VOLUME 69 | ISSUE 3 | JULY - SEPTEMBER 2018 ISSN 2241-4347

ACTA ORTHOPAEDICA ET TRAUMATOLOGICA HELLENICA

BASIC SCIENCE

- Bone tissue adaptation to muscular loads

ORIGINAL ARTICLE

- The effect of patient positioning on the relative positioning of the aorta to the thoracic spine in patients with scoliosis

REVIEW ARTICLE

- Classifications for the odontoid fracture: The significance and application of the "Korres classification"

CASE REPORT

- A closed degloving injury of the fifth toe: a case of empty toe

HELLENIC ASSOCIATION OF ORTHOPAEDIC SURGERY AND TRAUMATOLOGY

ACTA ORTHOPAEDICA ET TRAUMATOLOGICA HELLENICA

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Published by: ZITA MEDICAL MANAGEMENT S.A.
1st klm Peanias - Markopoulou Avenue, Peania, Attica, Greece, P.O BOX 155, 190 02, tel.: +30 211 1001 777, fax: +30 210 6642116, E-mail: info@zita-management.gr

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or

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Bone tissue adaptation to muscular loads

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ABSTRACT

This is a literature peer review of muscular loading influence to the functional bone adaptation. Reception of mechanical signals produced by either muscle forces or gravity affect bone formation. Muscle forces are capable of promoting functional bone adaptation. A number of clinical scientific reports points out that during exercise bone increase, muscle forces have a leading role in creating the mechanical stimulus. Muscle forces provide a significant amount of applied force and therefore are the main stimuli that lead to the adaptive response of the bone.

Keywords: Bone adaptation; bone tissue; gravity; mechanical stimulus; muscle forces

The Mechanostat Theory of Frost

Harold Frost proposed the theory of a bone homeostatic monitoring mechanism, which is liable for detecting alterations in the mechanical requirements applied on it. [1] Bone mass and structure are changed in order to achieve the best possible response to these new mechanical requirements. [1] In particular, Frost put forward that there are loading thresholds that monitor the mechanical usage of bone, changing its architecture when these loads are increased or decreased.[1] Underneath a ceratain mechanical usage threshold, bone tissue is absorbed and bone mass is decreased. [1] Over a different threshold in which mechanical loads are larger than typical peak strains, there is bone mass increase and therefore mechanical strength increase. [1] Accordingly, there is an inherent mechanostat, which adjusts the functional bone adaptation. [1]

Mechanical stimulus

Harold Frost suggested that the stimulus, which causes functional bone adaptation, depends on the magnitude of deformation that has been caused in it. Deformation is defined as the change in bone length compared to its original length or the alteration of particular characteristics of bone tissue, which occurs with loading. [2,3] Bone mass is maintained and adapted to mechanical deformation mainly

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as a result of muscle contraction. [4] Long bones deformation is achieved through muscular activity. [4] Forces that cause bone adaptation are associated with the action of muscles and not with simple gravitational forces. [5] Therefore, muscle mass and strength are correlated with bone strength. [6]

Bone modeling & remodeling

Process of bone modeling involves the independent action of osteoclasts and osteoblasts on the surfaces of bone, whereby new bone is builded along certain surfaces and removed from others. [7] Thus, the process of bone formation and resorption affects the size and shape of bones and therefore is a critical process for the remodeling of long bones as they grow and lengthen during adolescence. [7]

Bone remodeling is a local process involving the combined double action of both osteoclasts and osteoblasts, in which initially the osteoclasts absorb a small amount of bone and then the osteoblasts, in the specific site, form and mineralize new bone. [8] Generally, the amount of bone formed is equivalent to the amount of bone absorbed in each bone remodeling unit, with the exception of disuse. [9] The resorption period averages 30 - 40 days and is followed by bone formation lasting 150 days. [10]

Functional bone adaptation

Harold Frost introduced the term "mechanostat" to describe the mechanism of functional bone tissue adaptation. The mechanostat is a homeostatic regulative mechanism of the bone, which modifies bone structure, in response to changes that occur due to mechanical requirements applied in the bone. [1,9] It has been shown that bone mass is reduced in the absence of usual loading, while it is increased when loading is greater than the usual. [11,12]

An experiment with 26 adult female rats investigated the effect of mechanical loading, at separate time periods, on the bone structure and evaluated the biomechanical properties of the ulna after 16 weeks of loading. [13] The right ulnas of 26 adult female rats were subjected to 360 cycles of loading / day, with a maximum force of 17N, 3 days / week for 16 weeks. [13] In half of the rats, (n=13), the 360 daily loading cycles were given in a single period (360 x 1) without a break. [13] The other half of the rats (n=13) were given 90 cycles of four times a day (90 x 4), with a 3-hour break between the loading periods. [13]

In the rats that participated in the program of 360 cycles loading x 1 times / day, the ultimate force of their ulna was increased by 64% whereas those who participated in the program of 90 cycles loading x 4 times / day, increased by 87%. [13] Thus, mechanical loading was more effective in improving the biomechanical and structural properties of the bone, when the loads were applied in separate periods, segregated by pauses (90 cycles x 4 times / day), compared to the loads applied in one session (360 cycles x 1 time / day). [13] Significant increases in bone biomechanical properties occurred despite the very low benefits of 5-12% in bone density and bone mass, of 26 rats ulnas. [13] These findings demonstrate that a small increase in bone density and bone mass, which is put where it is mechanically optimal, as well as intermittent loading and not in a single period, can lead to significant biomechanical benefits. [13]

The role of Menopause to mechanostat

The outset of menopause results in the reduction of bone mechanical sensitivity which occurs when women become older. In an experiment, it was shown that estrogen regulates the bone cells mechanosensitivity through the synthetic prostaglandin pathway. [14] Hence, at the outset of menopause the reduction of estrogen, can make bone less sensitive to mechanical stimulus.

A study has demonstrated that moderate to strong intensity exercises, performed at high speed for short periods of time, either on water or on the ground, can be part of a program to prevent and treat postmenopausal osteoporosis. [15] The mechanical vibrations have been prooved useful for bone microarchitecture, for increase bone density and strength and for improvement of physical function. [15] Activities aimed at increasing muscle strength, body balance and improving the proprioception of postmenopausal women, with the aim

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Fig. 1: Humerus diaphysis bone associated with throwing the ball was more powerful compared to the one which did not participate in the throws. [16]

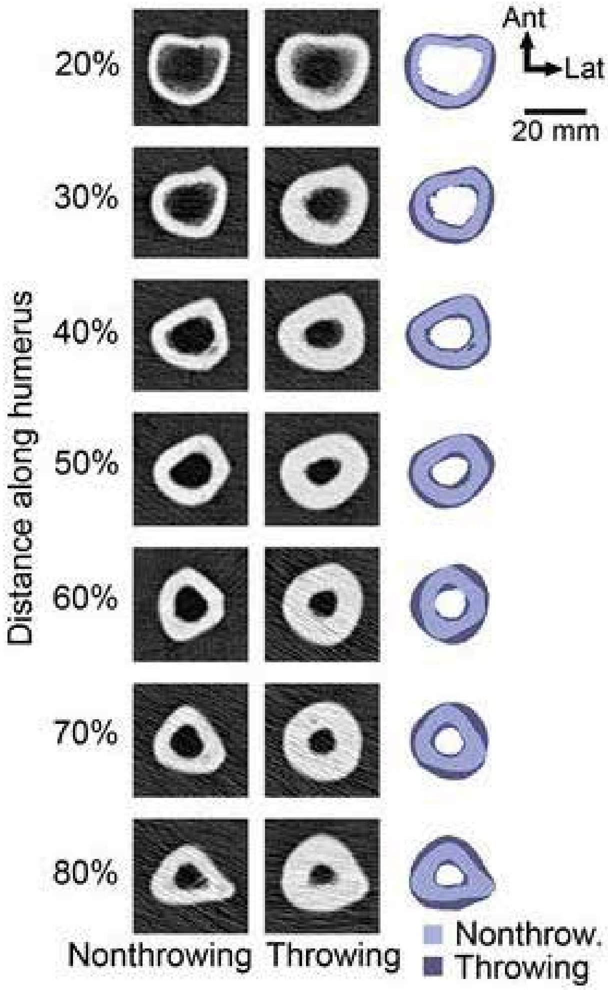

Fig. 2: More important benefits were observed in cortical bone mass and thickness and less medullary cavity (medullary canal) extension of the ball throwing arm than the not throwing arm. [16]

of preventing falls and fractures, should be recommended. [15]

