COMPARATIVE MORPHOLOGICAL ANALYSIS REGARDING THE HUMAN AND CANINE MASTICATORY APPARATUS AND THE EQUIVALENT BIOLOGICAL MECHANISM TO DOG BIOMECHANISM

Ruxandra Elena LUCA, University of Medicine and Pharmacy "Victor Babes" of Timisoara, Oral Rehabilitation and Dental Emergencies Department, luca.ruxandra@umft.ro
Iulian POPESCU, University of Craiova, member of the Romanian Academy of Technical Sciences
Liliana LUCA, "Constantin Brancusi" University of Targu Jiu, lylyanaluca@gmail.com

ABSTRACT: *A comparative morphological analysis of the masticatory apparatus of man and dog is presented. We start from the anatomical data of the masticatory apparatus and from the possible movements of these biological mechanisms. The paper proposes a biological mechanism equivalent to the biomechanism of the dog. The created mechanism can be used in the construction of some medical prostheses, in the construction of the gripping mechanisms of the robots, etc.*

KEYWORDS : masticatory apparatus, human, canine, biological mechanism

1. INTRODUCTION

The living world has become in recent decades a vast field of study for specialists in biomechanics, bionics, industrial robots and medical prostheses, as the constructive solutions found by living beings are optimal and they are based on a long evolution. Thus, the specialized literature offers many works in which are presented interesting studies made on different animals. In Romania, research in the field of bionics and biomechanics are given in the papers published by Wittenberger, Opriş, Popescu, Dudita and others [1, 2, 3, 4]. Also, many studies in the field of gripping biomechanisms have been noted [5, 6, 7, 8]. The study of biosystems has allowed the determination of biological mechanisms that are interesting and high-performance constructive solutions for industrial robots, medical prostheses, some toys, etc.

For instance, the temporomandibular joint (TMJ) is a cardinal feature that defines the class Mammalia and separates mammals from other vertebrates. Regarding its late evolutionary origin, the TMJ makes a tardy developmental appearance [9]. As Herring [10] emphasizes very well in his research, despite its status as a mammalian identifier, the TMJ shows remarkable morphological and functional variation in different species, reflecting the great mammalian adaptive character in feeding mechanisms. The majority of the anatomical differences in TMJs (loss of disc, variations in the orientation of the joint cavity etc.) are clearly in relation to biomechanics. The features mentioned above are either correlated to loading (e.g., size of articular surfaces) or to movement (e.g., orientation of the joint) or both. Opening of the jaw usually involves a combination of forward sliding and rotation around a transverse axis, but some carnivores have lost the ability to slide; instead of this, some use a rotation around the long axis of the curved mandible [11]. Similarly, transverse movement is usually accomplished by moving one condyle forward and the other one backward, but carnivores use a combination of lateral sliding and rotation around the long axis of the mandible [12].

The human masticatory system is a typical example of a kinematically and mechanically indeterminate system. The two segments, the mandible and the skull, are able to move with respect to each other, being guided by two mutually linked temporomandibular joints. Each temporomandibular joint is composed of a mandibular condyle which articulates incongruently with the articular surface of the temporal bone. This construction of both joints allow for movements with six degrees of freedom [13], which implies that these movements are not limited to rotations about one or more axes defined by the joint [14]. Therefore, if we assume that the joint surfaces are undeformable and maintain contact all the time, the mandible is still able to move with four degrees of freedom [15].

The number of biological models is very large and they are currently being studied more and more, in order to find new models that can be used in different fields. In some technical cases, not all movements from the natural biosystem are necessary, therefore some movements (certain movements of the joints, for example) are abandoned and simplified technical models are created.

In this paper the authors present the morphological and biomechanical analysis of the masticatory apparatus of human and dog, as well as an equivalent biological mechanism to the biomechanism of the dog. Similar studies have been performed on the human masticatory apparatus [16, 17].

