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ORIGINAL ARTICLE

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Fracture properties of the human mandible

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Abstract A total of seven human mandibles were struck to breaking point under standardised conditions using a pendulum. The cortical deformation for two impact directions was measured with strain gauge strips located at eight defined sites. Fronto-median impacts led to mostly bilateral and always multiple fractures in the posterior area of the bone, especially in the collum and the condyle. The fracture threshold was between 2.5 and 3.1 kN. Lateral impact caused fractures near the impact area as direct fractures of the ipsilateral corpus. Mainly single and double fractures were observed. For lateral impact the fracture threshold was between 0.6 and 0.8 kN.

Keywords Mandibular fracture · Biomechanics · Strain gauge measurement

Introduction

The reconstruction of forces applied to different body parts is a common task in forensic pathology [1, 2, 3]. Violence against the head can be accompanied by brain injuries and thus become a cause of death. The number of mandibular fractures in violent assaults and accidents is increasing [4, 5, 6] and the fracture patterns of the mandible can be helpful in reconstructing the type and intensity of violence [4, 5]. However, the relationship between impact and the resulting injuries such as fractures, is not always obvious and misinterpretation can occur [8].

The biomechanical properties of the human mandible in low impact experiments under variable conditions have been described previously [9]. The aim of the present study was to learn more about the fracture properties in high force impacts. The relationship between impact and fracture findings was analysed as well as the force necessary to break the bone.

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Material and methods

A total of 7 human mandibles were obtained from adults (5 male, 2 female, mean age 55.9 years, age range 35–71 years) who died from diseases not affecting either the orofacial region or the masticatory and osseal structures of the head. All individuals had given permission during their lifetime for the usage of body parts for postmortem scientific investigations.

The mandibles were exarticulated and after removal of soft tissue stored at a temperature of –18°C. After immersing in 0.9% saline solution for 1 h [10] the mandibles were positioned as described previously [9] and subjected to defined blunt force impact using a pendulum, while the cortical deformation was measured using eight symmetrically placed strain gauge strips (SGSs) [9].

The mandibles were impacted by the pendulum at two defined locations and from two defined directions (Fig. 1) as follows:

1. Fronto-median direction to the most prominent point of the chin
2. Lateral direction (90° to the corpus) between teeth 35 and 36.

A mass of 20 kg was used for an occlusal force of 200 N fixed at the coronoid process as would physiologically result from the masticatory muscles (Fig. 1).

Because the measured electrical resistance of the SGS wire reacts proportionally to the deformation of the attachment, the bone surface deformation could be continuously monitored in all areas of the SGS attachment points.

The metrical data and time of length changes were measured as described previously [9] and the results expressed as microstrain (µstrain=µm/m) and seconds (s).

The mandibles were impacted with stepwise increasing forces by adding 20 cm of pendulum distance in each consecutive impact

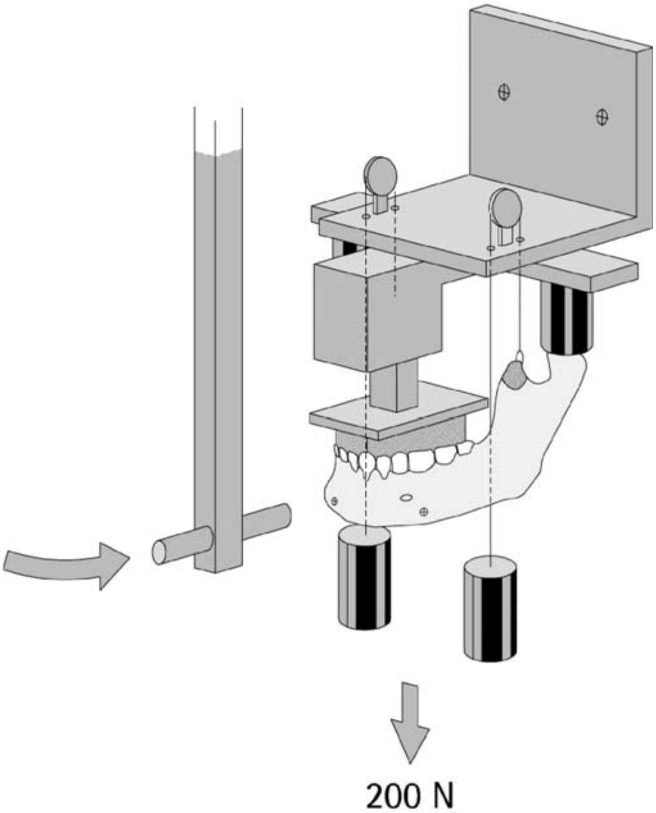

Fig. 1 Experimental setting showing the mandible in the apparatus with the simulated bite force and the pendulum. Impact locations on mandible surface are marked with ⊗