Ideal time to load bone tissue

In a study that was conducted, the differences in the properties of the humerus diaphysis bone in throwing the ball arm and of which did not throw the ball, of 103 professional baseball players, at different stages of their career, were compared with the properties of prevalent and non-prevalent arm of 94 persons of the control group. [16] In the humerus diaphysis bone associated with throwing the ball, extreme loads were caused and bone strength almost doubled (**Figure 1**). [16] After the cessation of sports activities, the benefits to cortical bone mass and thickness, which acquired during the youthful physical activity (**Figure 2**), were gradually lost due to larger extension of the medullary cavity (medullary canal) and greater cortical bone "trabecularization". [16] Nonetheless, half of the increase in bone size and one-third of improvement in bone strength that occurred from physical activity associated with throwing the ball during juvenile times, were maintained throughout the rest of the life of veteran athletes. [16] Former professional baseball players who continued to throw balls during their ageing retained a part of cortical bone mass and most of the benefits in humerus diaphysis bone strength due to physical activity during their youthfulness, as a result of lesser extension of the medullary cavity (medullary canal) and lesser cortical bone "trabecularization". [16] These results revealed that the theory of "use it or lose it" is not fully practicable to the human skeleton and that physical activity should be encouraged during the young age, aiming at the

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bones health throughout their lives of people, with an emphasis on optimizing bone strength and size instead of increasing bone mass. [16] Furthermore, the above results demonstrate that physical activity should also be encouraged throughout ageing, in order to restrict the bone structure degeneration. [16]

Ideal loading features

A study carried out on immature bones of female rats investigated the effects of training by jumping on bones morphological and mechanical properties.[17] Five week old rats were divided into 6 groups, 1 control group and 5 groups were trained at 5, 10, 20, 40 and 100 jumps per day. [17] Rats were trained 5 days / week for 8 weeks and jump height gradually rose to 40 cm. [17] In the group that followed 5 jumping / day, the femur and tibia had a significantly higher percentage of dry weight, without fat, per body weight and in fracture tests were able to withstand higher peak loads than rats in the control group. [17] While it was observed a modest proclivity to increase depending on the number of leaps per day, however there were few variations in morphological and mechanical bone parameters amongst the groups that followed 10, 20 and 40 jumps per day. [17] These data show that a small number of loads per day are sufficient to grow bone formation in response to workout. [17]

Exercise in the elderly

An eight week study aimed at researching the influence of a balance exercise and a program of elastic resistance exercises in muscular strength and elderly balance, in order to propose an effective intervention to prevent falls in this age group, which is at the highest risk of falling. [18] The study involved 55 elderly people who were divided into three groups: the first group followed a program of equilibrium exercises, the second followed a program of resistance exercises and the third was the control group. [18] In the group that followed a resistance exercises program, there were major ameliorations in strength of hip flexors, hip extensors, hip abductors, knee flexors, knee extensors, ankle dorsiflexors and ankle plantar flexors and balance of elderly. [18] In the group that followed a program with balance exercises, there were important enhancements in strength of all muscle groups apart from the knee flexors and ankle plantar flexors. [18] This study has proven that a program which uses either equilibrium exercises or elastic resistance exercises is efficient to enhance elderly muscle strength and balance in order to reduce risk of falls in them. [18]

Latest clinical data

An experiment carried out with 40 virgin female mice up to fourteen weeks of age, explored the skeletal consequences of muscle inhibition caused by Botox in cage control and tail suspended mice.[19] Each animal was injected with Botox in the right posterior leg and with vehicle in the left posterior leg. [19] After right posterior leg muscle inertia, animals were randomly separated into two groups: the first was the cage control and in the second, mice tail suspended for six weeks. [19] It was found that skeletal effects of Botox-provoked muscle inertia are not only due to retraction of gravitational forces.[19] Withdrawal of gravitational forces of the posterior legs through tail suspension caused a bone mass decrease due to diminished periosteal bone formation and intensified endosteal bone reabsorption. [19] The raise in endosteal bone absorption was remarkable by a considerable increase in medullary cavity (medullary canal) and a decrease in cortical area and cortical thickness. [19] Muscle inertia caused by Botox on tail suspension aggravated these skeletal alterations with both of removal of gravitational forces and muscle inertia had the largest damaging action on the skeleton, caused the least profits in midshaft tibial bone mass, cortical area and cortical thickness, greatest profits in midshaft tibial medullary cavity (medullary canal) and lowest proximal tibial trabecular bone volume fraction (**Figure 3**).[19] These results prove Botox-provoked muscle inertia triggers further skeletal influence than those caused only by excised gravitation-

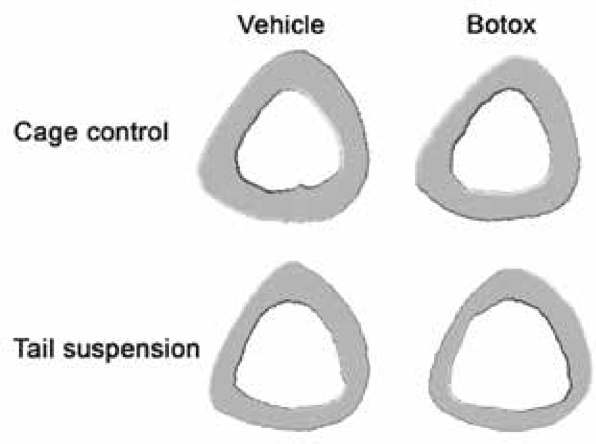

Fig. 3: The influence of gravitational and muscular interference on midshaft tibia structure. It is remarkable the decrease of tibia bone mass and cortical bone thickness, both in tail suspension and muscle inertia caused by Botox, due to the considerable increase in medullary cavity (medullary canal). These skeletal alterations deteriorated in tibiae subjected to tail suspension and Botox-provoked muscle inertia simultaneously. [19]

al forces.[19] Therefore, muscles have an immediate influence on bone tissue.[19]

Conclusions

Mechanical loads exerted on bones are distinguished by forces of gravity and muscular forces and determine bone architecture, structure and adaptation. Bone tissue has an inherent mechanostat, which adjusts the functional bone adaptation.

Muscle mass and strength are correlated with bone strength. A small increase in bone density and bone mass - gained easier with intermittent loading and not with a long but single loading period - can lead to significant biomechanical benefits. A small number of loads per day are sufficient to build bone in response to workout.

Physical activity should be encouraged throughout ageing, in order to prevent bone structure degeneration. A program which uses either equilibrium exercises or elastic resistance exercises is efficient to enhance elderly muscle strength and balance in order to reduce the risk of falls.

Muscular loads constitute the main stimulus which leads to functional bone adaptation.

Conflict of interest:

The authors declared no conflicts of interest.

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Kokkinias AD, Triantafyllopoulos KI. Bone tissue adaptation to muscular loads. *Acta Orthop Trauma Hell* 2018; 69(3): 126-131.

ΠΕΡΙΛΗΨΗ

Η παρούσα εργασία αποτελεί μία βιβλιογραφική ανασκόπηση της επίδρασης των μυϊκών φορτίων στη λειτουργική προσαρμογή του οστού. Η λήψη μηχανικών σημάτων με συγκεκριμένα χαρακτηριστικά, το σύνολο των οποίων μπορεί να παραχθεί είτε από μυϊκές είτε από βαρυτικές δυνάμεις, απαιτείται στον προκαλούμενο από τη φόρτιση οστικό σχηματισμό. Οι μυϊκές δυνάμεις είναι ικανές να προωθούν τη λειτουργική προσαρμογή του οστού. Αρκετές κλινικές επιστημονικές αναφορές επισημαίνουν ότι στην προκαλούμενη από την άσκηση αύξηση του οστού, οι μυϊκές δυνάμεις διαδραματίζουν κυρίαρχο ρόλο στη δημιουργία του μηχανικού ερεθίσματος. Οι μυϊκές δυνάμεις παρέχουν ένα σημαντικό ποσό της ασκούμενης δύναμης και επομένως συνιστούν το κύριο ερέθισμα που οδηγεί στην προσαρμοστική απόκριση του οστού.

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: Προσαρμογή του οστού, οστίτης ιστός, βαρύτητα, μηχανικό ερέθισμα, μυϊκές δυνάμεις.

ORIGINAL PAPER

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The effect of patient positioning on the relative positioning of the aorta to the thoracic spine in patients with scoliosis.

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ABSTRACT

A serious, although rare, complication of thoracic spinal surgery is iatrogenic vascular injury of the aorta. The position of the thoracic aorta relative to the spine is crucial in the preoperative planning of thoracic spine surgery, regardless of the surgical approach used. We performed this study in order to evaluate the displacement of the aorta relative to the spine (levels T4 to T12) in patients with scoliotic deformity in supine, prone and prone with padding position. Twenty patients underwent CT scan of the thoracic spine and the minimum distance from the entry point of the left pedicle screw to the thoracic aortic wall was calculated. Statistical analysis revealed significant difference in this distance between the three different patient positions per level. In particular, aortic wall tends to be closer to the left pedicle screw with the patient in prone with padding position. Thus, our findings may be useful in aortic displacement estimation and allow the surgeon to decide on the appropriate surgical approach aiming at the safe positioning of pedicle screws.