2. MORPHOLOGICAL ANALYSIS OF THE HUMAN AND CANINE MASTICATORY APPARATUS

a) Human masticatory apparatus

Humans have a gripping biomechanism which is represented by the oral cavity (masticatory apparatus). The role of this biomechanism is the grinding of food, the formation of the food bowl, the swallowing of the food and the development of the articulate language.

The movements performed by this biomechanism are possible by the existence of the temporo-mandibular joint, which is the only mobile joint that joins the bones of the skull, and compared to other mobile joints of the human body, it is the most evolved and the most frequently used.

Regarding the temporo-mandibular joint, *three types of movements can be performed in humans: downward and upward movement of the mandible, forward-backward projection movements (propulsion-retropulsion) and laterality movements (anteduction-retroduction).*

In fig. 1 it is given a skull, where the temporo-mandibular joint is observed, which is a condylar type joint.

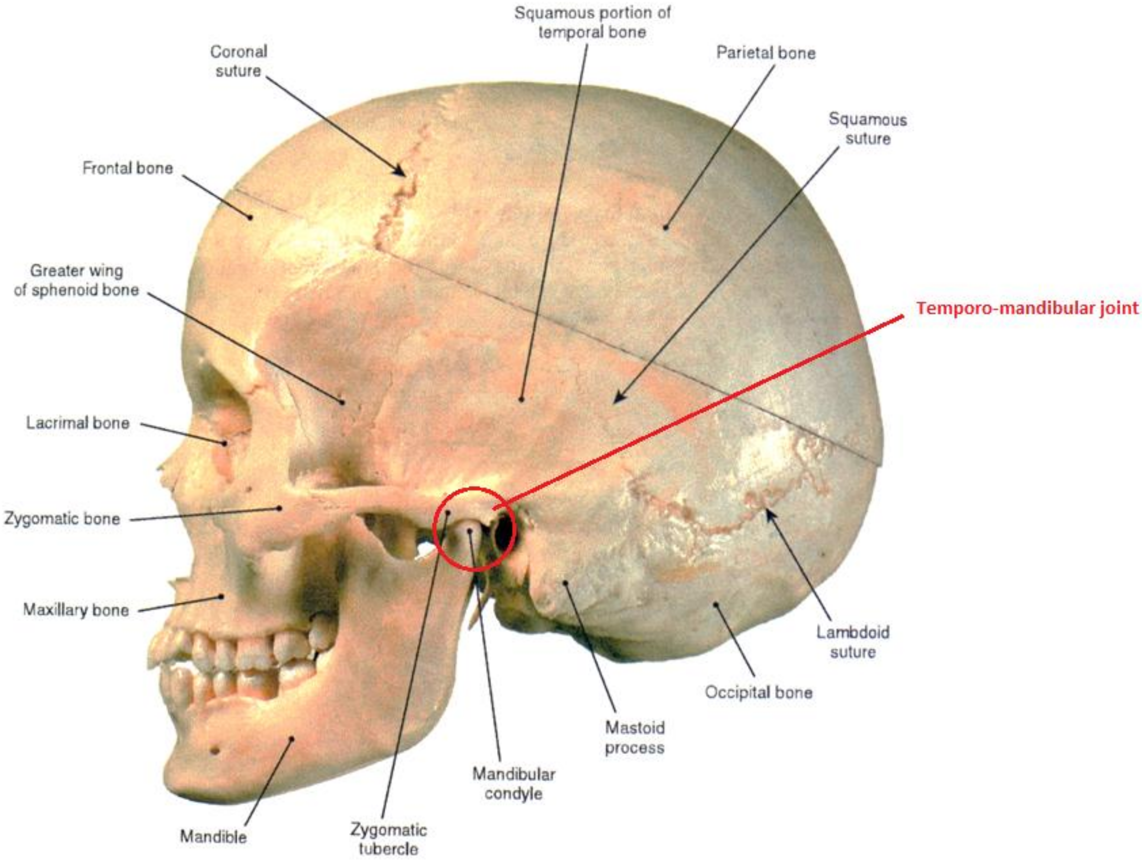

Fig.1. Human skull [after 18], with highlighting (red circle) the temporo-mandibular joint

The articular surfaces of the temporo-mandibular joint are: the mandibular fossa, the articular tubercle, the head of the mandible, the articular disc.

