Asymmetric Head Gear: A Comparison between Unilateral Outer Bow Expansion and Unilateral Outer Bow Shortening – an Energy Approach using the Finite Element Method

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Objective: *To compare the influence of outer bow length difference and unilateral outer bow expansion on the 'asymmetric effect' of the headgear.*
Methods: *Twelve 3D finite element models of a headgear with two tubes were designed, which were similar except for the outer bow length or the degree of unilateral expansion in SolidWorks 2011. A 3N force was applied to the outer bow ends in ANSYS Workbench 12.1 and the distalising, lateral forces to molars, moments and the energy of the system were evaluated.*
Results: *As the degree of unilateral expansion increased, the net differences in all findings were increased up to a point, and then changed. There was an increasing pattern in the length difference group. Buccal movement was observed in the intact/shorter side molar.*
Conclusion: *Unilateral shortened outer bow asymmetric headgears are more efficient and more predictable in clinical application than the unilateral outer bow expansion.*
Key words: *asymmetric cervical headgear, finite element method, unilateral expanded, unilateral shortened,*
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Unilateral class II malocclusion, with aetiologies like premature loss of deciduous molars in one side[1], require asymmetric distalising forces for treatment. The treatment options selected by orthodontists include asymmetric headgear, asymmetric protocols for extraction, unequal elastic patterns, intraoral appliances and temporary anchorage devices[2-7]. Asymmetric headgear has been used over in orthodontic practice before. Block designed a model to compare force distribution of two off-center extraoral appliances with a symmetrical one, and added uneven elastic traction with a midline appliance. He stated that we cannot extrapolate experimental conclusions regarding the clinical condition for factors such as mandibular displacement, occlusion and pillow habits; for example sleeping on one side frequently, unusual neck contour and improper gear insertion. These can convert an asymmetric headgear to a symmetric headgear and vice versa[8]. Hershey et al compared five different headgears as follows: power-arm, swivel offset, spring attachment, soldered offset bow and bilateral symmetrical. They reported that the two initial designs were effective at delivering unilateral forces[9]. According to Yoshida et al, in the side of the heavy traction force, usually lingual crossbite is seen and in the other side, a buccal crossbite is seen, whereby overjet differs in the two sides[1]. Chi et al, with the aid of elastic theory calculated vertical and lateral forces of asymmetric headgear. With regard to PDL stiffness, location of face bow junction, outer arm

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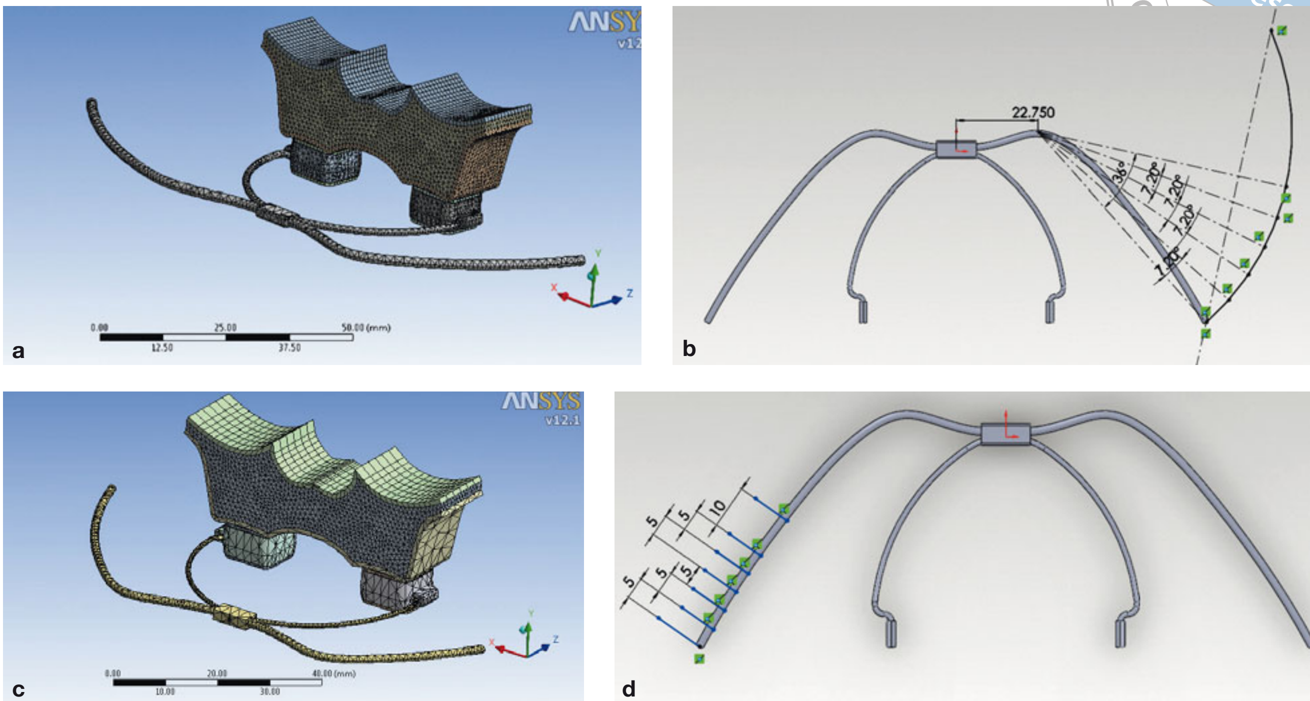