Keywords: spine surgery; surgical approach; thoracic aorta,

Introduction

Thoracic spinal surgery accounts for 5-10% of all spinal surgeries, with more frequent causes being fractures, degenerative stenosis, kyphoscoliotic deformities, and intervertebral disc herniation. Surgeons dealing with this field have developed fusion techniques for trauma and spinal deformity correction. The most commonly used approach is posterior, while anterolateral approach remains a possible option during thoracic spinal surgery [1]. Moreover, new percutaneously and endoscopically assisted fusion techniques have been developed, which offer many benefits, including less pain and shorter rehabilitation time, to patients over traditional surgeries [2]. A possible and serious complication is iatrogenic vascular injury either during pedicle screw placement or secondary relaxation and migration of the

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Fig. 1: *Patient in prone with padding surgical position in an effort to reproduce surgical positioning during posterior thoracic spinal surgery.*

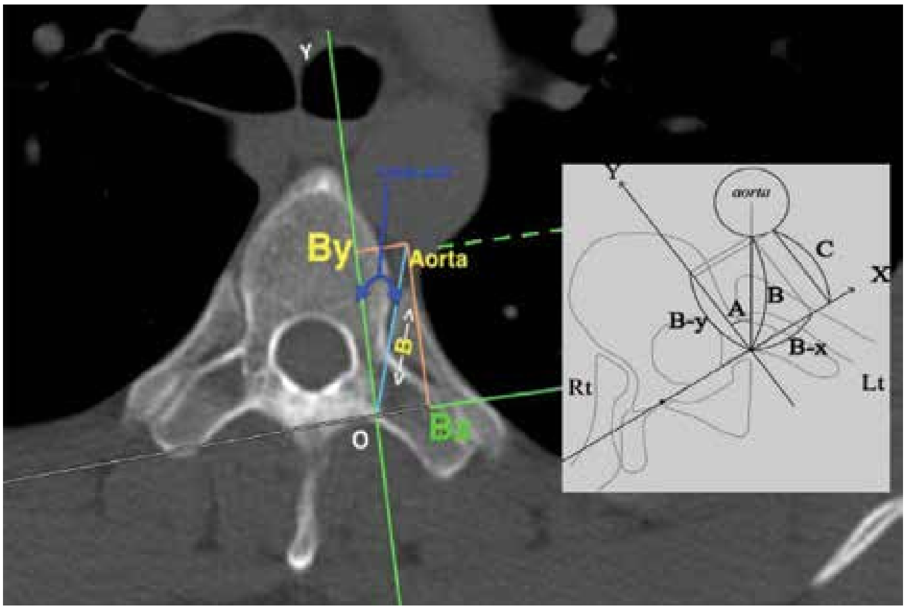

Fig. 2: *Axial view of the vertebrae. The reference point 0 is defined as the point of pedicular screw entry along the pedicular axial line (axis y). The minimum distance to the aortic edge B is drawn with the respective Bx - By projections defined on axis x and y.*

screw [3,4]. Thus, the position of the thoracic aorta relative to the spine is crucial in the preoperative planning of thoracic spine surgery, regardless of the surgical approach used. The purpose of this study was to evaluate the displacement of the aorta relative to the spine (levels T4 to T12) in patients with scoliotic deformity in supine, prone and prone with padding position.

Materials and Methods

Patients who were examined in the outpatient clinic of our department with a scoliotic deformity of >15 degrees Cobb angle and able to give informed consent were eligible for inclusion in the study. All patients underwent CT scan of the thoracic spine with slice thickness of 5 mm. All CT scans were performed in the standard supine, as well as in, the prone and prone with padding positions in an effort to reproduce surgical positioning during posterior thoracic

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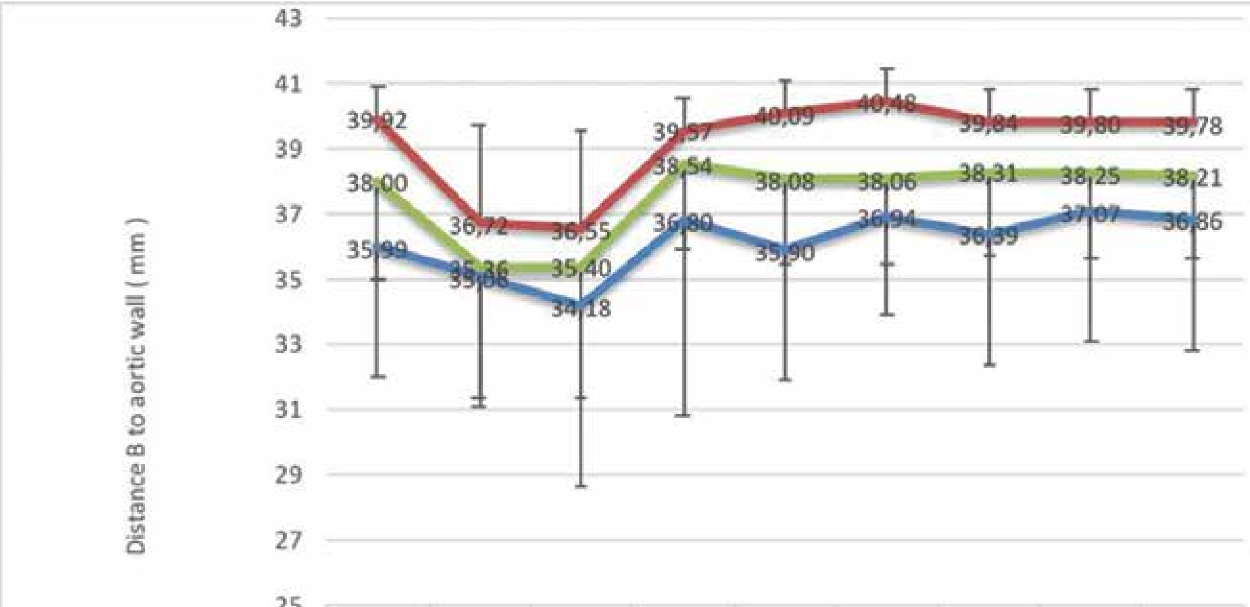

	T4	T5	T6	T7	T8	T9	T10	T11	T12
Supine	35,99	35,06	34,18	36,80	35,90	36,94	36,39	37,07	36,86
Prone	39,92	36,72	36,55	39,57	40,09	40,48	39,84	39,80	39,78
Prone with padding	38,00	35,36	35,40	38,54	38,08	38,06	38,31	38,25	38,21

Fig. 3: *Mean B values across all vertebrae in the three different patient positions.*

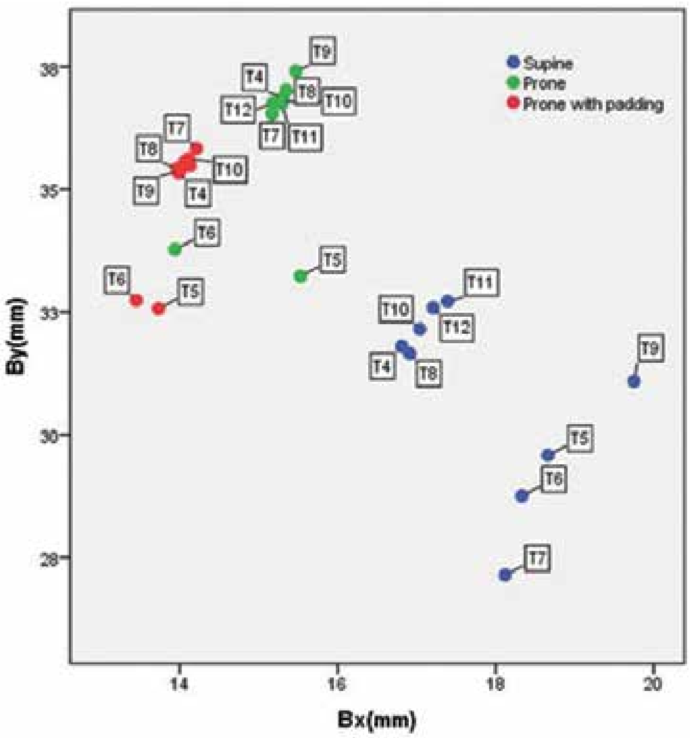

Fig. 4: *Scatter plot where a tendency of the aorta to shift medially and anteriorly in relation to the thoracic spine, while patient changes from supine in prone and prone with padding position, is depicted.*

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TABLE 1. *Mean distance B, Bx, By from pedicle entry point O to the aortic wall, across thoracic levels T4-12, with SD's, F-Values and P-values respectively*