experiment. Since microfractures invisible to visual inspection, x-ray or other common diagnostic techniques could have altered the results, a standardised control experiment with low impact was carried out before each consecutive high impact experiment [9].

The force applied to the specimen was measured using an SGS attached to the pendulum.

Results

In fronto-median impacts to the anterior point of the chin, the fractures occurred above a pendulum distance of 150 cm, which is equivalent to an impact force of approximately 2.5 kN (Fig. 2 and Table 1). The highest fracture threshold attained was approximately 3.1 kN.

The mandibles mainly fractured 1–4 times in the dorsal area of the bone and at least one collum fracture always occurred in each specimen (Table 2, Fig. 4).

The lateral impact experiments showed fractures at a pendulum distance of more than 70 cm which is equivalent to approximately 0.6 kN. The upper threshold necessary to break the bone was 0.8 kN. Single or double fractures of the ipsilateral corpus, angle or ramus area and the corpus fractures were located directly at the point of the impact (Table 2, Fig. 4)

An analysis of the data showed that the areas of maximal length changes of the bone corresponded to the later fracture sites.

The comparison of the standardised control experiments carried out before and after each impact without fracture revealed no relevant differences so that alterations of the bone structure, such as microfractures could be ruled out. When reaching the fracture limit, significant changes in the control experiments were observed (Fig. 3).

Discussion

Mandibular fractures can constitute an important finding in forensic case reconstruction. In this series of experiments we have continued our studies concentrating on the relationship between the impact and the deformation characteristics of the mandible.

The apparatus used for fixation of the bone allows simulation of the anatomical relationship of the human mandible

Fig. 2 Maximal cortical deformation of specimen No. 1 as a typical course of increasing impact experiments from the fronto-median direction. The highest deformations can be found in the frontal (compression) as well as in the dorsal (stretching) area where fractures occurred

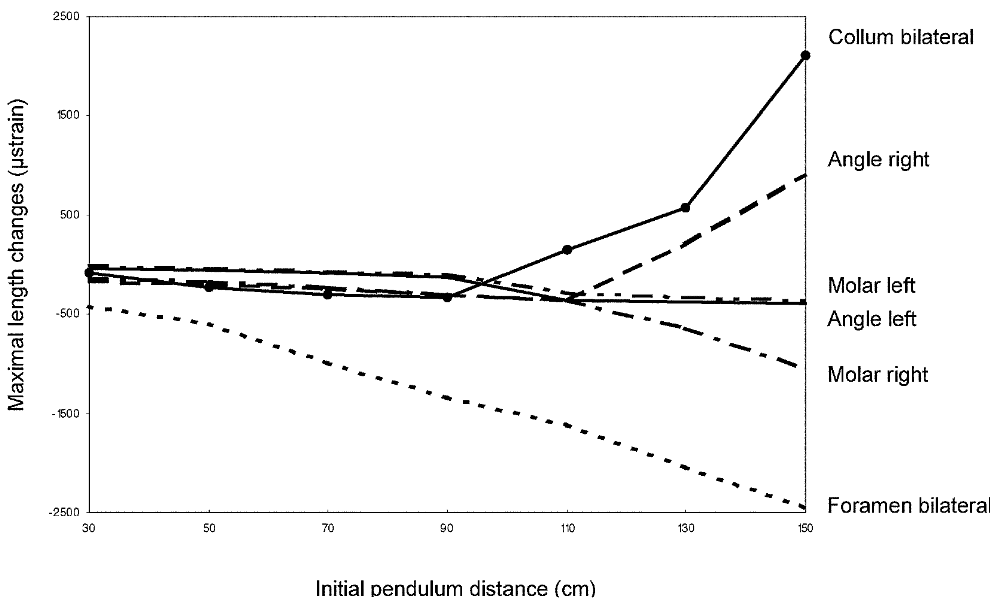

Table 1 Initial pendulum distance and corresponding force

Initial pendulum distance (cm)	Impact direction	
	Median force (N)[2]	Lateral force (N)[3]
10	170	123
20	314	190
30	489	253
50	821	444
70	1154	633
90	1479[1]	691
120	1972[1]	763
150	2465[1]	
170	2794[1]	
190	3122[1]	

[1]Calculated with method of linear regression.
[2]Pearson's correlation 1.000 (p=0.000).
[3]Pearson's correlation 0.979 (p=0.000).

