Int. J. Morphol.,
36(3):926-930, 2018.

Biomechanical Evaluation of the Sheep Mandible as a Model for Studying Fixation Methods

Evaluación Biomecánica de la Mandíbula de Oveja como Modelo para Estudiar los Métodos de Fijación

Pedro Henrique Carvalho[1]; Milton de Siqueira F. A. Saavedra[1]; Rafael Yague Ballester[2] & João Gualberto C. Luz[2]

CARVALHO, P. H.; SAAVEDRA, M. S. F. A. 1; BALLESTER, R. Y. & LUZ, J. G. C. Biomechanical evaluation of the sheep mandible as a model for studying fixation methods. *Int. J. Morphol., 36(3)*:926-930, 2018.

SUMMARY: Recently, there has been increased interest in the use of natural jaws for better results in bone fixation studies. Thus, the sheep mandible has been chosen for such studies. The aim of this study was to evaluate the length and resistance of the sheep mandible when submitted to a compression test with freedom in the three axes of space. Seventy fresh sheep (*Ovis aries*) mandibles were used in this study. Initially, the soft tissues were removed, and measurements of the mandible size were performed. Fifty mandibles were selected for mechanical testing based on the mean values from this assessment. The mandibles were joined by fixation in the symphyseal region and were tridimensionally deformed. A metallic support suitable for study of the mandible under efforts with freedom in the three axes in space was used. For this test, three displacement cycles were applied. Based on the mean stiffness, 35 mandibles were selected. The mean value of the sheep mandible mensuration was 13.6 cm ± 0.53 cm. The mean value of the sheep mandible stiffness was 153.5N ± 54.0 N. These data are useful for future studies on fixation systems for fractures and orthognathic surgery.

KEY WORDS: Mandible; *In vitro* techniques; Biomechanical phenomena.

INTRODUCTION

The main objective of open reduction and rigid internal fixation of mandibular fractures is to achieve proper healing and immediate restoration of form and function without the use of intermaxillary fixation (Sauerbier *et al*., 2008). In addition, sagittal split osteotomy fixation has been improved to increase stability and lower morbidity and complications (Peterson *et al*., 2005; Ozden *et al*., 2006).

Many studies on the fixation systems for fractures (Goulart *et al*., 2015; de Medeiros *et al*., 2016; Pereira-Filho *et al*., 2016) or orthognathic surgery (Peterson *et al*.; Pereira-Filho *et al*., 2013; Lima *et al*., 2015) have been performed in polyurethane hemimandibles. These comprise synthetic replicas with the purpose of providing anatomical and structural patterns similar to human bone, including dense and compact cortical structures filled by a porous medullary (Ribeiro-Junior *et al*., 2010). However, we believe that the single response of the mandible under stress should be taken into account in the choice of substrate to be used in the studies, as well as the possibility of entrapment observed after fracture in the natural mandibles. In this way, animal mandibles, particularly sheep mandibles, have been used by some researchers (Alkan *et al*., 2007; Pektas *et al*., 2012; Poon & Verco, 2013). In general, these materials can be easily obtained at a reduced cost.

The sheep mandible shows a number of characteristic morphological features that indicate that the analysis of the maximal loads to which a skeletal element is subjected in vivo may explain the shape of the element (de Jongh *et al*., 1989). This includes the right and left parts that are joined rostral in the median plane by a fibrous symphysis and presents eight alveoli for the lower incisor teeth. The alveolar margin is long, curved and thin. The mandibular space is narrow, the ventral margin is slightly convex and the lateral face is oblique dorsoventrally. The alveolar margin has six alveoli for the lower molar teeth, which increase in size rostrocaudally. The mental foramen is located midway along the region of the alveolar margin. Near the junction of the body and ramus there is a ventral bony prominence of which a crest of bone extends caudally to the angle of the mandible. The ramus curves laterally in the dorsal part and is accentuated by the coronoid process. The angles curl laterally, and the lingual face presents only a small

[1] Department of Oral and Maxillofacial Surgery, School of Dentistry, University of São Paulo, São Paulo, Brazil.
[2] Department of Biomaterials and Oral Biology, School of Dentistry, University of São Paulo, São Paulo, Brazil.

mylohyoideus groove. The condylar processes are simple, and the mandibular notch is shallow. The coronoid process is extensive and curves caudally, with a thicker rostral margin (Getty *et al*., 1975).

The purpose of this study was to evaluate the length and the resistance of the sheep mandible submitted to a compression test with freedom in the three axes of the space.