Fig 1 **a)** The 3D model of a slice of maxillae with the first molars, their PDLs, upper molar bands, spongy and cortical bone, and a unilateral expanded cervical headgear (the right side outer bow is expanded). **b)** Unilateral outer bow expansion. The angle formed between the extreme positions of the outer bow has been divided to have headgears with gradual expansion. The straight line (TT') in the right side is the tangent of the right outer bow end to the neck. The right outer bow was expanded with the center in "A". The arc segment limited by the TT' shows the end point of the outer bow, with gradual steps of expansion. It can be observed that the highest possible expansion with the unilateral effect is one that reaches the most prominent part of the arc (36 degrees in this headgear). More expansions will reduce its unilateral force system, due to its reoccurrence viewed after passing from the most prominent point in the segment cut by TT', to a less prominent part of the arc, when viewed from the right tangent point of TT' and the neck. **c)** The same 3D model cervical head gear that has unequal outer bow lengths (the left outer bow is shortened). **d)** Unilateral outer bow shortening is shown with 5 mm, 10 mm, 15 mm, 20 mm, 25 mm and 35 mm shortening in the left outer bow.

asymmetry and the length of the inner bow terminal, they concluded that outer arm asymmetry and PDL stiffness are the main determinants of distal forces in the power-arm model. They aimed to approximate *in vitro* findings with clinical conditions[10]. Geramy et al evaluated the effect of different unilateral outer bow expansions of asymmetric headgear on distal and lateral forces[11]. They concluded that evaluating net moments produced by this asymmetric headgear can be best carried out with FEM, and based on their results, there are details in asymmetric headgear clinical adjustment that are mostly neglected by current literature. The outer bow length difference is also assessed by Geramy et al, in order to clarify the force systems on terminal molars produced[12]. They concluded that increasing the length difference in the outer bows would produce unequal distalising forces on terminal molars, a lateral driving force, which is in accordance with previous literature[1,10,13,14]. They also showed a yawing moment, which tends to rotate the system clockwise or counterclockwise when viewed from above the patient's head, according to the shorter and longer outer bow arm sides. Geramy and his colleagues assessed an unintentional type of asymmetric headgear formed by the unequal distance of molars to the midline. They showed unequal distal forces when a symmetric cervical head gear was loaded by symmetric forces[15].

The finite element method (FEM) subdivides a system into individual components or 'elements' whose behaviour is readily understood and enables one to rebuild the original system so that its behaviour can be understood[11]. The FEM has been used to study a number of different problems in orthodontics, which resulted in proving its efficiency with regard to various kinds of questions arising from basic to clinical topics[16-20]. The aim of this study is to compare the effect of unilateral outer bow shortening and unilateral outer bow expansion on distal and lateral forces, produced by asymmetric headgear, via a 3D finite element analysis (FEA). In other words, the efficiency and predictability of the unilateral distalising force will be assessed.

Materials and methods

Twelve 3D finite element models of an anteroposterior slice of the maxilla, containing cortical and spongy bone, right and left upper first molars, their PDLs, molar bands and headgear were designed. The models were the same except for the outer bow form which was symmetric in model 1; unilaterally (right side) expanded in models 2 through to 6 and unilaterally shortened (left side) in models 7 to 12.