Table 2 Results of the fracture experiments for each mandible in detail

Mandible	Pendulum distance	Force	Fracture localisation
Median direction			
1	170 cm	2796 N	Collum B/L, Proc. musc. L, Ramus R
2	150 cm	2465 N	Proc. musc. L, Collum R
3	190 cm	3122 N	Proc. musc. L, Angle L, Collum R
4	190 cm	3122 N	Corpus L, Collum B/L
Lateral direction			
5	120 cm	763 N	Corpus L
6	70 cm	633 N	Angle L, Ramus R
7	70 cm	633 N	Corpus L

Pendulum distance initial pendulum distance
Force applied impact force
B/L bilateral
Proc. musc. Processus muscularis
Ramus Ramus ascendens
R right
L left

[11], especially for the simulation of the physiological properties of the temporo-mandibular joint which can be crucial for the generation of fractures. In particular, the semirigid elastic fixation provides conditions close to the physiological setting [12]. A soft tissue covering was not simulated because this has no significant effect on the force level necessary [7].

A "physiological" occlusion force was simulated as well. The force of 200 N used in these experiments corresponds to about one-third of the maximal bite force [13, 14] and in unexpected impacts to the chin during assaults or accidents there is probably less occlusion force.

The majority of mandibular fractures occur from fist blows [4]. Joch et al. [15] reported the peak force of trained boxers to be 3.8 kN with average forces between 2.4 and 2.9 kN [15]. In a more recent study a maximum impact force of 4.8 kN has been described for professional boxers and 2.4 kN for beginners [16]. In the present study the mandibles broke at 2.5–3.1 kN (frontal impact) and at 0.6–0.8 kN (lateral impacts), respectively. Since in assaults most fractures are due to lateral impacts [4, 17, 18], the level of the peak forces measured in boxing is well above the fracture thresholds elaborated in this study. Professional boxers usually occlude their teeth and use a gum-shield for injury prevention [15].

The SGS method is simple and allows continuous measurement of the deformation [19]. Although the SGSs used here cover only a small area of the bone cortex, conclusions can be drawn for most of the bone. In bicortical bones like the mandible, the cortex layers tend to react in opposition to each other. Stretching of the outer layer leads to compression of the inner layer and vice versa [11, 20]. Since the occurrence of a fracture is a loss of tissue integrity due to stretching – known as a "stretching failure" [20, 21] – this relationship between both cortical layers helps to predict and evaluate the fracture occurrence [22]. The deformation obtained in this study causing a "stretching failure" was well above 2,200 µstrain (Fig. 2). In experiments with tibial bones Verma et al. [23] reported the deformation necessary to cause a fracture to be above 3,000 µstrain.