MATERIAL AND METHOD

For this work, 70 fresh mandibles from 7-month-old sheep (*Ovis aries*), collected from the same abattoir, were used. The mandibles were dissected with complete removal of the soft tissues. Coronoid processes were removed bilaterally to facilitate positioning of the mandible during the experiment. This research project was approved by the local committee on animal use ethics under number 009/2015.

Initially, 50 mandibles were selected based on their sizes. This was done with a caliper based on distances from the posterior margin to the mental foramen and from the lower margin to the condyle of the mandible (Foley & Beckman, 1992). Subsequently, 35 mandibles were selected based on initial stiffness analysis (Landgraf, 2008). The mandibles were stored wrapped with compresses soaked in saline solution and stored at -20 °C (Pimentel, 2013). The samples were thawed in saline solution at room temperature between 16 and 25 °C.

The mandibles were subjected to fixation with two screws in the anterior portion to the mental foramen. This fixation was carried out according to the pattern of the lag screw to maintain a rigid assembly of the two hemi-mandibles (Fig. 1). Subsequently, acrylic resin was adapted over a half-round section of tube (rigid polyvinyl chloride - PVC). This PVC base served as a sliding holder in each assay (Fig. 2) for the anterior region of the mandible. A thin layer of acrylic resin was placed in the region of the angles, for better adaptation of the metal rod and to avoid slips. After correct positioning of the mandible and centralization of the apparatus on the universal testing machine, the mechanical testing was executed.

A rigid metal support mounted on bearings capable of allowing the movement of the whole mandible was used, while preserving the alignment of the load application point with the cross head of the testing machine throughout the test (Landgraf) (Fig. 3). The load was applied on the central sliding bearing, which was mounted in a rigid metal bar with three sliding bearings. The anterior region of the mandible was then supported over a rolling bearing to allow the deformation of the mandibles by increasing the angle between the body and the ramus to mimic the freedom of functional movement of a human mandible. Both condylar processes were supported in a holder that mimicked the mandibular fossae, which allowed only spinning. The mandible was free in all other regions. The positioning of the mandible in the apparatus occurred at three points of support: the condyle of the mandible and the anterior region. The load application occurred bilaterally in the region between the mandibular body and angle, which is the area with the greatest muscle insertion, as represented by the region of the masseter muscle. The direction of the force applied was approximate to that of the masseter fibers.

Fig. 1. Fixation with screws in the anterior portion to the mental foramen.

Fig. 2. Mandible ready for the test, with sliding holder in the anterior region and thin layer of acrylic resin in the region of the angles.

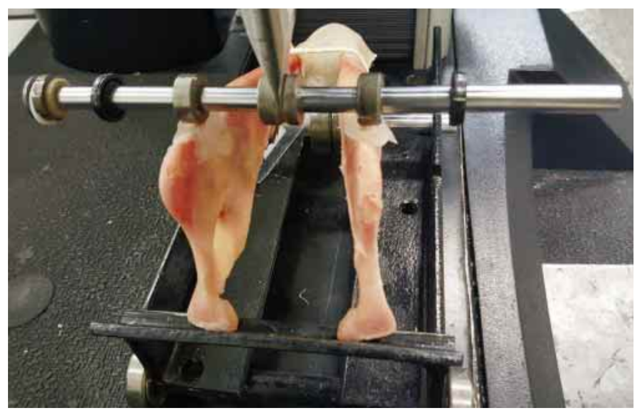

Fig. 3. Mandible positioned in the load application device.

After correct positioning of the mandible and centralization of the metallic support, the mechanical test was performed in a universal testing machine, Instron 5565 (Illinois Tool Works Inc., Norwood, MA, US). The load and crosshead displacement data were recorded during the test, thus allowing the creation of a load versus displacement graph. The mandibles were subjected to testing for rigidity in a non-destructive test. Three displacement cycles were applied at a rate of 0.07 mm/s for loading and 0.14 mm/s for unloading with an interval of 120 s between each cycle. The first displacement was 0.25 mm, the second was 0.5 mm and the third was 0.75 mm (Fig. 4). The waiting time for the mandible to return to the starting position was two minutes. To calculate the mandibular stiffness, the third cycle was adopted as a standard because it had better uniformity in the graphic layout, possibly due to a better accommodation of the jaw on the metal apparatus (Landgraf). The formula a = y/x, where a = stiffness, y = load, and x = displacement, was used for analysis.