According to Geramy et al[11,12], five different positions between the symmetric outer bow and the most expanded bow were designed. An arc was drawn with the center in the most anterior point of the outer bow, which divided the angle of outer bows between the two extremes of outer bow positions (the symmetric position and the most expanded one). In this way, the gradual unilateral expansions of the outer bow were almost the same between models 2 to 6. In models 7 to 12, the left outer bow was shortened 5 mm, 10 mm, 15 mm, 20 mm, 25 mm and 35 mm, respectively. The wire diameter was 1.6 mm and 0.9 mm for the outer and inner bow, respectively (Figs 1a to 1d).

The models were designed in SolidWorks 2011 (Massachusetts, USA) and then transferred to ANSYS Workbench Version 12.1 (Pennysylvania, USA) for the solving process. To find the angles formed between the outer bow and its tangent to the neck, accurate trigonometric calculations were made by using SolidWorks. Linear measurements were derived from an average of the findings of 10 volunteer dental students, measured by a clinical caliper. These dimensions were used in decomposing a 3N force vector in the horizontal plane. In this way, the exact force components in the anteroposterior and mediolateral directions were found; which were later used in the ANSYS Workbench for the analysis phase. Statistical analysis was done by using force components that were calculated in the previous stage. The bends of the outer bow under loading were analysed. Headgear and tubes were made of stainless steel. Material properties were defined according to Table 1. Meshing was carried out by the powerful meshing program in the Workbench. Meshed models contained 142486 nodes and 84023 tetrahedron elements. Outer bow ends were loaded with a 3N force vector in the horizontal plane decomposed in the mediolateral and anteroposterior direction (Figure 1). The distalising force to the molars, the lateral force to the molars, the moments, and the energy of the system that was transferred to the right and left sides of the molar tubes, plus the net difference, were evaluated. The vertical component of the force and its effects on the terminal molar was ignored to make the results easier to interpret. The geometric non-linearity was allowed, if any existed.

Table 1 The mechanical properties of the materials used in the models.

	Young's Modulus (MPa)	Poisson's Ratio
Tooth	20300	0.26
Spongy Bone	13400	0.38
Cortical Bone	34000	0.26
PDL	0.667	0.49
Stainless Steel	200000	0.30

Results

Distal force

The numerical data of the distal force on molars are shown in Table 2. As the degree of unilateral expansion increased, the amount of distal force on the expanded side molar was increased (from 3.2395 N in model 2 to 3.6777 N in model 6). The distal force in the intact side decreased between model 2 (2.9575 N) and model 6 (2.1038 N). In the series of length differences, the more the outer bow length difference was prepared, the more the net distal force generated, i.e. the asymmetric effect. In other words, from model 7 through to 12, the increase of distal force and subsequently the distal movement of teeth was seen. Distal force increased from 3.1197 N in model 7 to 4.2189 N in model 12.

Lateral force

Lateral forces in two sets of models followed the same pattern as the distal force. In the outer bow length asymmetric headgear, the shorter side showed buccal movement of teeth (1.72 N on average) and in the intact side, lingual movement of teeth (1.41 N on average) was seen. In the unilateral expansion model, the finding was 1.66 N on average for the intact side molar and 1.40N (average) on the expanded side molar. Numeric findings are presented in Table 3.

Table 2 Distal force findings in two asymmetric headgears (N).

Unilateral outer bow expansion				Unilateral outer bow shortening			
	Left/intact (N)	Right/ expanded (N)	Difference (N)	Left/ short (N)	Right/intact (N)	Difference (N)	
Symmetric	2.93	2.93	0	2.93	2.93	0	Symmetric
Model 2	2.5759	3.2395	0.664	2.7581	3.1197	0.3616	Model 7
Model 3	2.3355	3.4566	1.12	2.5869	3.3075	0.7206	Model 8
Model 4	2.1855	3.5919	1.41	2.4153	3.4918	1.0765	Model 9
Model 5	2.1116	3.663	1.55	2.2423	3.6744	1.4321	Model 10
Model 6	2.1038	3.6777	1.57	2.0726	3.8506	1.778	Model 11
-	-	-	-	1.7098	4.2189	2.5091	Model 12

Table 3 Medial force findings in two asymmetric headgears (N).