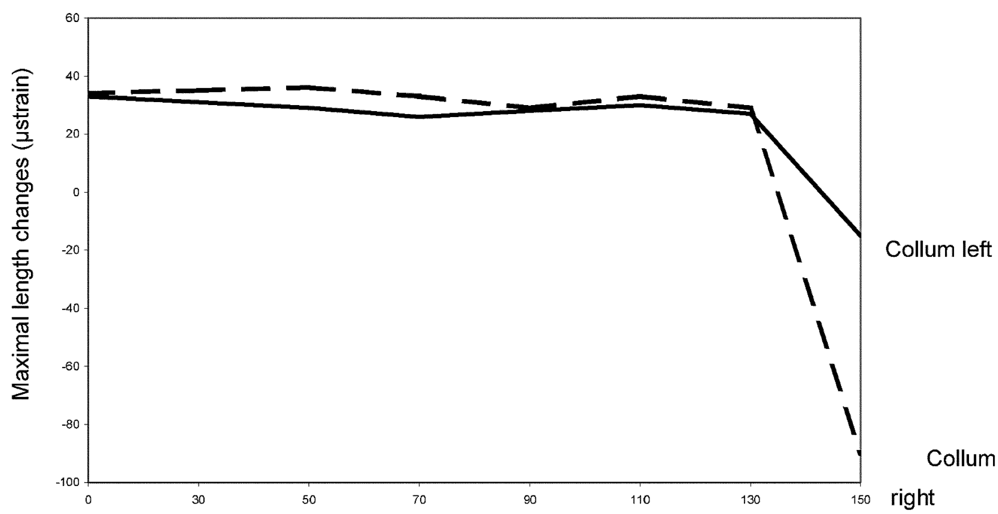

Fig. 3 Maximal cortical deformations of specimen No. 1 as a typical example for control experiments before each impact experiment showing collum measurement points in a median impact direction. Since the fractures occurred at a pendulum distance of 170 cm, the rough deformation changes of the control experiment before are most likely due to an altered force translation within the dorsal bone area. At the other measurement points there were never any significant length changes in the control experiments

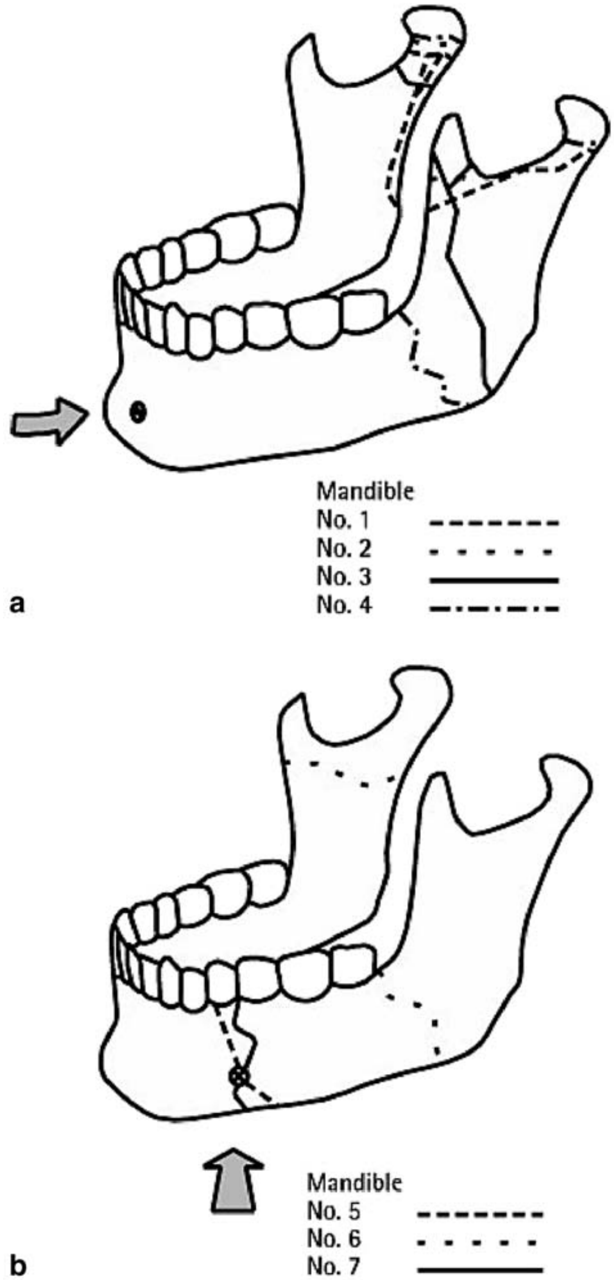

Fig. 4 Fracture localisations for all specimens used with median and lateral impact directions. Impact locations on mandible surface are marked with ⊗. *a* Median impact direction, *b* lateral impact direction

Special problems in studies with bones can be generated if microfractures occur. Since such fatigue fractures can be a source of error in the experimental setting, there have to be appropriate controls to monitor and detect them. Radioimaging methods such as CT scan or bone scan were not possible for practical reasons. Also, we are not sure that these methods are capable of detecting microfractures. Several authors have reported reliable control experiments using a functional parameter [12, 19, 24] and the control method used in this investigation was a functional one and seemed to be both sensitive and reliable.