		Supine position		Prone position		Prone with padding position		F-value	p-value
Distance B	T4	**35.99**	3.98	**39.92**	2.92	**38.00**	1.05	47.05	**<0.001**
	T5	**35.06**	4.3	**36.72**	4.47	**35.36**	3.02	10.38	**<0.001**
	T6	**34.18**	5.5	**36.55**	4.05	**35.40**	2.64	8.26	**0.004**
	T7	**32.78**	5.85	**39.57**	2.44	**38.54**	0.72	186.51	**<0.001**
	T8	**35.90**	3.80	**40.09**	2.64	**38.08**	1.21	113.68	**<0.001**
	T9	**36.94**	3.01	**40.48**	2.65	**38.06**	0.89	114.06	**<0.001**
	T10	**36.39**	3.90	**39.84**	2.70	**38.31**	1.05	75.48	**<0.001**
	T11	**37.07**	3.62	**39.80**	2.96	**38.25**	1.00	51.84	**<0.001**
	T12	**36.86**	3.43	**39.78**	2.45	**38.21**	0.95	66.06	**<0.001**
Distance Bx	T4	**16.81**	1.94	**15.31**	1.23	**13.99**	0.45	227.47	**<0.001**
	T5	**18.66**	3.1	**15.53**	2.37	**13.73**	1.25	223.53	**<0.001**
	T6	**18.33**	3.50	**13.94**	1.54	**13.45**	1.10	279.48	**<0.001**
	T7	**18.12**	4.13	**15.17**	1.02	**14.21**	0.31	134.78	**<0.001**
	T8	**16.91**	1.84	**15.35**	1.10	**13.97**	0.46	266.10	**<0.001**
	T9	**19.75**	3.02	**15.47**	1.10	**14.00**	0.40	499.71	**<0.001**
	T10	**17.04**	1.93	**15.26**	1.11	**14.11**	0.45	247.56	**<0.001**
	T11	**17.39**	1.95	**15.29**	1.26	**14.06**	0.41	315.92	**<0.001**
	T12	**17.21**	1.68	**15.18**	1.00	**14.13**	0.39	351.65	**<0.001**
Distance By	T4	**31.81**	3.56	**36.87**	2.71	**35.33**	1.00	198.41	**<0.001**
	T5	**29.58**	3.83	**33.23**	4.13	**32.57**	2.84	63.44	**<0.001**
	T6	**28.75**	4.91	**33.78**	3.79	**32.74**	2.46	103.62	**<0.001**
	T7	**27.14**	5.20	**36.54**	2.26	**35.83**	0.68	480.37	**<0.001**
	T8	**31.66**	3.39	**37.02**	2.46	**35.42**	1.15	238.32	**<0.001**
	T9	**31.09**	2.78	**37.41**	2.45	**35.38**	0.85	427.33	**<0.001**
	T10	**32.15**	3.45	**36.79**	2.50	**35.62**	1.00	182.48	**<0.001**
	T11	**32.72**	3.13	**36.75**	2.73	**35.57**	0.90	147.98	**<0.001**
	T12	**32.59**	3.08	**36.76**	2.28	**35.49**	0.86	170.61	**<0.001**

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spinal surgery (**Figure 1**). Axial images of the vertebrae, in which both vertebral pedicles are depicted, were obtained for measurements from T4 to T12 level in supine, prone and prone with padding position. The entry point of the left pedicle screw was selected as the point where the left transverse process intersects with the longitudinal axis of the left screw, and was designated as the reference point 0. The y-axis was defined as the front axis of the left screw and the x-axis as the perpendicular to y-axis passing through the reference point 0. Finally, the following parameters were measured in the axial tomography: 1) minimum distance B from the entry point 0 to the thoracic aortic wall and 2) projections Bx, By as defined by the x and y axes, representing the lateral and anterior-posterior displacement of the aortic wall relative to the left pedicle entry point O (**Figure 2**). All measurements were performed by two independent observers and mean values were calculated using Vitrea 2 Imaging Software. Intraobserver and interobserver variability were examined using the intra-class correlation coefficient (ICC). One-way ANOVA was used to compare the mean values of the three different positions and pairwise comparisons were performed using the Bonferroni test. Statistical analyses were performed using SPSS Software (Version 17.0, Statistical Package for the Social Sciences, SPSS Inc., Chicago, Ill., USA) and p values less than 0.05 were considered significant.

Results

A total of 20 patients (7 female and 13 male) were enrolled in the study. Mean patient age was 60 years and mean BMI was 27. Our measurements reveal that aorta moves closer to the T5-T7 vertebrae in all three different positions (**Figure 3**). In particular, in supine position, the minimum distance B decreases gradually from T4 to T7 and then, continuing to lower levels of the thoracic spine, increases again. The minimum distance B connecting left pedicle entry point to the edge of the aortic wall is summarized in Table 1. Statistical analysis showed significant difference in distance B between the three different patient positions per level (**Table 1**) while it was not affected by sex and body mass index of the patient. By creating a scatter plot of Bx and By values, we observe a tendency of the aorta to shift medially and anteriorly in relation to the thoracic spine while patient changes from supine in prone and prone with padding position (**Figure 4**). Therefore, aortic wall tends to be closer to the left pedicle screw with the patient in prone with padding position.

Discussion

In 20 patients with scoliotic deformity, the position of the aorta compared with the thoracic spine (levels T4 to T12) was studied, with the patient in supine, prone and prone with padding surgical position. Significant displacement of the aortic wall was observed as the patient was transferred from supine to prone position. Jiang et al. have studied 26 patients with idiopathic right thoracic scoliosis using MRI in both supine and prone positions and have shown similar results [5]. Nevertheless, in this study patients were not investigated in prone with padding position. In the present study the anterior-posterior By distance significantly increased from the left spinal cord to the aortic wall when the patient was placed in prone with padding position. According to our knowledge, there is no other study in the literature to compare the standard supine with the prone with padding position. Sucato et al investigated the anatomic relationship between aorta and thoracic spine in scoliotic and non-scoliotic patients and demonstrated a more anterior position of the aorta in patients with left thoracic scoliosis compared to a more posterior position in patients with right thoracic scoliosis [6,7]. Finally, Vaccaro et al. studied 19 non-scoliotic patients and noted that the aorta is at higher risk of injury when the pedicle screw penetrates the anterior vertebral cortex [8]. This study concludes that iatrogenic vascular injury is higher when the patient is placed in the prone with padding position. In contrast to previous studies we calculated the minimum safe distance, to avoid iatrogenic aortic wall injury by a pedicle screw. Both in posterior and anterior approaches the understanding of the relative position of the aorta defines the safe placement zone of the pedicle screw. Although di-

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rect iatrogenic injury is rarely reported, direct contact of hardware with the aorta has been reported up to 17% of patients undergoing thoracic spinal surgery [9]. Thus, our findings may be useful in preoperative planning of thoracic spine surgery. The position of the aorta should be checked by imaging -either CT or MRI- with the patient in both supine and prone positions. Aortic displacement estimation would allow the surgeon to decide on the appropriate surgical approach aiming at the safe positioning of pedicle screws. As shown, aorta position is dependent on patient position which in turn is largely determined by the surgical approach selected. Prone and prone with padding surgical position significantly influence relative aortic wall position and distance from the thoracic spine. Preoperative planning should take into account these observed changes, acknowledging that imaging in supine position depicts a defined static relationship which probably differs remarkably from surgical anatomical reality. A

Conflict of interest:
The authors declared no conflicts of interest.

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Plataniotis N, Evangelopoulos DS, Bakalakos M, Vlamis J, Pneumaticos S. The effect of patient positioning on the relative positioning of the aorta to the thoracic spine in patients with scoliosis. *Acta Orthop Trauma Hell* 2018; 69(3): 132-138.

ΠΕΡΙΛΗΨΗ

Μία σπάνια αλλά βαρύτατη επιπλόκη της χειρουργικής αντιμετώπισης προβλημάτων της θωρακικής μοίρας της Σπονδυλικής Στήλης, αποτελεί η ιατρογενής τρώση της αορτής κατά την τοποθέτηση των διαυχενικών κοχλίων. Η ανατομία της κατιούσας θωρακικής αορτής και η σχέση της με τη θωρακική μοίρα της Σπονδυλικής Στήλης, αποτελούν κρίσιμα στοιχεία του προεγχειρητικού ελέγχου. Σκοπός της παρούσας μελέτης είναι η αξιολόγηση της μετατόπισης της αορτής σε σχέση με τη Σπονδυλική Στήλη (Θ4-Θ12) σε ύπτια, πρηνή και χειρουργική πρηνή θέση, σε ασθενείς με σκολίωση. Είκοσι ασθενείς υποβλήθηκαν σε Αξονική Τομογραφία της θωρακικής μοίρας της Σπονδυλικής Στήλης και υπολογίστηκε η ελάχιστη απόσταση από το σημείο εισόδου του αριστερού διαυχενικού κοχλία μέχρι το τοίχωμα της θωρακικής αορτής. Η στατιστική ανάλυση ανέδειξε στατιστικά σημαντική διαφορά της απόστασης ανάμεσα στις τρεις διαφορετικές θέσεις για κάθε επίπεδο. Πιο συγκεκριμένα, το αορτικό τοίχωμα έχει την τάση να βρίσκεται πιο κοντά στον αριστερό διαυχενικο κοχλία με τον ασθενή σε χειρουργική πρηνή θέση. Συνεπώς, τα ευρήματα αυτά είναι χρήσιμα στην εκτίμηση της μετατόπισης της αορτής σε σχέση με τη θέση του ασθενούς και επιτρέπουν στο χειρουργό να επιλέξει την κατάλληλη προσπέλαση κάθε φορά, ώστε να εξασφαλίσει την ασφαλή τοποθέτηση των διαυχενικών κοχλιών.