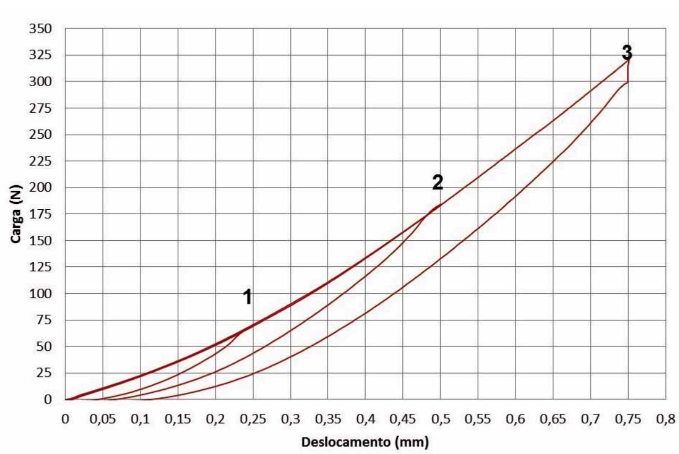

Fig. 4. Illustrative image demonstrating the three cycles of vertical displacement performed by the Instron machine of a mandible. 1 = first cycle; 2 = second cycle; 3 = third cycle. Load (N) x displacement (mm).

RESULTS

Size of the sheep mandible. Seventy mandibles were measured, and the smallest mandible was 12.5 cm and the largest 14.8 cm. The mean size of all mandibles was 13.62 cm, with a standard deviation of 0.54 cm.

The mandibles that had values higher than the sum of the mean plus the standard deviation and those that had values lower than the subtraction of the standard deviation from the mean value were discarded, resulting in 50 selected mandibles.

Stiffness of the sheep mandible. The mechanical assay was performed with 50 mandibles. The lowest stiffness value found was equal to 36.12 N and the highest stiffness value found was 264.93 N. The mean stiffness value of all mandibles was equal to 153.55 N and the standard deviation was equal to 54.06 N.

The mandibles that had values higher than the sum of the mean plus the standard deviation and those with values less than the subtraction of the standard deviation from the mean value were discarded, resulting in 35 selected mandibles.

DISCUSSION

To evaluate the length and resistance of the sheep mandible submitted at the compression test with freedom in the three axes of the space, this study found a mean value of its size. With the measurement of the distances posterior margin - mental foramen and lower margin - condyle of the mandible (Foley & Beckman), it was possible to select mandibles close to the mean. Next, the rigidity of the sheep mandible was evaluated by a mechanical test, and an average value was found. With this value it was possible to select the mandibles that performed close to the average value (Landgraf). Thus, representative values of this species were obtained that could be used in studies of fixation in investigations of fractures and orthognathic surgery. The use of fresh mandibles appears to be valid for extrapolation to comparable properties of bone in the living animal (Wittenberg *et al*., 1997).

Polyurethane hemimandibles have been used in many studies regarding fixation systems for fractures or orthognathic surgery (Goulart *et al*.; de Medeiros *et al*.; Pereira-Filho *et al*., 2013, 2016; Peterson *et al*.; Lima *et al*.). However, the natural mandible has a single response under stress that should be taken into account in the choice of substrate to be used in the studies, and this presents the possibility of entrapment observed after fracture. The mandible has the ability to flex inwards around the mandibular symphysis with changes in shape and decreases in mandibular arch width during opening and protrusion of the mandible. This movement, which ranges from a few micrometers to more than 1 mm, occurs due to the contraction of lateral pterygoid muscles that pulls the condyle of the mandible medially and causes a sagittal movement of the posterior segments (Sivaraman *et al*., 2016). In addition, during biting and the power stroke of mastication, a combination of sagittal bending, corpus rotation, and transverse bending occurs. The result is a complex pattern of stresses and strains in the mandible, including compressive, tensile, shear, and torsional forces (van Eijden, 2000).