The mandibular fossa is presented as a semi-ellipsoidal depression with the oblique axis oriented from front to back and from the outside inwards.

The articular tubercle presents as a protrusion located in front of the mandibular fossa. This tuber is convex in front and slightly concave in the transverse direction.

The head of the mandible is ellipsoid in shape. Each condyle is located at the postero-superior part of the mandibular branch by which it is joined by a narrower portion. On each mandibular head two slopes are observed: one anterior and one posterior. From their meeting a ridge is formed parallel to the great axis of the head of the mandible. Only the anterior slope and ridge constitute articular surfaces.

The articular disc is a fibrocartilage developed between the articular surfaces in order to restore concordance between them. It is elliptical in shape and has a concave lower part corresponding to the convexity of the mandibular head and an upper one in the shape of the lying letter S.

The complex functioning of the temporo-mandibular joint in humans is ensured by the skeletal muscle system having two bone inserts, one on the mandible. The four masticatory muscles are the motor muscles of the mobile bone of the skull (mandible). The 4 masticatory muscles themselves with the exclusive mobilizing role of the mandible, are:

- the temporalis muscle;
- the masseter muscle;
- the medial pterygoid muscle;
- the pterygoid muscle;

The 6 elementary movements of the mandible are made with the unequal participation of the masticatory muscles, their main force being necessary to raise the mandible and the lateral pterygoid has a special role in the propulsion and in the lateral movement.

The *downward of the mandible* is initiated by the bilateral contraction of the lateral pterygoids, through which the head of the mandible together with the articular disc are removed from the mandibular fossa and placed under the articular tubercle. The movement is continued by the intervention of the suprahyoid muscles and the weight of the mandible. The opening of the mouth can be done in reverse also, the mandible being fixed and the skull overturning back by actuating the neck muscle. The downward movement of the mandible is performed in three stages:

- Stage I: It consists of performing a rotational movement of the condyle on the meniscus around a transverse axis that passes through the center of the condyles and corresponds to the inferior insertion of the temporomandibular ligament. The movement is of the 'hinge' type and the mouth opens with approximately 2-4 mm;
- Stage II: It consists of performing two movements in TMJ: one of condylo-meniscal rotation and another of temporo-meniscal translation. The sum of the two movements (rotation, translation) determines the opening of the mouth by 4 centimeters.
- Stage III: It is performed additionally and voluntarily. At the end of stage II, the internal masseter and pterygoid muscles are stretched to the maximum and their fibers become parallel to the ascending branch of the mandible. When these muscles suddenly relax, the external pterygoid muscles contract which pull back from the small arm of the mandibular lever and also pull the meniscus forward. The forward translational movement of the meniscus and the backward rotational movement of the condyle occur.

The *upward/lifting of the mandible* is produced by the tri-muscular complex (temporalis, masseter, medial pterygoid). For the upward of the mandible during speech, the action of the temporalis alone is sufficient. The force of the lifts is manifested between the two dental arches as masticatory pressure and not as pressure in the joint.

Propulsion (anterior projection) is done by simultaneous contraction of the lateral pterygoids. *Retropulsion (posterior projection)* is done through the posterior bundle of the temporalis. The propulsion movement of the mandible is performed by translating the meniscus and the condyle. The propulsion movement must be accompanied by a downward movement of the mandible. The amplitude of the lowering movement of the mandible depends on several factors. In maximum propulsion, the anterior slope of the articular condyle presses on the meniscus and the articular tubercle. The retropulsion of the mandible is done by sliding back the meniscus and the condyle and it is done along a horizontal or an oblique plane that makes an angle of 40°-45° with the occlusal plane.

