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V-bend force system: 3D analysis using Finite Element Method

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ABSTRACT

Aim: Several bracket characteristics are now in market. Preformed archwires are used without frequent need to add bends. V-bends are used in many situations. This bend as a basic maneuver is assessed thoroughly in this study.

Materials and Methods: Finite Element Method (FEM) was selected to analyze the situation. A 3D model of two maxillary central incisors with their supporting structures and an archwire were modeled. A V-bend in different positions relative to the teeth was defined. Forces produced were monitored.

Results: Center V-bend ($a/L=1/2$) produced two moments in opposite direction. Moving towards one tooth added vertical forces in opposite direction . At $a/L \simeq 1/5$, intrusive movement was noticed; while signs of intrusion and change in angulation was detected at $1/10< a/L<1/5$. When a/L reached 0.42/6.408 same direction of moments were shown.

Conclusion: V-bend force system is quite sensitive to its position.

Keywords: Orthodontic wire bends, V-bend, Force system, Finite element method
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In spite of adding different characteristics to brackets such as various base thicknesses, angulations of the bracket slots, and built-in torques to reduce the inaccuracies caused by bending wire, bends are needed in many ways in orthodontic treatments. Categorizing and suitable application of these bends will help us follow the nearest way from malocclusion to an acceptable occlusion and prevent unwanted side effects which is the goal of the biomechanics.[1] Normal variation in tooth form necessitates using different kinds of wire bends to settle the occlusion and accomplish treatment satisfactorily.

Bends are useful in many ways, root parallelism, in the process of the extraction site closure, tipping back the terminal molar for anchorage purposes. V-bends have different names depending on their position and purposes.[2]

Less than half a century ago finite element method (FEM) was introduced in aerospace industry and soon entered in biologic sciences. From the very beginning of its application in biologic sciences, FEM has proven its efficiency in different ways from confirming a basic topic[3] to evaluating a theoretic background[4] and from normal situations concerning tooth movements[5] to special situations like alveolar bone resorption in orthodontic tooth movements[6,7,8] and from extra oral force application in orthodontics[9] to optimization of orthodontic mechanotherapies[10] or treatment procedures[11] and also in finding an answer to a clinical question[12].

Burstone and Koenig[13] presented an excellent classification of wire bracket relationships and discussed the force systems produced in each situation. In 1988 the same authors published a detailed survey of the forces generated by step and V-bend[14]. Clinical application of a V bend in canine

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retraction has been clearly evaluated by Siatkowski[15].

Material and Method

A three-dimensional (3D) finite element model (FEM) of two maxillary central incisors and an archwire was designed. The model consisted of 7165 nodes and 25761 elements (Fig. 1) based on Ash's dental anatomy[16] with minor modifications to obtain the best shape. 3D brick isoparametric octahedral element was chosen to construct the solid model and 3D beam element to construct the archwire. The model contained the upper central incisors, PDM, spongy and cortical bone and 13 archwire models with the same shape except for the position of the V-bend. At each phase, one of the archwires has been assembled to the 3D solid model.

The roots were split into fifteen levels of varying vertical heights (Fig. 1). The boundary condition is important in FEM and reflects the real situation of the body under study. This characteristic shows the manner of movements that occur at the nodes and their relationships. All the nodes at the base of the model were fixed so as not to move when subjected to force systems. The analyses were performed on a Pentium IV personal computer by ANSYS Ver.5.4 (ANSYS Inc. Southpointe, 275 Technology Drive Cononsburg PA 15317, USA). In this study, Poisson's ratio of the PDM was assumed to be 0.49, which gives an incompressible nature to it and explains its biological characteristics rather accurately (Table 1).

Archwire insertion was modeled by defining real relationships between a definite point of the archwire and tooth. It is called constraint in FEM modeling. In this way, some given parameters between two or more points in a part of the model are related to other points. Points of interest on tooth surface were similar to mesial and distal wings of the brackets. Interbracket distance was assumed to be 6.408 mm. Harmonic movements between these points will be considered. This is the method by which bracket engagements were modeled.