Unilateral outer bow expansion			Unilateral outer bow shortening		
	Left/intact (N)	Right/ expanded (N)	Left/shortened (N)	Right/intact (N)	
Symmetric	0.0016	0.0016	0.0016	0.0016	Symmetric
Model 2	1.6270	1.4600	1.6090	1.5100	Model 7
Model 3	1.6797	1.3886	1.6631	1.4665	Model 8
Model 4	1.6847	1.3851	1.7141	1.4236	Model 9
Model 5	1.6748	1.3964	1.7621	1.3821	Model 10
Model 6	1.6748	1.3964	1.8089	1.3422	Model 11
-	-	-	1.8017	1.3612	Model 12

Moment

The moments generated in expanded and shortened sides are summarised in Table 4. As the degree of expansion was increased, the pattern of net moment modification was to increase up to model 5 (-8.245 N.mm) and then decrease in model 6 (-5.774 N.mm). The trend was not the same in shortening models (model 7 to 12). Unilateral shortening outer bow models showed an increase in the net moment from -2.589 Nmm in model 7 to -12.384 Nmm in model 12.

Energy

The numeric findings for energy produced by loading in the right and left side molars are summarised in Table 5. These findings are in accordance with the moments in Table 4. The pattern of net energy change in unilateral outer bow expansion is to increase between model 2 (8.099×10^{-4} mJ) and model 5 (1.5077×10^{-3} mJ) and decrease between model 5 and model 6 (1.4421×10^{-3} mJ). The pattern in unilateral shortened outer bow models, shows an increase between model 7 (5.096×10^{-4} mJ) and model 12 (2.3209×10^{-3} mJ).

Discussion

This study aimed to compare the effects of two asymmetric headgears in distal and lateral forces and the moments generated on molar teeth or the whole dentition. Different methods were found in the literature that evaluates the effects and side effects of asymmet-

Table 4 Moment findings in two asymmetric headgears (N.mm).

	Unilateral outer bow expansion			Unilateral outer bow shortening			
	Left/intact (N.mm)	Right/ expanded (N.mm)	Net moment (N.mm)	Left/short (N.mm)	Right/ intact (N.mm)	Net moment (N.mm)	
Symmetric	-28.569	28.588	0.019	-28.569	28.588	0.019	Symmetric
Model 2	-30.547	26.199	-4.348	-29.954	27.365	-2.589	Model 7
Model 3	-31.527	24.902	-6.625	-31.288	26.235	-5.053	Model 8
Model 4	-32.107	24.244	-7.863	-32.569	25.089	-7.48	Model 9
Model 5	-32.336	24.091	-8.245	-33.766	23.965	-9.801	Model 10
Model 6	-30.09	24.316	-5.774	-34.934	22.883	-12.051	Model 11
-	-	-	-	-35.164	22.78	-12.384	Model 12

Table 5 Energy findings in two asymmetric headgears (mJ).

	Unilateral outer bow expansion			Unilateral outer bow shortening			
	Left/intact	Right/ expanded	Difference	Left/shortened	Right/intact	Difference	
Symmetric	1.7744E-03	1.7744E-03	0.0000E+00	1.7700E-03	1.7700E-03	0.0000E+00	Symmetric
Model 2	2.2153E-03	1.4054E-03	8.0990E-04	2.0850E-03	1.5754E-03	5.0960E-04	Model 7
Model 3	2.4224E-03	1.2261E-03	1.1963E-03	2.3343E-03	1.4011E-03	9.3320E-04	Model 8
Model 4	2.5535E-03	1.1265E-03	1.4270E-03	2.5849E-03	1.2364E-03	1.3485E-03	Model 9
Model 5	2.6094E-03	1.1017E-03	1.5077E-03	2.8930E-03	1.0845E-03	1.8085E-03	Model 10
Model 6	2.5665E-03	1.1244E-03	1.4421E-03	3.0925E-03	9.4919E-04	2.1433E-03	Model 11
-	-	-	-	3.2161E-03	8.95E-04	2.3209E-03	Model 12

ric headgears: experimental methods *in vitro*, *in vivo* evaluation with a magnet and FEM analysis. The present study used 3D FEM analysis.

The first series showed unilateral gradual expansion (model 2 to 6). The second series represented headgears with different outer bow lengths in two sides. Chi et al[10] also assessed similar models; they analysed vertical and lateral forces of asymmetric headgear in relation to PDL stiffness, face-bow joint location, outer arm asymmetry and the length of the inner-bow terminals. They simulated PDL stiffness with a spring and found that with the presence of PDL, the difference in forces, both lateral and distal, is smaller in magnitude than without it. Nevertheless, in the power-arm model, joint location was less important than outer arm asymmetry in determining distal forces. This was in agreement with our study: outer bow expansion asymmetric headgear was not as predictable as outer bow length difference asymmetric headgear in exerting lateral and distal forces. Moreover, the forces and moments were dependent on the amount of expansion up to a point; a small amount of expansion could be offset by traction force, and the asymmetric headgear behaved as a symmetric one , in terms of applied forces. It is worth mentioning that the headgear may apply equal forces to the terminal molar, but to some degree, the net moment produced may be present, that a net yaw moment would produce. It meant that under traction force, the position of the expanded arm would change. In addition, we found that by increasing the amount of expansion, the force difference did not increase continually; it increased up