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: Χειρουργική σπονδυλικής στήλης, τοπογραφία θωρακικής αορτής

Classifications for the odontoid fracture: The significance and application of the "Korres classification"

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ABSTRACT

Purpose: Our intention with this article is to review current literature concerning the classification of the fractures of the odontoid process and present their treatment concerning classification with special emphasis to the Korres classification that we routinely use. In addition we intend to review and summarize the classification significance and compare their usefulness with one another.

Methods: We conducted an extensive search in the literature using PubMed, Web of Science and Google Scholar and used in our study the most important of such articles.

Results: Fractures of the odontoid process represent a particular entity; they need a careful handling as their behavior is not easily predictable. Diagnosis of the correct type of fracture is very important. Complications due to multiple factors, are usual and have to be carefully managed. Pseudarthrosis is the most common complication related to many factors the most important being instability.

Conclusions: The Korres classification has been proven successful and is now considered more realistic as it is simple, it includes the whole spectrum of fractures, it refers to one single anatomical structure, it correlates to the biomechanics of the axis, it indicates the prognosis and it suggests the management of the fracture. The study of cases by Korres et al. revealed some directions for the development and treatment of these fractures. It is showed that type A and D fractures can and should be treated conservatively; they usually have a good prognosis. Type B fractures are prone to further complications and hence should be treated – in their majority - surgically. Type C fractures need to be followed closely and in case of instability and/or late displacement have to be operated.

KEY WORDS: odontoid process fracture; classification; review; treatment choice; cervical spine

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Introduction

Fractures of the odontoid process are not rare and they represent an individual entity. The interest these fractures are linked to is first, the fact that they involve an anatomic element which is developed in a very important area of the skeleton, in close relationship to vital structures and second, the multiple pattern of fracture this anatomic element can sustain. A third interesting point is the physical history and the management of these fractures which is closely related to the type of the lesion.

The incidence of these fractures is around 14%[1] among the cervical spine fractures and may occur at any age, with a higher risk for patients older than 65 years old. Nevertheless it is important to clarify that in this age group the fracture of the odontoid is more likely to be missed at the initial examination.

The main causes of injury is a road traffic accident or a fall, but, other causes are, also, implicated to these injuries concerning high energy trauma. However, the exact prevalence is not known as a certain number of patients who sustained such an injury do not survive and are dead in the time of arrival to the hospital. The fracture of the odontoid is often caused by high-energy trauma with the implication of a combination of forces and the major loading path that cause the lesion is not well established. According to experimental data the causes of the fractures of the odontoid process are a combination of vertical compression and horizontal shear which, acting in a different angle, create different patterns of fracture. In practice we can assume that the main forces responsible for a fracture of the odontoid process are the hyperextension, the flexion and the lateral bending, but it is certain that combined forces could also be responsible for a fractured odontoid.

The purpose of this study is to review current literature concerning the classification of odontoid fractures and the contribution of the existing classifications to clinical decision making for treating such fractures. Furthermore, we intend to expose several advantages of the Korres classification that we prefer to use.

Diagnosis

The clinical presentation of this injury varies from a mild to a severe one (quadriplegia or even death). [1] Patient sometimes present in the emergencies department holding their head or they are transferred on a stretcher complaining of pain in the cervical region; they usually keep their head still unable to move it because of the pain. A thorough clinical examination to exclude the symptoms corresponding to a neurological damage is mandatory although these are usually missing. The severity of the neurological disorder correspond to the degree of displacement and the consequent instability of the odontoid process. Older people have a higher rate of mortality [1].

In addition, it is important to look for an involvement of the vertebral arteries which, if damaged, could induce symptoms not only at an early stage, but, also, several days after the accident. The fracture of the odontoid process represents a separate entity and special attention is needed in order to recognize the fracture, but also, to apply the appropriated treatment protocol. Nowadays, it is clear that the pattern of the fracture contributes in favor of poor prognosis, that is, in the occurrence of complications, and of pseudarthrosis in particular; at the same time, it may indicates the way these lesions could be managed. So, there is a necessity for a complete and precise clinical and radiological approach, which will permit us to put the correct diagnosis. Problems could arise in children (the presence of congenital malformations, the immature skeleton etc.) and in old people (degenerative disease, pathological condition like tumors etc.). Radiological investigation is of importance. This must include apart the conventional x-ray views [Anterolateral (open mouth view), lateral and in certain instances dynamic views], and also, CT-scan (with reconstruction imaging), MRI and in certain instances 3-D imaging. Of course this will be done in a 'step by step' manner. If the patient is unconscious, then, the entire spine has to be investigated. The raison for such a meticulous radiologic investigation is due to the fact that the fracture pattern is unforeseen, and as multiple forces can be applied to the entire spine, simultaneously or in continuity, fractures at different levels of the spine may be present.

Classification

Two basic classification categories are proposed according to: **a**. the position of the fracture and **b**. to the direc-

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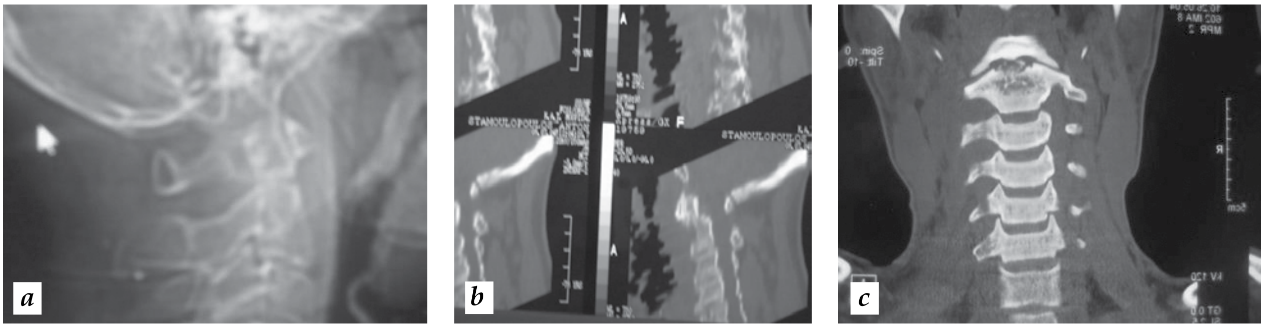

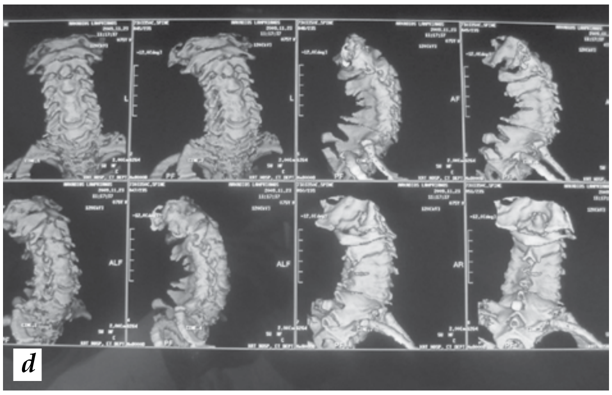

Fig. 1.
(A) *Lateral conventional view,*
(B) *CT Scan of fracture type B displaced,*
(C) *CT-Scan of fracture type C1,*
(D) *3-D imaging of the upper cervical spine showing fracture at the base of the odontoid process*

tion of the fracture line. In the first category there are four different classifications described: (a) The Schatzker classification [2], (b) The Mourgues Classification [3], (c) The Anderson-D'Alonzo classification [4], (d) The Althoof classification [5].

The second category, in which the direction of the line is considered, includes the classification of Roy-Camille [6] with three types of fractures: Anterior oblique, posterior oblique and horizontal.

The evolution in the diagnostic methods revealed the existence of other types of fractures like the vertical one, and the complex fractures. The vertical fracture is characterized by the division of the odontoid process into two parts with the line fracture extending from the apex to the base (**Fig 2e**), while the complex fractures are characterized by a diversity of fracture lines creating the compound or double level fractures.