Table-1. Mechanical properties of the structural elements of the study

Material	Young's Modulus (N/mm2)	Poisson's Ratio
Tooth	20300	0.30
PDM	0.667	0.49
Cortical Bone	34000	0.26
Spongy Bone	13700	0.38
Orthodontic Archwire	180000	0.26

Archwire ends were modeled so that all kinds of displacements were restricted except for the mesio-distal one.

At each phase, force data for the defined nodes on the tooth surface resembling bracket wings were derived, interpreted (according to different tooth movement types) and reported in tables.

Results

Numeric data was derived from nodes defined as bracket wings. In center V-bend, (a / L= 3.204/6.408) the force system produced is two equal and opposite moments. Following the displacement of V-bend from the center position towards off-center ones, a clear change in the nature of the findings is noticeable. (Table 2)

Decreasing the distance between the bend and the upper right bracket produced a force system containing both forces and moments. Moving towards UR1, when a/L=1/5 (=19.94%), intrusive movement of UL1 is started in addition to a change in angulation (i.e.; presence of a moment). Pure intrusion was attained at a/L=1/10 (a/L=0.636/6.408) at this point, angulation change was not detected.

At the end stage of V-bend study (a / L= 0.422 / 6.408), same direction of moments can be noticed in both brackets in addition to vertical forces same as previous stages. (Table 2)

The more V-bend moves from the center position, the more increase in intrusion was noticed at the long arm segment of the V-bend and more extrusive movement in the small segment of the wire. (Table 2)

A brief summary of the above mentioned movements is presented in figure 2a through 2d

Discussion

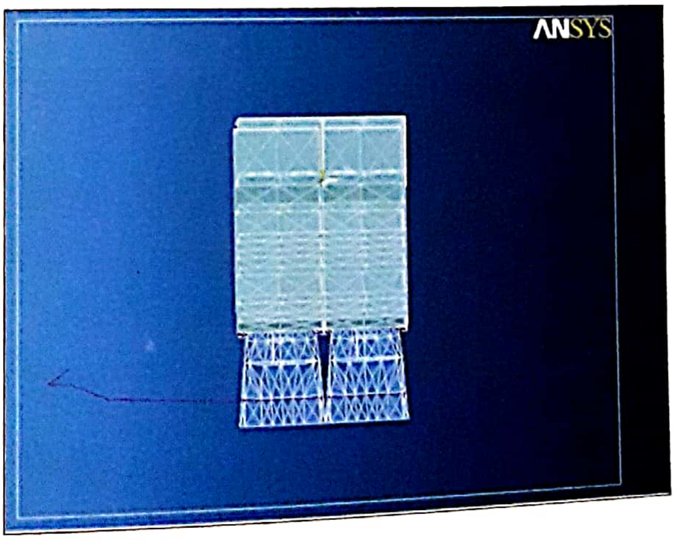

Fig.1.