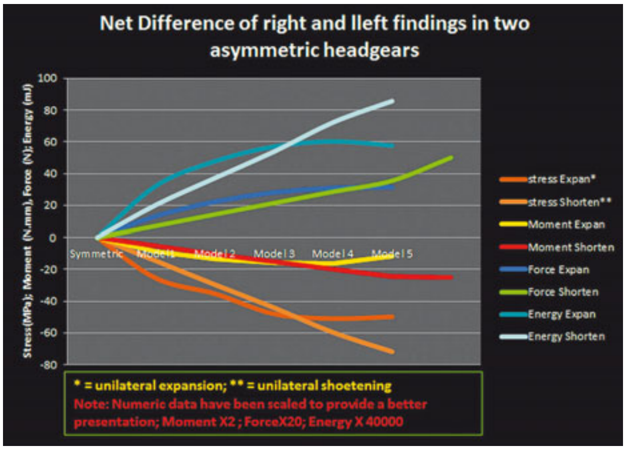

Fig 2 Numerical findings of net differences superimposed to show facts about inefficiency or unpredictability of unilateral outer bow expansion headgears. The crossing point shows that unilateral outer bow expansion can be relied on up to a point beyond which its efficiency decreases. Regardless of the nature of the findings, crossing of the curves indicates a limited range of asymmetric headgears that can be predicted to exist when outer bows expand unilaterally.

to a point, and then began to decrease after it passed the most prominent point of the path.

Nobel and Waters found that the amount of lateral force in the heavy-force side was smaller than the light-force side[21]. Yoshida et al approved these results in their *in vivo* study[1] and Chi et al confirmed it by simulating the PDL elasticity[10]. Therefore, we suggest that, in order to maximise the force difference in outer bow expansion asymmetric headgear, the bend should be placed on the center of the curvature, not in the inner/outer bow connection point. As Chi et al concluded, an asymmetric joint rather than a midline joint could prevent undesirable crossbite. Otherwise, it can be prevented by an asymmetric inner bow[10]. In outer bow arm expansion asymmetric headgear, a net moment was produced that tended to rotate molars or whole dentition around the third axis of space, which was dependent on the attachment mechanisms. This effect is called the yawing moment. If the expanded arm was on the right side, the molar tooth or dental arch would rotate clockwise and if the expanded arm was on the left, it rotated counterclockwise from the point of view of a witness eye standing above the patient's head.

Energy is the ability to do work. According to the work-energy principle, the work carried out by forces acting on a particle is equal to the change of energy in it[22]. Analysing the energy transferred to the buccal tubes can provide an image of the work that is expected in the system in both molars. Work and energy are considered equal. The net energy difference between two molar tubes can be considered as an indicator of the difference between the molar displacements. The more energy difference that is produced, the greater the difference in tooth displacement expected to occur.

Figure 2 is a combination of net differences produced by two types of asymmetric headgear. It is worth mentioning that the efficiency of an asymmetric headgear is measured by some of these net differences. Regardless of the type of findings, the curves drawn to present the same net difference in unilateral outer bow shortening and unilateral expansion crossed each other. This shows that the unilateral outer bow expansion is not as effective as the unilateral outer bow shortening in producing asymmetric effects; these findings were scaled in order to be presentable for the same image. In other words, the efficiency to produce asymmetric headgear can be considered to be moving parallel up to a point and more efficient asymmetric headgears can be considered to exist exclusively with unilateral outer bow shortening. Geometrical issues are the limiting factor in the process of making unilateral shortening headgear. It is widely known that the unilateral force produced in headgears, regardless of the manner of the production, slides the main force vector towards one side molar (i.e. to be decomposed between molars)[23].

According to the results of this FEM study, unilateral shortening outer bow headgears can be made by using the available distance between the midline and one molar in a predictive manner; while the results are not so predictive for the unilateral outer bow expansion. The main limiting factor in this process is the distance of the midline to one side molar.

Conclusion

Based on the present FEM study, despite its limitations, it can be concluded that unilateral shortened outer bow asymmetric headgears are more efficient and more predictable in clinical application than the unilateral outer bow expansion.