Laterality movements are movements that are made horizontally and are performed asymmetrically. They follow each other alternately to the right and to the left. The head of the mandible and the active hemi-arch rotate in place. The lateral movements of the mandible are made by sliding the condyle and the meniscus on one side and the condyle on the opposite side remains in place or slides slightly back. If the interincisive line moves to the right, the condyle and meniscus on the left side move forward, downward and inward, forming an angle of 15 ° with the mid-sagittal plane. The condyle on the right side stands still or moves very little back and forth and represents the vertical axis around which this lateral movement is made to the right. Then follows the lateral movement to the left, when the left condyle acts as a pivot. The amplitude of the lateral movements decreases with the opening of the mouth or with the retropulsion of the mandible.

b) *The canine masticatory apparatus*

The dog (canis familiaris) belongs to the *Canidae* family, the Carnivora superorder, Mamalia class. In fig. 2 it is given the skeletal system of a canine skull comprising the masticatory apparatus.

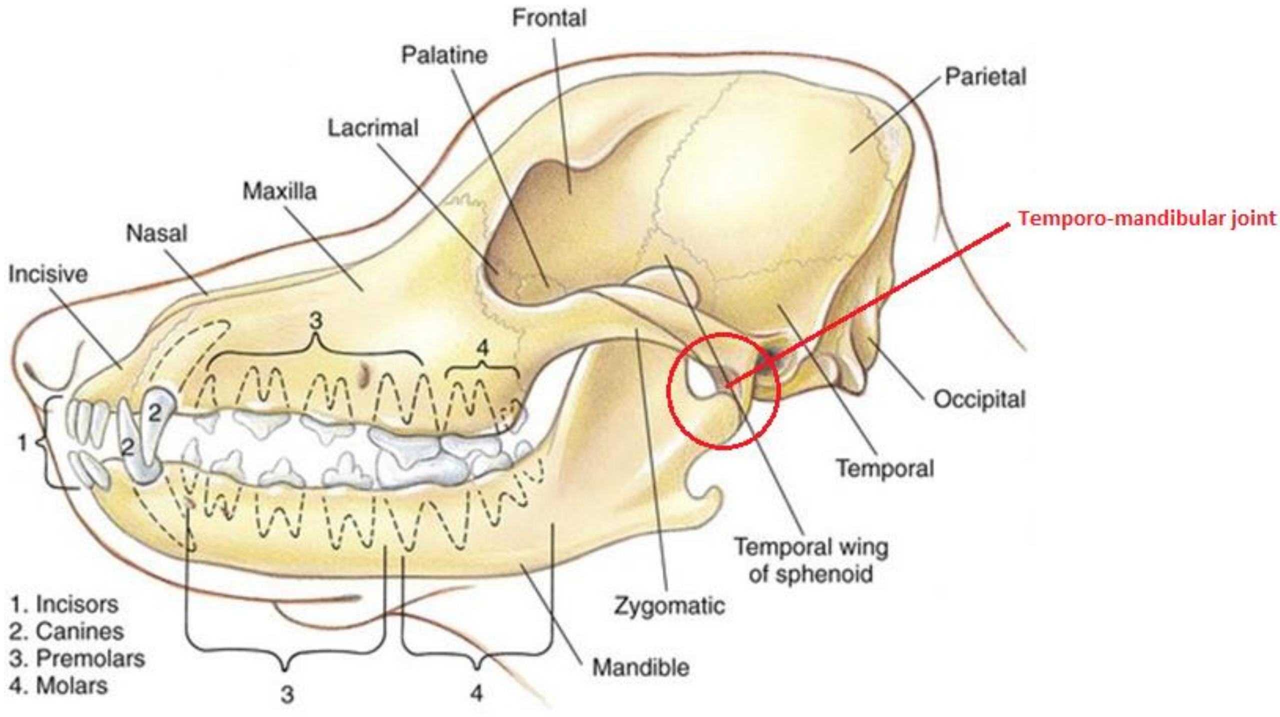

Fig.2. The canine masticatory apparatus [after 19], with highlighting (red circle) the temporo-mandibular joint