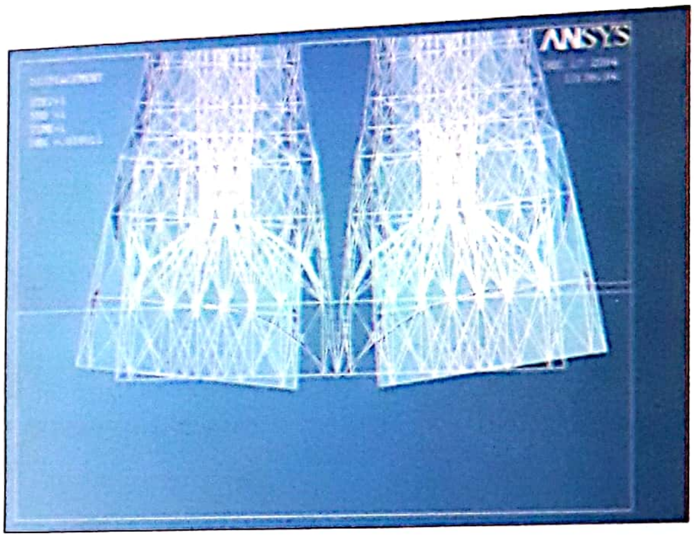

Fig.2a. Opposite moment senses

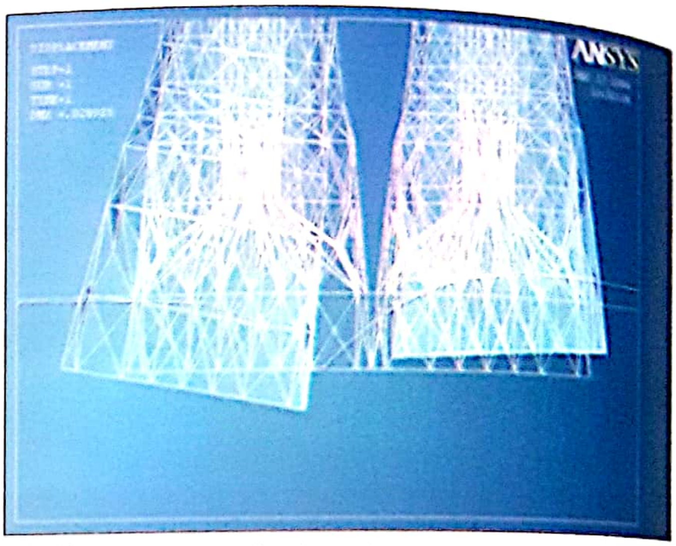

Fig.2b. Opposite force directims and moment senses

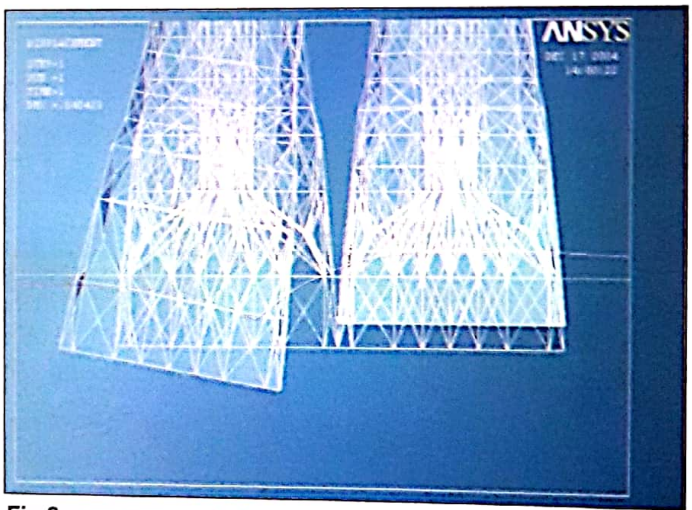

Fig.2c. pare intrusion in UL1

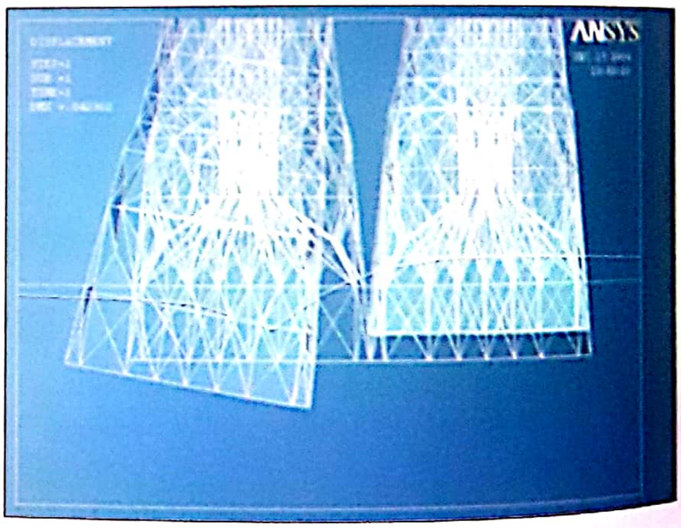

Fig.2d. moments in two teeth with same sense

V-bend is employed in many situations in accurate adjusting of teeth for example after extraction space closure. The force system developed by adding a V bend to a wire has been estimated on the basis of small deflection theories. Output data shows that the position of the V bend is quite important in the force system developed and delivered to the adjacent teeth.