Conflicts of interest

The authors reported no conflicts of interest related to this study.

Author contributions

- Dr Allahyar Geramy for the basic idea, for FEM modelling, analysis and approval of the final version of the manuscript.

- Dr Domingo Martin and Dr Joseph Bouserhal for suggesting two different ideas worth being assessed and providing documents relating to their clinical experience.
- Dr Emadian and Dr Hassanpour for reviewing the literature, preparing the primary draft and finishing the revised text.

References

1. Yoshida N, Jost-Brinkmann PG, Miethke RR, König M, Yamada Y. An experimental evaluation of effects and side effects of asymmetric face-bows in the light of in vivo measurements of initial tooth movements. Am J Orthod Dentofacial Orthop 1998;113:558–566.
2. Gelgor IE, Karaman AI, Buyukyilmaz T. Use of the intraosseous screw for unilateral upper molar distalization and found well balanced occlusion. Head Face Med 2006;2:38.
3. Keles A. Maxillary unilateral molar distalization with sliding mechanics: a preliminary investigation. Eur J Orthod 2001;23:507–515.
4. Pancherz H. The mechanism of Class II correction in Herbst appliance treatment. A cephalometric investigation. Am J Orthod 1982;82:104–113.
5. Rothenberg J, Campbell ES, Nanda R. Class II correction with the Twin Force Bite Corrector. J Clin Orthod 2004;38:232–240.
6. Shroff B, Lindauer SJ, Burstone CJ. Class II subdivision treatment with tip-back moments. Eur J Orthod 1997;19:93–101.
7. Karaman AI, Basciftci FA, Polat O. Unilateral distal molar movement with an implant-supported distal jet appliance. Angle Orthod 2002;72:167–174.
8. Block AJ. An analysis of midline and off center extraoral force. Angle Orthod 1954;24:1–7.
9. Hershey HG, Houghton CW, Burstone CJ. Unilateral face-bows: a theoretical and laboratory analysis. Am J Orthod 1981;79:229–249.
10. Chi L, Cheng M, Hershey HG, Nguyen T, Ko CC. Biomechanical reevaluation of orthodontic asymmetric headgear. Angle Orthod 2012;82:682–690.
11. Geramy A, Mortezai O, Esmaily M, Darvishpour H. Unilateral Outer Bow Expanded Cervical Headgear Force System: 3D Analysis Using Finite Element Method. J Dent (Tehran) 2015;12:271–280.
12. Geramy A, Hassanpour M, Emadian Razavi ES. Asymmetric Outer Bow Length and Cervical Headgear Force System: 3D Analysis Using Finite Element Method. J Dent (Tehran) 2015;12:216–225.
13. Baldini G. Unilateral headgear: lateral forces as unavoidable side effects. Am J Orthod 1980;77:333–340.
14. Breier M, Drescher D, Bourauel C. The lateral and transverse forces with indirect headgear and its modifications [In German]. Fortschr Kieferorthop 1993;54:83–90.
15. Geramy A, Kizilova N, Terekhov L. Finite element method (FEM) analysis of the force systems produced by asymmetric inner headgear bows. Aust Orthod J 2011;27:125–131.
16. Geramy A. The same amount of CRes displacement in various orthodontic tooth movements while the applied force is remained constant: 3D analysis using finite element method. J Dent Shiraz Univ Med Sci 2002;3:59–65.
17. Geramy A. Moment/Force ratio and the center of rotation alteration: 3D analysis by means of the FEM. J Dent Shiraz Univ Med Sci 2000;2:26–34.
18. Geramy A. Stresses around a miniscrew. 3-D analysis with the finite element method (FEM). Aust Orthod J 2009;25:104–109.
19. Geramy A. Cervical Headgear force sysem: 3D analysis using finite element method. J Dent Shiraz Univ Med Sci 2000;2:21–30.
20. Geramy A. Optimization of unilateral overjet management: three-dimensional analysis by the finite element method. Angle Orthod 2002;72:585–592.
21. Nobel PM, Waters NE. Investigation into the behavior of symmetrically and asymmetrically activated face-bows. Am J Orthod Dentofacial Orthop 1992;101:330–341.
22. Pytel A, Kiusalaas J. Engineering mechanics: dynamics, ed 2. London: Cenange Learning EMEA, 2001:136.
23. Nikolai RJ. Bioengineering: Analysis of Orthodontic Mechanics. Philadelphia: Lea & Febiger,1985:325–335.