Two bilateral bones barely attached to each other by strong fibers at the intermandibular joint comprise the mandible and are called the symphysis. The horizontal ramus (body of the mandible) has teeth (pars incisive and pars molaris), and the vertical ramus (ramus of the mandible) contains the coronoid, condyloid, and angular processes [20]. The canine jaw has certain peculiarities. The incisor portion is thick, short, and comprises 3 alveoli for incisors, which are oriented obliquely and whose dimensions increase laterally, followed immediately by the alveolus of the canine, which is spacious, deep and aburally curved. The lingual face is slightly convex. The height of the mandible body remains constant until the junction with the mandible branch. The molar alveoli increase to the fifth and decrease to the next two. On the branch of the mandible, the masseter fossa is highlighted, as being very deep.

The body of mandible has an evident medullar cavity called the mandibular canal that begins at the mandibular foramen in the ventral face near the angle of the mandible and opens at two or three mental foramina rostrally in the lateral face of the mandible. Between the two horizontal rami, there is a space called the intermandibular space, where the tongue, pharynx, cranial portion of larynx, and hyoid apparatus are located [20]. The condylar process has a convex articulated surface, medially inclined and very elongated in the transverse direction. The highly developed coronoid process has the free extremity almost as wide as its base. The rostral edge of the coronoid process is thick and convex. The sigmoid notch is narrow and shallow.

The articular (condylar) process of the mandible and the mandibular fossa of the temporal bone form the temporomandibular joint. A cartilaginous disk divides the joint into two cavities: dorsal (or temporal) and ventral (or mandible) [20, 21, 22]. The joint is covered by a capsule that is attached around the joint surfaces, with synovial fluid inside. Fibrous tissue is present around the capsule, forming a ligament laterally. The movements of this joint are limited by all these structures [20, 23].

The perpendicular anatomic shape of the condylar process in dogs is the most important characteristic permitting only vertical movement of this joint [24]. In carnivorous animals, in general, *the possible movements due to the temporomandibular joint are only the lowering and lifting of the mandible (opening - closing).* Characteristically, the cartilaginous disk is fibrous and thin, but with evident rostral thickness to avoid anterior luxation during substantial vertical movements [20].

3. BIOLOGICAL MECHANISM EQUIVALENT TO THE CANINE BIOMECHANISM

To determine the equivalent biological mechanism we relied on data from the literature regarding the anatomy, morphology and biomechanics of the temporomandibular joint of the mammal-dog [20, 25, 26].

In the elaboration of the equivalent biological mechanism the following three principles are taken into account: the kinematic elements of the bionic mechanism are considered rigid; the number and order of the elements are kept; the mobilities of the joints of the biomechanism are preserved.

The possible fundamental movements of the mandible are: a) the opening-closing movement (lowering-lifting); b) propulsion-retropropulsion movement; c) laterality movement. The movement of the segments refers to a system consisting of three reference planes: frontal, sagittal and transverse. In biomechanics studies, two possible elementary motions are considered: the translational motion and the rotational motion. All the other movements of the body segments, such as the roto-translation, pivoting, plane-parallel movements, etc., are obtained by combining the elementary ones, considered in the plane or in space.

The equivalent biological mechanism proposed for the canine masticatory apparatus is given in figure 3. The mandible is considered to be a space bar. The temporomandibular joint (TMJ) of the dog allows only one type of movement, opening-closing. The result is a space mechanism with 2 (A and B) rotation couplings, corresponding to the two TMJs, on the left and right of the skull.