As shown in table 3 there are four sets of force systems produced by a V bend according to its position with a gradual change from one to the other. a/L is the ratio of the distance of the V-bend apex to the whole distance between two brackets.

a- When a/L is equal with 0.5, the bend is placed in the middle of the distance between two brackets, the force system is two equal and opposite moments without any force. This finding is in accordance with previous studies[13,14,17-19]. The nature of the moments, depending on the apex of the V bend, can be to converge or to diverge the root apices of the teeth involved. In this stage, there is not any vertical movement in teeth involved. On the other hand, no vertical discrepancies can be tolerated between the teeth at the beginning of center V bend application. Applying this bend before termination of leveling is not suggested.(Fig 3a)

b- When 0.2< a/L<0.5, There are different amounts of vertical forces in addition to two moments of different signs and magnitudes. The nature of the vertical forces is extrusive in the tooth nearer to the V bend and intrusive in farther one. Moving towards one bracket decreases the moment applied

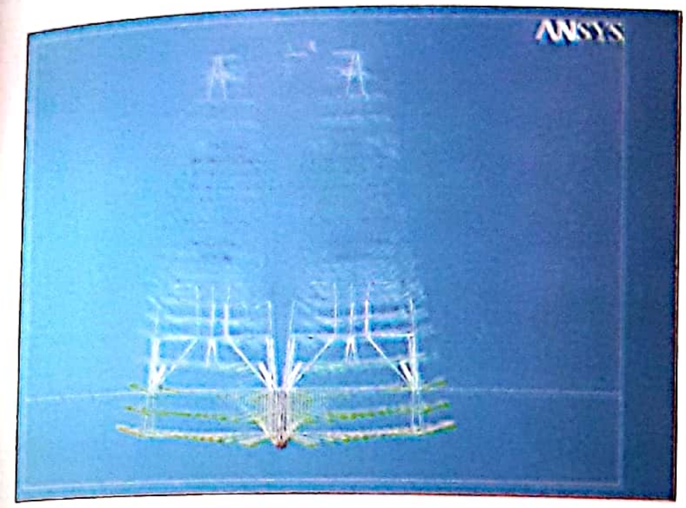

Fig.3a. Opposite moment senses

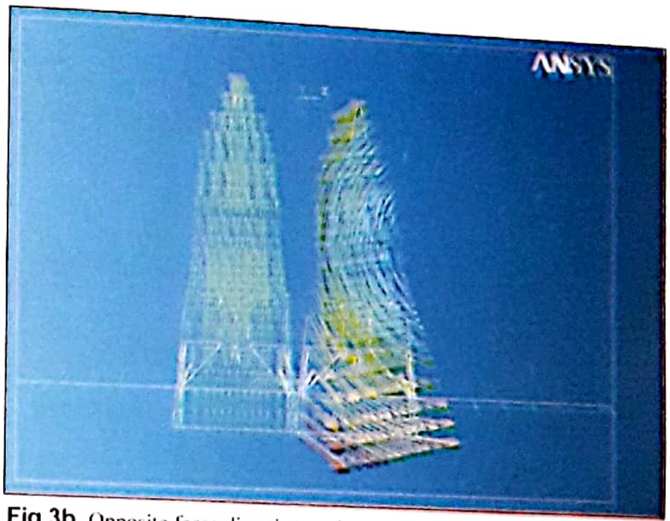

Fig.3b. Opposite force directims and moment senses

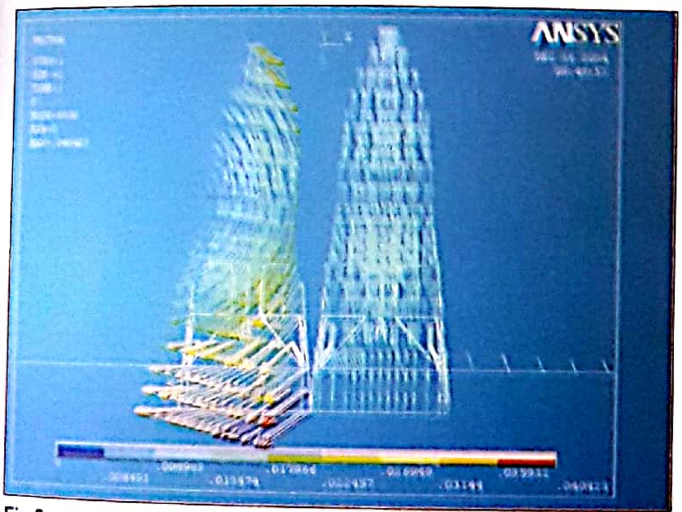

Fig.3c. pure intrusion in UL1

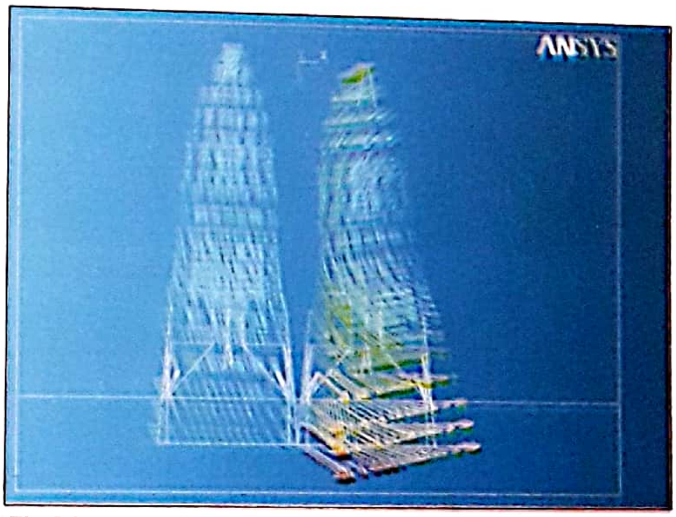

Fig.3d. moments in two teeth with same sense

on the farther bracket making its displacement more like an intrusive one. This finding, by nature, is in quite agreement with other data published [13, 14, 17-19] but not in quite agreement with the findings of other researchers published, numerically[2,13,14,19]. The differences may be due to the various data available in wire stiffness, bending, and interbracket distances.(Fig 3b)

c- When 0.1< a/L< 0.2, intrusive movement is achieved, however mixed with a change in angulation which is caused by the presence of a moment in that bracket. This finding also differs from other researchers. Ronay et al.[2] reported this as 0.33.