Most studies have used models with a cantilever setup, in which one end of the specimen is held rigidly fixed and the load is applied at the other end. Comparative studies on these mechanical fixing methods have been carried out and characterized in hemi-mandibles that are fixed in the condylar process, and the force is applied in the molar region (Ribeiro-Junior *et al*.; Pektas *et al*.). Therefore, a single movement is allowed, and the effects are limited. We must take into account that when using the entire mandible, we can promote a more reliable simulation with freedom in the three axes in space, which is impossible when using hemi-jaws. The sheep mandible has been chosen for these studies because of its similarities in size and thickness to the human mandible (Wittenberg *et al*.). A few studies that used the entire mandible included mechanical tests with the possibility of applying homolateral and contralateral levers (Pereira-Filho *et al*., 2013; Trivellato *et al*., 2014). Finally, we must consider that a metallic support on bearings was used for the mechanical test, allowing the movement and deformation of the mandibles as a whole during the application of the load, to imitate the freedom of functional movement of a human mandible, docked in the mandibular cavities and free in all other regions (Landgraf).

This study evaluated the length and the resistance of the sheep mandible submitted to a compression test with freedom in the three axes of the space, and we believe that these data will be useful for future studies on fixation systems for fractures and orthognathic surgery when testing the resistance of types of fixation by plates and screws to be used.

CARVALHO, H. P.; SAAVEDRA, M. S. F. A. 1; BALLESTER, R. Y. & LUZ, J. G. C. Evaluación biomecánica de la mandíbula de oveja como modelo para estudiar los métodos de fijación. *Int. J. Morphol., 36(3)*:926-930, 2018.

RESUMEN: Recientemente, ha aumentado el interés en el uso de mandíbulas naturales para obtener mejores resultados en estudios de fijación ósea. Por lo tanto, la mandíbula de las ovejas se ha elegido para tales estudios. El objetivo de este estudio fue evaluar la longitud y la resistencia de la mandíbula de oveja al ser sometida a una prueba de compresión con libertad en los tres ejes del espacio. Se utilizaron 70 mandíbulas de oveja fresca (*Ovis aries*). Inicialmente, se extirparon los tejidos blandos y se realizaron mediciones del tamaño de la mandíbula. Cincuenta mandíbulas fueron seleccionadas para pruebas mecánicas basadas en los valores promedio de esta evaluación. Las mandíbulas se unieron por fijación en la región sinfisial y se deformaron tridimensionalmente. Se utilizó un soporte metálico adecuado para el estudio de la mandíbula bajo esfuerzos con libertad en los tres ejes en el espacio. Para esta prueba, se aplicaron tres ciclos de desplazamiento. En base a la rigidez media, se seleccionaron 35 mandíbulas. El valor medio de la medición de la mandíbula de oveja fue de 13,6 cm ± 0,53 cm. El valor medio de la rigidez de la mandíbula de oveja fue 153,5 N ± 54,0 N. Estos datos son útiles para futuros estudios sobre sistemas de fijación para fracturas y cirugía ortognática.

PALABRAS CLAVE: Mandíbula; Técnicas *In vitro*; Fenómenos biomecánicos.

REFERENCES

Alkan, A.; Metin, M.; Muglali, M.; Ozden, B. & Celebi, N. Biomechanical comparison of plating techniques for fractures of the mandibular condyle. *Br. J. Oral Maxillofac. Surg., 45(2)*:145-9, 2007.

de Jongh, H. J.; Dantuma, R. & Sluijsmans, H. M. The shape of the mandible in the domestic sheep: a biomechanical analysis using EMG as an estimator of muscle force. *Acta Morphol. Neerl. Scand., 27(1-2)*:63-73, 1989.

de Medeiros, R. C.; Sigua, E. A.; Navarro, P.; Olate S. & Albergaria Barbosa, J. R. *In vitro* mechanical analysis of different techniques of internal fixation of combined mandibular angle and body fractures. *J. Oral Maxillofac. Surg., 74(4)*:778-85, 2016.

Foley, W. L. & Beckman, T. W. *In vitro* comparison of screw versus plate fixation in the sagittal split osteotomy. *Int. J. Adult Orthodon. Orthognath. Surg., 7(3)*:147-51, 1992.

Getty, R.; Sisson, S. & Grossman, J.D. *Sisson and Grossman's. The Anatomy of the Domestic Animals.* 5th ed. Philadelphia, Saunders, 1975.

Goulart, D. R.; Kemmoku, D. T.; Noritomi, P. Y. & de Moraes, M. Development of a titanium plate for mandibular angle fractures with a bone defect in the lower border: finite element analysis and mechanical test. *J. Oral Maxillofac. Surg., 6(3)*:e5, 2015.

Landgraf, H. *Avaliação da Estabilidade na Fixação da Osteotomia Sagital Mandibular Utilizando Parafusos Bicorticais Inseridos com Angulação de 60o E 90o. Estudo Biomecânico em Mandíbulas de Carneiro.* Masters Dissertation. São Paulo, Faculdade de Odontologia da Universidade de São Paulo, 2008.