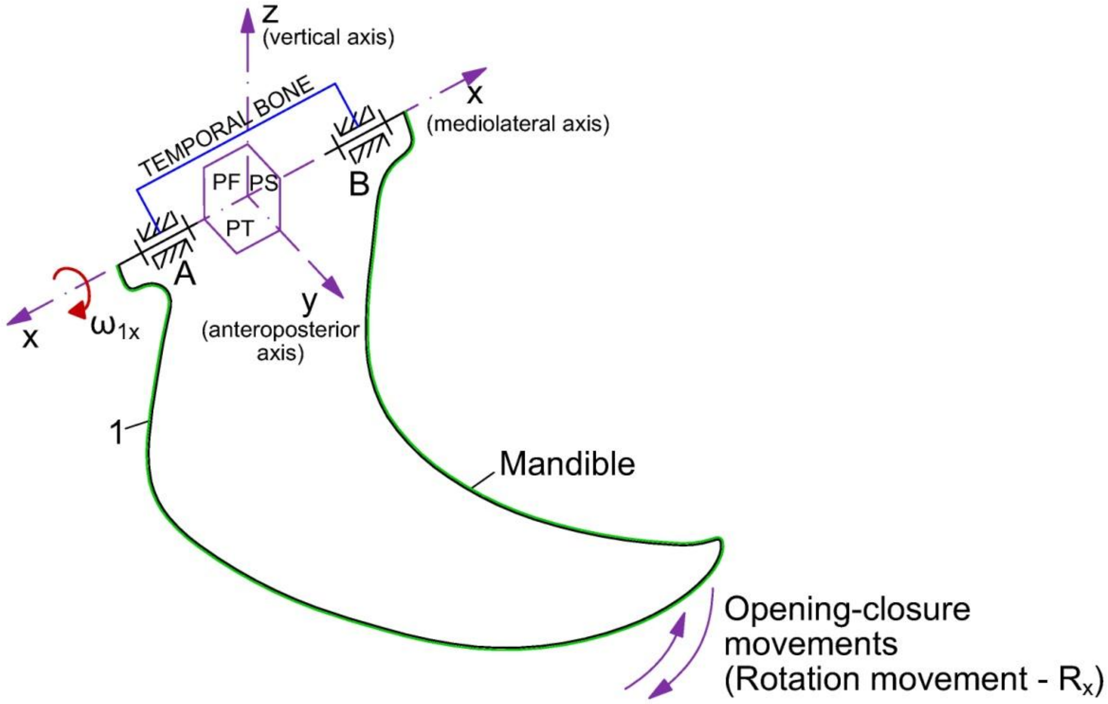

Fig. 3. Equivalent mechanism – dog

The degree of mobility of the mechanism depends on the number of kinematic elements and couplings and on certain geometric conditions that impose certain restrictions. The degree of mobility of the mechanism in figure 3 is determined based on the formula of Dobrovolski:

$$M = (6 - f)n - \sum_{i=f+1}^{5} (i - f)C_i \qquad (1)$$

where f is the family number of the mechanism, n is the number of moving elements of the mechanism and C_i is the number of kinematic couples of class i.
The movements performed by the elements of the mechanism are summarized in table 1.

Table 1

Movements / Elements	ω_x	ω_y	ω_z	V_X	V_Y	V_Z
1- mandible	ω_{1x}	-	-	-	-	-
Family: f=5	ω_x	-	-	-	-	-

It is found that there is only one movement (rotational movement ω_x), missing 5 movements, so the family of the mechanism is f = 5 and by applying the formula (1) results M = n = 1. The rotation torque in B is structural the parasitic torque and it is not considered in the calculation of the degree of mobility.

4. CONCLUSIONS

Through the methods of the theory of mechanisms and the rules of invention, many variants of biological mechanisms equivalent to some biomechanisms can be found. Canine masticatory apparatus, with a much simpler biomechanics than the human one, offer models for technical mechanisms. The mechanism proposed in this paper can be used to build medical prostheses, robots, toys, etc. Also, this mechanism can be calculated with the usual methods from the theory of mechanisms.

