants. Osteoporos Int 2003;14:13–8.
21. Njeh CF, Nicholson PH, Rho J-Y. Mechanical testing. In: Langton CM, Njeh CF, editors. Physical measurement of bone. Bodmin, Gornwall, UK: MRG books Ltd; 2003. p. 133–4.
22. Burstein AH, Zika JM, Heiple KG, Klein L. Contribution of collagen and mineral to the elastic–plastic properties of bone. J Bone Jt Surg Am 1975;57:956–61.
23. Einhorn TA. Bone strength: the bottom line. Calcif Tissue Int 1992;51:333–9.
24. Kuriakose MA, Fardy M, Sirikumara M, Patton DW, Sugar AW. A comparative review of 266 mandibular fractures with internal fixation using rigid (AO/ASIF) plates or mini-plates. Br J Oral Maxillofac Surg 1996;34:315–21.
25. Fridrich KL, Pena-Velasco G, Olson RA. Changing trends with mandibular fractures: a review of 1.067 cases. J Oral Maxillofac Surg 1992;50:586–9.
26. Bither S, Mahindra U, Halli R, Kini Y. Incidence and pattern of mandibular fractures in rural population: a review of 324 patients at a tertiary hospital in Loni, Maharashtra, India. Dent Traumatol 2008;24:468–70.
27. Boole JR, Holtel M, Amoroso P, Yore M. 5196 mandible fractures among 4381 active duty army soldiers, 1980–1998. Laryngoscope 2001; 111: 1691–6.
28. van Eijden TM. Biomechanics of the mandible. Crit Rev Oral Biol Med 2000;11:123–36.
29. Smith RJ. The mandibular corpus of female primates: taxonomic, dietary and allometric correlates of interspecific variations in size and shape. Am J Phys Anthropol 1983;61:315–30.
30. Hylander WL. Implications of in vivo experiments for interpreting the functional significance of "robust" australopithecine jaws. In: Grine FE, editor. Evolutionary history of robust Australopithecines. New York: Aldine de Ruyter; 1988. p. 55–83.
31. Deagling DI. Biomechanics of cross-sectional size and shape in the homonoid mandibular corpus. Am J Phys Anthropol 1989;80:91–106.
32. Deagling DJ, Ravosa MJ, Johnson KR, Hylander WL. Influence of teeth, alveoli, and periodontal ligaments on torsional rigidity in human mandibles. Am I Phy Anthropol 1992;89:59–72.