The fractures of the odontoid process represent the mechanical failure of this particular anatomic element following the application of force [1]. The direction of these forces, the internal architecture, the mechanical strength of the bone trabeculae, the proportion of the cortical and cancellous bone, the magnitude of the odontoid process displacement, the vascular supply of the odontoid process and the age of the patients are the most important factors in the creation of specific fracture types and the prognosis of these injuries. In line, but not, well-documented in the literature, radiographic, and histomorphometry studies outline the structural difference between the odontoid process and the body of the axis. Data from these studies could distinguish the fractures at the base of the odontoid process and the underlying body of the axis. This was also revealed in a recent study using peripheral quantitative computed tomography (pQCT) in cadaveric specimens of the axis [7]. Moreover, this study showed the difference of the internal architecture of the axis between young and older patients; in subjects more than 40-year-old a large void of thin trabecular bone has been identified extending from anterior-inferior to superior- posterior to the base of the odontoid process indicating a mechanically weak region that may predispose to specific fracture patterns [7]. The classification proposed by Anderson-D'Alonzo offers a simple and topographic approach to odontoid process fractures. However, it does not contribute to the thorough understanding of the mechanism of the fracture, nor it incorporates any biomechanical characteristics or specific characteristics of

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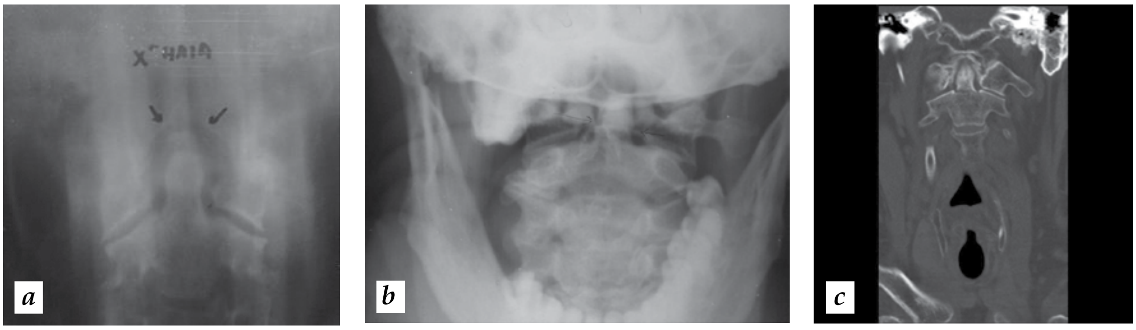

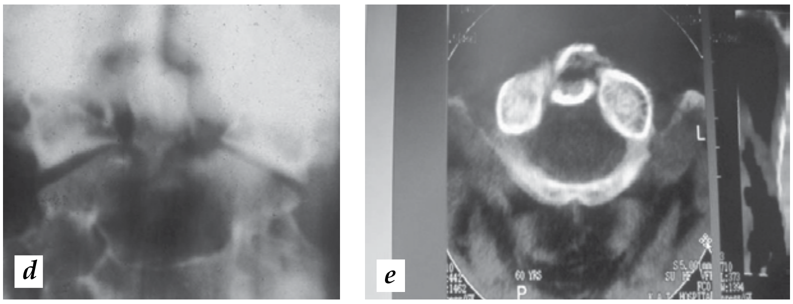

Fig. 2.
(A) *Type A fracture (top of the dens),*
(B) *Type B fracture in the neck of the dens,*
(C) *Type C1 at the base of the dens,*
(D) *Type C2 fracture extended to the body of the axis,*
(E) *Type D or complex fracture*

the internal architecture of the odontoid process and it also has certain limitations. In addition, all the attempts made for its improvement or replacement, the existence of alternative classifications based on the direction of the fracture line, the heterogeneity of the reported pseudarthrosis rates at type II fractures and the presence of various unclassified fracture types such as some vertical or oblique fractures may suggest the inadequacy of the aforementioned classification schemes. The Anderson-D'Alonzo classification is misleading and contributes to confusion regarding fracture location as type III fracture is not a fracture of the odontoid process, but rather a horizontal rostral fracture through the upper aspect of the body of the axis [8]. Further addition of subtypes, such as type IIA [9], type IIB [10], type IIC, type II 1-5 [11] and type IIIA [12] perpetuate the confusion. At the same time, Koller stressed the point of a lack of comprehensive classification for fractures of the body and the odontoid process [13].

The Korres Classification

In the literature there are fractures not corresponding to the already existing classifications and there is an evident confusion, so, it is clear that a more appropriate one would be obligatory [14]. The Korres classification is based on the structural, anatomical and biomechanical properties of the odontoid process [7] and it is an anatomy-based one recognizing four types of fracture pattern, all involving the odontoid process; it also recognizes a zone where practically no fractures are noted (the neutral zone), which is found at the level of transverse ligament, an area of phylogenetically strong bone.

Type A fractures are rare. It is an avulsion fracture at the points of insertion of the alars or apical ligaments with an incidence of 2,3% [1]; Their stability is questionable, but they responded favorable to a conservative treatment.

Type B fractures represent the most common fracture of the dens in the literature, and particularly in the elderly population although they are second in incidence with 44,1% [1]. They are the result of lateral force which initiates a rotational movement. In the presence of osteoarthritic changes this leads easier to a type B or C fracture seeing most frequently in older people. These fractures represent unstable lesions with a tendency to pseudarthrosis, so they need a careful evaluation and appropriate treatment, conservative or surgical, particularly in the old patients.

Type C fractures were found to represent 46,6% [1];

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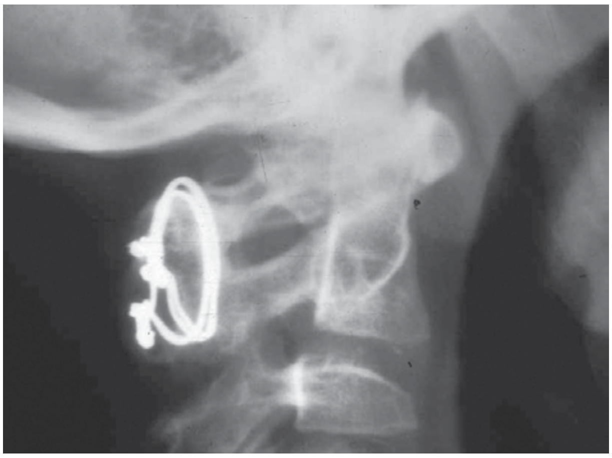

***Fig. 3**. Posterior fusion*

***Fig. 4**. Anterior osteosynthesis*

they have a more favorable outcome than type B, responding to a less aggressive management. Notable is the easiness to recognize a type B from a type C fracture in the lateral view. In type B fracture the Harris ring is intact as the fracture line is above this ring. In type C the fracture line is projected at the upper part of the Harris ring [15].

Type D fractures are not so uncommon (7 % found by Korres, et al. [1]). The axial loading, while the neck is in extension, as well as, a combination of applied forces, which act either simultaneously or not, are probably responsible for this injury. Although it is an unstable lesion, it seems to respond better to a non-surgical treatment.

This classification is considered more realistic since it is simple, it includes the whole spectrum of fractures, it refers only to one anatomical structure (the odontoid process), it correlates to the bio-mechanical characteristics of the axis, it indicates the prognosis of the different fracture types and it provides one with an adequate evaluation and management of these fractures. Fractures not involving the odontoid process, like the type III in the Anderson-D'Alonzo classification, could not be called odontoid fractures but rather fractures of the axis' body in terms of topographic anatomy.

Treatment

Nonsurgical

Fractures of the odontoid process should be divided into (a) stable and (b) unstable [6]; this is necessary in order to proceed with an efficient therapeutic plan. Stable injuries are managed conservatively, while unstable injuries are treated surgically. Fracture's instability depends mostly on the presence of associated lesions, the type of fracture and the initial displacement, particularly if there is vertical displacement.

Type A fractures are treated conservatively by using external mobilization, like a rigid cervical collar or a halo vest; rarely an operation should be required.

In type B fractures, although there are unstable, a controversy is still ongoing among different authors regarding the surgical approach and management of such lesions [16]. An initial conservative treatment should be attempted unless a score of more than 10 points is found [17].

In type C, either conservative or operative management is applied in relation to the instability these injuries present with.

In type D, the appropriate conservative management is offering excellent results. Several treatment modalities are proposed in the presence of this injury, but, before taking any decision, it is prudent, particularly in the elderly, to look for any clinical comorbidities that may affect the management, and to rule out any concomitant or double level fracture of the cervical spine.

Conservative treatment is suggested by the use of traction with the application of a Crutchfield skull tong, in order to reduce and stabilize the fracture or with the use of external immobilization like custom-made orthoses, halo vest or cervical collar. In case of application of traction, the weight applied should not exceed 2-3 kg, in order to avoid distraction of the fractured fragments. Special care must be given, not only to the application of traction, but, also, in its direction. Attention must be paid when traction in flexion is applied, because of the potential danger of a vertebral artery lesion or of a neurological injury which may induce respiratory compromise or other neurological conditions.

Stabilization must be kept for at least 4 to 6 weeks during which radiographic control of the position of the fracture is necessary, as well as careful examination for avoidance of complications related to the traction and prolonged bed rest. After this period the patient may be mobilized using a four-point support brace for a period of four to six more weeks. At the end of 10 to 12 weeks, dynamic x-ray views in flexion and extension are taken in order to detect any sign of instability. If instability is proven, then, surgical treatment must be considered. If no instability is detected and the fusion is complete, the patient must use a soft collar for a short period of time.

The use of a Halo vest is not always recommended as the rate of complication reported is as high as 26% with older patients suffering from severe discomfort. Even more, the traction obtained at the beginning, is slowly turned into compression, in the mobilized patient, resulting in malunion, if the reduction of the fracture has been lost due to sliding.

The fusion rate in the conservatively treated patients is reported to be from 35% as high as 85%, but this is related to their age and other parameters, like the time the treatment was applied, the type of the fracture and the initial displacement; the latter is correlated to the direction (anterior or posterior) the fracture is displaced towards. In addition, the traction applied leads sometimes to distraction of the fracture site; this leads to the development of late instability and pseudarthrosis.