REFERENCES

[1] Dudiţă F. et.al., - *Mecanisme articulate. Inventica, Cinematica*. Ed. Tehnica, Bucureşti, 1987

[2] Opriş T., - *Bios*. Ed.Albatros, Bucureşti, 1986

[3] Popescu I. et.al., - *Mecanisme biologice*. Editura Sitech, Craiova, 1997

[4] Witenberger C., Keul M., - *Mecanismele mişcării în lumea vie.* Ed. Academiei R.S.R., Bucureşti, 1987

[5] Stareţu I., - *Mecanisme de prehensiune.* Ed. Lux Libris Braşov, 1996

[6] Popescu I., Luca L., - *Biomecanisme de prehensiune.* Ed Scrisul romanesc, Craiova, 2000

[7] Luca L., Popescu I., Ghimisi S., - *Prehensile and stepping mechanisms for robots, based on biomechanisms.* Book Series: Advanced Materials Research Volume: 463-464, 2012, pp. 877-880.

[8] Luca L., Popescu I., Luca R.E., - *A biological gripping mechanism equivalent with the biomecanism of the human.* Fiability & Durability, No.1, 2019 pp. 68-72.

[9] Smith K.K. - *The evolution of mammalian development.* Bull Mus Comp Zool 2001; 156:119-135.

[10] Herring S.W., - *TMJ anatomy and animal models.* J Musculoskelet Neuronal Interact. 2003;3(4):391-407

[11] Naples V.L., - *Morphology, evolution and function of feeding in the giant anteater* (Myrmecophaga tridactyla), J Zool 1999; 249:19-41

[12] Scapino R.P., - *The third joint of the canine jaw*. J Morphol 1965; 116:23-50.

[13] Koolstra J.H, van Eijden T.,- *Three-dimensional dynamical capabilities of the human masticatory muscles*. J Biomech 1999;32:145–52.

[14] Andrews J.G. Hay J.G. - *Biomechanical considerations in the modeling of muscle function.* Acta Morphol Neerl Scand 1983; 21:199–223.

[15] Gaivile Pileicikiene, Algimantas Surna, - *The Human Masticatory System From A Biomechanical Perspective:* A Review, Stomatologija, Baltic Dental and Maxillofacial Journal, 6:81-84, 2004

[16] Ciortan M., Luca L., Stancioiu A.,- *Study on a gripping biomechanism represented by the human dento-maxillary apparatus*. Conference OPTIROB 2013, Applied Mechanics and Materials, Vol. 332 , 2013, pp 515-520.

[17] Ciortan M., Luca L., Luca R.E., - *Study on the mastication movements of the temporomandibular joint.* Fiability & Durability, No.2, 2018, pp.144-149.

[18] **Frank J. Weaker Ph.D**. - *Structures of the Head and Neck* 1st Edition, ISBN-13: 978-0803629585, ISBN-10: 0803629583, Publisher: F.A. Davis Company; 1 edition, 2013

[19] https://veteriankey.com/management-of-specific-fractures/

[20] Gioso M.A., Carvalho V.G., - *Oral anatomy of the dog and cat in veterinary dentistry practice*, Vet Clin North Am Small Anim Pract. 2005 Jul;35(4):763-80.
[21] Harvey C.E., Emily P.P., - *Function, formation, and anatomy of oral structures in carnivores*. In: Small animal dentistry. St. Louis: Mosby; 1993. p. 10–3.
[22] Wiggs R.B, Lobprise H.B., - *Oral anatomy and physiology.* In: Veterinary dentistry. Principles and practice. Philadelphia: Lippincott-Raven; 1997. p. 77–9.
[23] Umphlet R.C., Johnson A.L., Eurell J.C., et al., - *The effect of partial rostral hemimandibulectomy on mandibular mobility and temporomandibular joint morphology in the dog.* Vet Surg, 1988;17(4):186–93.
[24] Shipp A.D., Fahrenkrug P., - *Eruption and dentition*. In: Practitioners's guide to veterinary dentistry. 1st edition. Glendale (California): Griffin Printing; 1992. p. 8–15.
[25] Ghetie V., - *Anatomia animalelor domestice,* Ed. Academiei RSR, Bucuresti, 1971.
[26] Miscalencu D., et.al., - *Anatomia comparată a vertebratelor.* E.D.P. Bucureşti, 1982.