Lima, C. J.; Falci, S. G.; Rodrigues, D. C.; Marchiori, É. C. & Moreira, R. W. Mechanical and photoelastic analysis of conventional screws and cannulated screws for sagittal split osteotomy fixation: a comparative study. *Oral Maxillofac. Surg., 19(4)*:397-402, 2015.

Ozden, B.; Alkan, A.; Arici, S. & Erdem, E. *In vitro* comparison of biomechanical characteristics of sagittal split osteotomy fixation techniques. *Int. J. Oral Maxillofac. Surg., 35(9)*:837-41, 2006.

Pektas, Z. O.; Bayram, B.; Balcik, C.; Develi, T. & Uckan, S. Effects of different mandibular fracture patterns on the stability of miniplate screw fixation in angle mandibular fractures. *Int. J. Oral Maxillofac. Surg., 41(3)*:339-43, 2012.

Pereira-Filho, V. A.; Iamashita, H. Y.; Monnazzi, M. S.; Gabrielli, M. F.; Vaz, L. G. & Passeri, L. A. *In vitro* biomechanical evaluation of sagittal split osteotomy fixation with a specifically designed miniplate. *Int. J. Oral Maxillofac. Surg., 42(3)*:316-20, 2013.

Pereira-Filho, V. A.; Oliveira, L. F.; Reis, J. M.; Gabrielli, M. A.; Neto, R. S. & Monnazzi, M. S. Evaluation of three different osteosynthesis methods for mandibular angle fractures: Vertical load test. *J. Craniofac. Surg., 27(7)*:1770-3, 2016.

Peterson, G. P.; Haug, R. H. & Van Sickels, J. A biomechanical evaluation of bilateral sagittal ramus osteotomy fixation techniques. *J. Oral Maxillofac. Surg., 63(9)*:1317-24, 2005.

Pimentel, L. F. R. O. *Estudo Biomecânico de Flexão (Ex-Vivo) em Osteotomia no Diastema de Mandíbulas de Eqüinos Estabilizada* *com Placas Bloqueadas e Implantes Transdentários.* Doctor's Thesis. São Paulo, Faculdade de Medicina Veterinária e Zootecnia da Universidade de São Paulo, 2013.

Poon, C. C. & Verco, S. Evaluation of fracture healing and subimplant bone response following fixation with a locking miniplate and screw system for mandibular angle fractures in a sheep model. *Int. J. Oral Maxillofac. Surg., 42(6)*:736-45, 2013.

Ribeiro-Junior, P. D.; Magro-Filho, O.; Shastri, K. A. & Papageorge, M. B. *In vitro* evaluation of conventional and locking miniplate/screw systems for the treatment of mandibular angle fractures. *Int. J. Oral Maxillofac. Surg., 39(11)*:1109-14, 2010.

Sauerbier, S.; Schön, R.; Otten, J. E.; Schmelzeisen, R. & Gutwald, R. The development of plate osteosynthesis for the treatment of fractures of the mandibular body - a literature review. *J. Craniomaxillofac. Surg., 36(5)*:251-9, 2008.

Sivaraman, K.; Chopra, A. & Venkatesh, S. B. Clinical importance of median mandibular flexure in oral rehabilitation: a review. *J. Oral Rehabil., 43(3)*:215-25, 2016.

Trivellato, P. F.; Pepato, A. O.; Ribeiro, M. C.; Sverzut, C. E. & Trivellato, A. E. *In vitro* evaluation of the resistance of a 2.0-mm titanium fixation system in the sectioned angle without continuity of the inferior border of the mandible. *Int. J. Oral Maxillofac. Surg., 43(5)*:559-63, 2014.

van Eijden, T. M. Biomechanics of the mandible. *Crit. Rev. Oral Biol. Med., 11(1)*:123-36, 2000.

Wittenberg, J. M.; Mukherjee, D. P.; Smith, B. R. & Kruse, R. N. Biomechanical evaluation of new fixation devices for mandibular angle fractures. *Int. J. Oral Maxillofac. Surg., 26(1)*:68-73, 1997.

Corresponding author:
João Gualberto C. Luz
Rua Duarte de Azevedo, 284 – cj. 22
02036-021, São Paulo
São Paulo
BRAZIL

Email:jgcluz@usp.br

Received: 17-04-2017
Accepted: 10-03-2018