Vieweg and Schultheib [18], in contrast to Wolter and Reimann [19], advocate the use of Halo vest in type II fractures, as the percentage of healing is as high as 85%, particularly in the non-displaced ones; they conclude, also, that in type III fractures, the application of a Halo vest is the treatment of choice as the healing rate is about 97%.

The fractures of the odontoid process are prone to complications either at the trauma scene or later in the hospital. Two of the complications appearing in a later period are very significant and have to be well clarified: pseudarthrosis and malunion. Most important is the pseudarthrosis these fractures may develop and the potential danger for late myelopathy or for direct injury of the spinal cord. According to the literature the percentage of pseudarthrosis related to the applied treatment, is 4% to 100 % for all types of fractures and consequently complicating their treatment. The predisposing factors which have been accused for pseudarthrosis include age, mechanism of injury, displacement, the blood supply of the odontoid process, the direction of the fracture line and the type of fracture. Also, the application of excessive traction, the stability of immobilization, the timing of immobilization, as well as the co-existence of another fracture, either in the atlas or even in the axis itself, should be considered carefully. The internal architecture of the axis seems to play an important role in the development of pseudarthrosis. Finally, the possibility of interference of the transverse ligament between the fragments may, also, cause difficulties in the reduction of the fracture, resulting in the development of pseudarthrosis.

Some authors may disagree as to the importance of some of the above factors. To our experience all the above mentioned factors play a certain role and contribute to the development of pseudarthrosis resulting in instability at the fracture site.

Age is an important factor towards pseudarthrosis since it has been proved that nonunion or pseudarthrosis is found at a higher incidence in patients over the age of 50 years. Fracture displacement according to Blokey and Purser [20] should not be correlated to pseudarthrosis. However, other authors did not accept this opinion. Appuzo et al. [21] described that an evident displacement of more than 4 mm should be considered predesposing to pseudarthrosis.

However, it is extremely difficult to be aware of the original displacement that was present at the time of the accident. The traction applied, as well as its direction, plays a significant role according to Ryan and

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Taylor [22]. This is due to the possibility of creating a greater wedging at the fracture level than the one acceptable, and to lead to a deformed odontoid process.

The type of fracture is also implicated in the development of pseudarthrosis since in fractures involving the neck of the dens as well as the direction of the fracture line this was in a rate of 32% and as high as 90%. In our experience the types A, C and D are prone to unite, while type B fracture have a high rate of pseudarthrosis, particularly the one that shown a posterior displacement of more than 5 mm or an angulation of more than 10 degrees.

There is no doubt that the presence of co-existing injuries, as well as a delay in the diagnosis or if the immobilization is not the proper one, then this will increase the instability of the fracture. The knowledge of these parameters as factors influencing the development of a pseudarthrosis, obliged us to proceed in their grading, according to the role each one plays. In this manner, the evaluation of a fracture is easier, as we will predict the risk for pseudarthrosis. It has been estimated that if the sum of the graded factors is greater than 10 points, then the fracture must be characterized as being at risk of pseudarthrosis and surgical treatment must be considered [1, 22].

The blood supply of the odontoid process is not considered to participate in the development of pseudarthrosis. Although a recent experimental study of ours revealed decreased blood supply at the area where type B fractures happen, which is the area where pseudarthrosis often develop [23]. Pseudarthrosis in the elderly is not always a major problem as it was proven; this is not accompanied always by a clinically significant instability due to the development of fibrous tissue at the fracture site. However operation has to be considered if instability persists or if signs of myelopathy are present.

Operative treatment of dens non-unions is not without risk, taking into consideration the age of the patients the high comorbidity those patients have and, also, knowing that the success rate is low.

The second most frequent and severe complication of the fractures of the odontoid process concerns their malunion [1]. Special care so must be given to this complication as may result in spinal canal stenosis which may induce, in long term, cervical myelopathy.

The greater the displacement and wedging of the fracture, the less the width of the spinal canal. This results in chronic compression or friction of the dura matter and the spinal cord on the upper posterior corner of the body of the axis and hence cervical myelopathy. The treatment of this complication is difficult. It requires anterior or posterior decompression combined with posterior fusion extending from the occipital bone to C1, C2 or C3 and even lower.

A number of minor complications may accompany a fractured odontoid. Stiffness, decreased range of motion, discomfort or even mild pain are easily managed with physiotherapy or other conservative methods. Younger patients respond better and an acceptable outcome is usually achieved.

Surgical treatment

Failure to treat conservatively a fractured odontoid is an indication for surgical intervention. Instability must be treated operatively as soon as possible. The operative treatment is suggested by many authors. There are several methods that allow the safe management of the unstable fractures. This is done by closed or open reduction, the use of osseous graft, and stabilization by means of a wire or nylon or use of metallic implant(s). Auto-graft is the most suitable material to be used for achievement of a stable fusion. The approach used is either anterior, lateral, posterior or combined.

Posterior stabilization includes:

Posterior C1-C2 wiring technique with Gallie's or Brooks' techniques [24] or other methods (**Fig 3**).

Anterior stabilization includes:

a. Application of a plate between the anterior arch of the atlas and the body of the axis or the vertebral body of C3.

b. Internal fixation with screw(s). This technique is gaining popularity, but indications have to be set very carefully as osteoporosis, fracture of the anterior wall of the body of C2, posterior displacement, comminuted or type D fractures or even a narrow diameter of the spinal canal are among the contraindications. The

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use of one or two screws depends on thw anatomical characteristics of the odontoid process [25] The osteosynthesis of the odontoid process permits a nearly normal function of the C1-C2 level [26] (**Fig 4**).

Lateral stabilization includes:

Fusion using the Dutoit technique. The lateral approach is used for a C1- C2 arthrodesis in case of traumatic instability, tumors or infections and for cases in which another exposure had been used previously, or a counterindication is present [27].

The surgical results seems to be better than these achieved with a non-operative management as the reported fusion rate is high between 80-100%. However, there is not unanimous acceptance of an appropriate treatment for patients with these fractures, particularly in the elderly population. (**Table I** summarizes the indications for the appropriated management of an odontoid fracture). Physiotherapy in both instances, has an important role to play in the final outcome those patients should have.

We can easily appreciate the importance of dens fractures; they need correct diagnosis and appropriated treatment trying to minimize the side effects to the patient and to the society. In the later, the financial cost is very important as in the last decade, the cost for the treatment of these fractures is very high with the increased hospitalization and the increased number of patients treated surgically [28].

Current literature supports the use of the Korres classification by both biomechanics experts [29] and surgeons [30]. This is due to the fact that this classification is biomechanically oriented as it is clinically and surgically. It is pinpointed that it comprises all significant fracture types, it is more relevant to the biomechanics and cause of injury [29], it is useful in decision making concerning treatment and it is more simple to use in everyday clinical and surgical practice [29,30] for decision making.

The study of cases by Korres et al. revealed some directions for the development and treatment of these fractures. It is showed that type A and D fractures can and should be treated conservatively; they usually have a good prognosis. Type B fractures are prone to further complications and hence should be treated – in their

TABLE I. *The Korres classification and its treatment options*

Type	Treatment
A	Conservative
B	Surgical or Conservative
C1	Conservative or Surgical
C2	Conservative
D	Conservative

majority surgically. Type C fractures need to be followed closely and in case of instability and/or late displacement have to be operated.

Conclusions

Fractures of the odontoid process represent a particular entity; they need a careful handling as their behavior is not easily predictable. Diagnosis of the correct type of fracture is very important. Complications due to multiple factors, are not rare and have to be carefully managed and treated. Pseudarthrosis is the most common complication related to many factors the most important being the instability at the fracture site.

The Korres classification has been proven successful and is now considered more realistic as it is simple, it includes the whole spectrum of fractures, it refers to one anatomical structure (the odontoid process), it correlates to the biomechanics of the axis, it indicates the prognosis and it suggests the management of the fracture.

The study of cases by Korres, et al. revealed some directions for the development and treatment of these fractures. It is showed that type A and D fractures can and should be treated conservatively; they usually have a good prognosis. Type B fractures are prone to further complications and hence should be treated – in their majority surgically.

Type C fractures need to be followed closely and in case of instability and/or late displacement have to be operated.

Conflict of interest:

The authors declared no conflicts of interest.

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Markatos KN, Efstathopoulos NE, Kaseta M-K, Lazaretos J, Chytas DS, Nikolaou VS. Classifications for the odontoid fracture: The significance and application of the "Korres classification". *Acta Orthop Trauma Hell* 2018; 69(3): 139-148.

ΠΕΡΙΛΗΨΗ

Περιγράφονται και αξιολογούνται τα συστήματα ταξινόμησης των καταγμάτων του οδόντος ενώ αναπτύσσεται η ταξινόμηση «Κορρέ».