The fractures that occurred in this series show a stereotype pattern. Fronto-median impacts reproducibly caused indirect comminuted fractures of the dorsal and collum area, while uni-lateral corpus fractures were due to lateral impacts (Table 2, Fig. 4). Although only a limited number of specimens were available, we found a relatively small range of the fracture thresholds and the fracture patterns were quite homogeneous. It can therefore be assumed that interindividual variability plays a less important role in the generation of mandibular fractures. Because of the different gross anatomy of the bone specimens used, it can be assumed that this small variability is due to the anatomical changes of the bone when under stress according to Wolff's law [20].

There are few experimental studies in the literature describing the fracture threshold of the lower jaw (Table 3) and although all study groups used different models the results are similar [25]. In contrast to most of these studies we have applied a model simulating physiological conditions and the number of specimens used was relative large.

The lower jaw fracture can be seen as a typical "fist fighting fracture" [4, 30] and is thus highly connected with the socio-cultural and geographical setting [31]. The incidence of mandibular fractures caused by assaults is increasing [4, 5, 26, 31], while the numbers of this type of inury in motor vehicle accidents (MVA) seems to be falling

Table 3 Fracture thresholds from experimental studies

Author	Fracture threshold (N)	Impact direction	Annotation
Schneider and Nahum [32]	1800	Median	
	900	Lateral	
Nahum [33]	1890–4120	Median	
	820–2600	Lateral	
Huelke and Compton [31]	1887	Median	Simple subcondylar fracture
	2442	Median	Bilateral subcondylar fracture
	2442–3996	Median	Symphyseal fractures
	1332–3330	Lateral	Corpus fractures
Hodgson [24]	1598–2664		
Unnewehr et al. This study	2465–3122	Median	Mostly dorsal fractures
	633–763	Lateral	Corpus fractures

1 N (Newton)=0.225 lb

[4, 6, 27]. In MVAs the vast majority of collisions are from the frontal direction causing most of the facial injuries, including mandibular fractures [28]. Huelke and Compton [29] as well as Meyer et al. [4] pointed out that the direction of the impact force is of special influence for the fracture threshold and pattern.

The fracture patterns observed in the present study are typical for violence with intensities near the fracture threshold. Such intensities are especially reached in cases of physical assault. In other types of trauma with much more intensive impact (e.g. MVAs) fractures in all regions of the mandible can be observed [4].