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: Κατάγματος Οδόντος, Ταξινόμηση Κορρέ

A closed degloving injury of the fifth toe: a case of empty toe

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ABSTRACT

Empty toe injury is a rare type of closed degloving injury; only seven cases have been reported previously, with controversial outcomes. Our case is a 22 year old male who was drafted by a trolley bus. The patient presented at our emergency department with extensive swelling of the right foot, deformity of the fifth toe, bruising and intact skin. On clinical examination the phalangeal bone could not be palpated in the fifth toe and there was no capillary refill. The patient was immediately taken to the operating room and underwent open reduction combined with fasciotomies. The toe regained perfusion after the reduction and was under close observation to ensure its viability. Finally the distal and part of the middle phalanx of the toe was amputated. The purpose of this report is to inform health providers about this unique type of injury and contribute to a more sufficient treatment plan.

Keywords: closed degloving injury; toe; compartment syndrome

Introduction

Closed degloving injuries are rare and occur as a result of a violent shearing force applied across the skin surface that separates the skin and subcutaneous soft tissue from the deeper fascia planes without rupture of the dermal or epidermal tissue plane. The shear force transects the perforating vessel anastomoses between the tissue planes, creating a resultant void, liquefied fat necrosis and vascular injury [1,2]. The management of closed degloving injuries is not as well established as in open degloving injuries due to the rarity of such cases. To the best of our knowledge only seven cases have been documented describing "empty-toe" and "closed degloving injuries" specific to the lower extremity and only one case of "empty thumb". According to the literature in four cases amputation of the toe was the final outcome (**table**).

Material and Methods

A 22 year old male motorbike driver was treated from July 2017 until December 2017 in our department. He presented in the emergency room after he was drafted by a trolley bus, with no other injuries. His right foot was swollen, with a deformity of the fifth metatarsal and of the fifth toe but the skin was intact. The fifth toe was extremely flexible, insensate and with no capillary refill. The rest of the foot

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TABLE. *Review of the literature*

Author	Age	Sex	Mechanism of injury	Injured toe/finger	Circulatory status	Treatment	Outcome
Matelic and Manoli	38	M	His left foot and leg were caught under the wheel of a forklift	Fifth toe	No evidence of capillary refill but regained normal color after open reduction	Open reduction	Returned to normal activities as tolerated
Flaherty et al.	46	M	A forklift truck ran over his left foot	Secondary toe	Distal circulation was absent	Closed reduction	Amputated
Singh and Downin	33	F	A truck ran over her right foot	Fifth toe	Capillary refilling was sluggish	Open reduction	Amputated
Chen-Ling Tang MD	20	F	Foot was stuck between 2 collided motorcycles	Fifth toe	Capillary refilling was sluggish	Open reduction	Amputated
Andrew A. Tarleton	25	M	Twisting injury in a motorcycle accident	Fifth toe		Open reduction and K-wire.	Gangrene auto-amputated
Adam L. Bingham	27	M	Foot was crushed by train car wheel	Dislocation of hallux IP,translocation of toes 2,3,5	intact biphasic dorsalis pedis and posterior tibial pulses	Open reduction and K-wires	Transmetatarsal amputation
Adam L. Bingham	60	M	a hydraulic fork lift was driven over his left foot	fifth toe	dorsalis pedis and posterior tibial arteries were intact	Closed reduction, K-wire	Non amputated-chronic pain
Our case	22	M	RTA	Fifth toe	the digital arteries of the fifth toe could not be found on Doppler scan	Open reduction	Partial amputation

was neurovascularly intact. The dorsalis pedis artery was palpable, but the digital arteries of the fifth toe could not be found on Doppler scan.

Plain imaging identified a dislocation of the fifth toe with only the distal phalanx being contained under the skin. (**Figures 1,2**) There was also a nondisplaced fracture of the fourth metatarsal. Treatment The patient underwent immediate open reduction and fasciotomies of the foot compartments, in the operating theatre. After reduction the skin colour immediately improved and digital artery pulses were identified by Doppler. The patient could feel the touch of a 14G needle in the whole dorsal and plantar area of the foot including the fifth toe. The foot was placed in a cast and elevated. The patient was on a strict non weightbearing status for the first

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Fig. 1: *Preoperative AP Radiograph Note the displacement of the 5th proximal and part of middle phalanx in the web space. Fracture of the neck of the fourth metatarsal*

Fig. 2: *Post reduction and fasciotomy clinical image. Use of the shoelace technique for wound closure. Note the normal color of the fifth toe indicating adequate return of perfusion.*

Fig. 3: *Post amputation Radiograph. Note the absence of distal and part of the middle phalanx and fracture of the neck of the fourth metacarpal.*

Fig. 4: *Post amputation clinical photograph. Almost complete healing of the fasciotomy wound and no signs of ischaemia around the stump.*

2 weeks, and was under enoxaparin 4000IU and acetylsalycilic acid 100mg once per day. However, 48 hours after the operation the distal phalanx of the fifth toe displayed signs of inadequate perfusion and necrosis as there was no capillary refill and no sensation of the plantar area of the distal phalanx, while the rest of the toe seemed normal. We decided to wait and observe the progress of the necrosis.

Results

Five days postoperatively the patient was discharged and he was followed up as an outpatient every three days. The patient started hyperbaric oxygen therapy ten days after the fasciotomies. He completed three hyperbaric oxygen sessions within twelve days. The toe was evaluated for edema, sensation, and temperature in the follow up visits. Outcome One month after injury the necrotic area of the middle and distal phalanx that included the nailbed was amputated. The patient had uneventful wound healing and has had painless ambulation on the affected limb at the six month postoperative visit.

Discussion

Reviewing the literature available we could only find seven previously reported similar cases and one case of "empty thumb". The earliest case was reported by Metalic and Manoli in 1994. A crush injury with degloving and translocation of the fifth digit into the fourth web space was described, treated with closed reduction which led to immediate restoration of perfusion. The patient was placed in a walking cast for one week, after which he returned to his normal activities with no

Fig. 5: Final Radiograph. Union of the fourth metacarpal neck fracture.

Fig. 6: Final clinical photograph. Complete healing, no signs of hypoperfusion.

subsequent complications [3]. In 1998 Flaherty et al reported a similar injury of the second toe. A forklift truck ran over the patient's left foot, distal circulation was absent, the digital soft tissue envelopes were unsalvageable, and the patient underwent transametatarsal amputation [4]. The third case was reported by Singh and Dowinf. A 33 year old female, had her right foot run over by a truck with injury of the fifth toe. The capillary refill was sluggish and the toe was amputated. Moreover, Tang et al reported a similar case of the fifth toe which underwent open reduction and fasciotomies, but eventually, after one week amputation was necessary [5]. Auto-amputation was the final outcome in the case described by Page 2 of 13 3 Tarleton et al. It concerns a 25-year-old man who sustained a twisting injury to his left foot in a motorcycle accident. Open reduction of the fifth toe was performed and it was immobilized by a Kirschner wire, the patient was placed into short leg splint and the toe appeared viable that time. On day twenty the patient presented to the emergency department diagnosed with a deep venous thrombosis. One month after the injury the patient developed dry gangrene of the toe [5]. Bingham et alreported two cases. The first case, was a crush injury with dislocation of the right interphalangeal joint and translocation of the second digit, also complete translocation of the third digit with reentry into the second digit soft tissue envelope and of the fifth digit into the fourth digit soft tissue envelope. Fasciotomies of the second, third interosseous and deep central compartments were performed, closed reduction was performed with intraoperative fluoroscopic assistance. Kirschner wires were used to maintain the reduction and stabilize toes 2 through 5 [6]. At about seven months the patient agreed to transmetatarsal amputation due to complex regional pain syndrome [6]. The other case of A.L. Bingham was a crush injury with transposition of the fifth digit into the fourth web space and distal tuft fractures of the distal phlanges of digits 3 through 5. Open reduction with K-wires was performed to stabilize the fifth digit and distal tuft fracture and keep the toe in its soft tissue envelope [6]. At week ten the patient presented deep vein thrombosis. The toe was not amputated after 16 months follow up, but the patient complained of chronic pain and disability. Empty toe injury is an extremely rare type of injury that could provoke a great amount of disability. In case it is not on time recognized and managed could lead to amputation. The purpose of this report is to describe this rare injury and suggest that clinicians should work on a common therapeutic policy so as the patient to have the best therapeutic results.

Conflict of interest:

The authors declared no conflicts of interest.

VOLUME 69 | ISSUE 3 | JULY - SEPTEMBER 2018

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Kyriakopoulos G, Vlachou M, Kotsarinis G, Oikonomou L, Kateros K. A closed degloving injury of the fifth toe: a case of empty toe. *Acta Orthop Trauma Hell* 2018; 69(3): 149-153.

ΠΕΡΙΛΗΨΗ

Περιγράφεται η σπάνια περίπτωση απογαντισμού δακτύλου ποδός τύπου «empty toe» σε νεαρό άρρενα ηλικίας 22 ετών μετά από εμπλοκή του σε τροχαίο ατύχημα.

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: Απογαντισμός δακτύλου, σύνδρομο διαμερίσματος