References

1. Rougé-Maillart C, Tracqui A, Tortel MC, Pessaux P, Penneau M, Ludes B (2002) Fatal blunt pancreatic trauma secondary to assault and battery: a case report. Int J Legal Med 115:162–164
2. Darok M, Beham-Schmid C, Gattering R, Roll P (2001) Sudden death from myocardial contusion following an isolated blunt force trauma to the chest. Int J Legal Med 115:85–89
3. Vock R (2001) Liver rupture caused by isolated blunt force impact: the result of a blow, a kick or a fall? Int J Legal Med 114:244–247
4. Meyer U, Benthaus S, Du Chesne A, Wannhof H, Zöllner B, Joos U (1999) Untersuchung von Patienten mit Gesichtsschädelfrakturen unter ätiologischen und rechtsrelevanten Gesichtspunkten. Mund Kiefer Gesichtschir 3:152–157
5. Brook IM, Wood N (1983) Aetiology and incidence of facial fractures in adults. Int J Oral Surg 12:293–298
6. Van Hove A, Lolom P, Sapanet M, Descrozailles JM (2000) Les fractures mandibulaires. Etude de l'activité du service de chirurgie exmaxillo-faciale et stomatologie du CHU de Poitiers de 1978 à 1997. Rev Stomatol Chir Maxillofac 101:309–318
7. Allan BP, Daly CG (1990) Fractures of the mandible. A 35-year retrospective study. Int J Oral Maxillofac Surg 19:268–271
8. Gordon I, Shapiro HA (1975) Forensic medicine – a guide to principles. Churchill-Livingstone, Edinburgh
9. Du Chesne A, Unnewehr M, Schmidt PF et al (2003) Deformation characteristics of the human mandible in low impact experiments. Int J Legal Med, in press
10. Arendts FJ, Sigolotto C (1990) Mechanische Kennwerte des Human-Unterkiefers und Untersuchung zum "in-vivo"-Verhalten des kompakten Knochengewebes. Ein Beitrag zur Darstellung der Biomechanik des Unterkiefers – Teil 2. Biomed Tech (Berl) 35:123–130
11. Huelke DF, Harger JH (1968) Mechanisms in the production of mandibular fractures: an experimental study. J Oral Surg 26: 86–91
12. Meyer U, Vollmer D, Homann C et al. (2000) Experimentelle und Finite-Elemente-Analyse der Biomechanik des Unterkiefers unter Belastung. Mund Kiefer Gesichtschir 4:14–20
13. Ohkura K, Harada K, Morishima S, Enomoto S (2001) Changes in bite force and occlusal contact area after orthognathic surgery for correction of mandibular prognathism. Oral Surg Oral Med Oral Pathol 91:141–145
14. Shinogaya T, Sodeyama A, Matsumoto M (1999) Bite force and occlusal load distribution in normal complete dentitions of young adults. Eur J Prosthodont Restor Dent 7:65–70
15. Joch W, Krause J, Fritsche P (1982) Schlagkraft und Bewegungsschnelligkeit des Boxers. Leistungssport 12:40–46
16. Smith MS, Dyson RJ, Hale T, Janaway L (2000) Development of a boxing dynamometer and its punch force discrimination efficacy. J Sports Sci 18:445–450
17. Boole JR, Holtel M, Amoroso P, Yore M (2001) 5196 Mandible fractures among 4381 active duty army soldiers, 1980 to 1998. Laryngoscope 111:1691–1696
18. Fridrich KL, Pena-Velasco G, Olson RA (1992) Changing trends with mandibular fractures: a review of 1067 cases. J Oral Maxillofac Surg 50:586–589
19. Vollmer D, Meyer U, Joos U, Vegh A, Piffko J (2000) Experimental and finite element study of a human mandible. J Craniomaxillofac Surg 28:91–96
20. Austermann K-H, Lisiak O (1980) Untersuchung zur Biomechanik von Kiefergelenkbrüchen. Fortschr Kiefer Gesichtschir 25:124–128
21. Huelke DF, Patrick LM (1964) Mechanics in the production of mandibular fractures: strain-gauge measurements of impacts to the chin. J Dent Res 43:437–446
22. Kober C, Sader R, Thiele H, Bauer H-J, Zeilhofer H-F, Hoffmann K-H, Horch H-H (2001) Spannungsanalyse des menschlichen Unterkiefers bei traumatologischen Standardsituationen mittels numerischer Simulation. Mund Kiefer Gesichtschir 5: 114–119
23. Verma RB, Sherman O (2001) Athletic stress fractures: part I. History, epidemiology, physiology, risk factors, radiography, diagnosis, and treatment. Am J Orthop 30:798–806
24. Hodgson VR (1967) Tolerance of the facial bones to impact. Am J Anat 120:113–122
25. Hampson D (1995) Facial injury: a review of biomechanical studies and rest procedures for facial injury assessment. J Biomech 28:321–327
26. Azevedo AB, Trent RB, Ellis A (1998) Population-based analysis of 10,766 hospitalizations for mandibular fractures in California, 1991 to 1993. J Trauma 45:1084–1087
27. Busuito M J, Smith DJ, Robson MC (1986) Mandibular fractures in an urban trauma center. J Trauma 26:826–829
28. Dischinger PC, Cushing BM, Kerns TJ (1993) Injury patterns associated with direction of impact: drivers admitted to trauma centers. J Trauma 35:454–459
29. Huelke DF, Compton CP (1983) Facial injuries in automobile crashes. J Oral Maxillofac Surg 41:2414
30. Oikarinen K, Ignatius E, Kauppi H, Silvennoinen U (1993) Mandibular fractures in northern Finland in the 1980s – a 10-year study. Br J Oral Maxillofac Surg 31:23–27
31. Shepherd JP (1989) Surgial, socio-economic and forensic aspects of assault: a review. Br J Oral Maxillofac Surg 27:89–98
32. Schneider DC, Nahum AM (1974) Impact studies of facial bones and skull. Proceedings of the 16th Stapp Car Crash Conference, SAE No. 720966, p 204
33. Nahum AM (1975) The biomechanics of facial bone fracture. Laryngoscope 85:140–156