d- When a/L= 0.1, pure intrusive movement of the farther bracket (i.e.; UL1 in this study) is noticed. (Fig 3c)

e- In the last stages of displacing V bend along the distance between two brackets, when a/L< 0.1, two moments of the same sense appear in the force system in addition to two vertical forces of opposite sense. It can be considered that in this situation, while the moments have the same sense, a relatively greater amount of forces should be generated to maintain the equilibrium. (Fig 3d)

Dellinger[20] after conducting a cephalometric and histologic study concluded that the intrusion is not likely to occur clinically while the extrusion occurs. In this way, it is important to be aware that hyalinization and indirect resorption can be anticipated. Loss of vertical control is the other important point worth considering in clinical use which is not in complete accordance with the findings of this study.

	Distal Wing of UR1	Mesial Wing of UR1	Mesial Wing of UL1	Distal Wing of UL1
	Vertical Force (grf)	Vertical Force (grf)	Vertical Force (grf)	Vertical Force (grf)
Center Position	-27.592 •	26.977	26.998	-27.600
•• 1	-14.778	15.737	11.250	-12.817
2	-15.433	17.296	9.7507	-12.162
3	-16.088	18.735	8.2514	-11.507
4	-16.743	20.234	6.7521	-10.852
5	-17.421	21.728	5.2789	-10.194
6	-18.074	23.222	3.7846	-9.5412
7	-18.727	24.716	2.2904	-8.8883
8	-19.379	26.210	0.79618	-8.2354
♦ 9	-20.032	27.704	-.69804	-7.5825
10	-20.685	29.198	-2.1923	-6.9296
11	-21.337	30.692	-3.6865	-6.2767
♦♦12	-21.990	32.186	-5.1807	-5.6238
13	-22.643	33.680	-6.6749	-4.9708

Table-2. Force data of mesial and distal wings of the brackets adjacent to the V-bend. Inter-bracket span = 6.408 mm.
• = Negative data refer to intrusion and positive ones to extrusion
•• = V-bend position moving away from the center towards upper right central incisor (UR1).
♦ = the beginning stages of the intrusive movement
♦♦ = Pure intrusion

a/L	• F(dist.)-F(mes.)	Moment (gr-mm)	F(dist.)-F(mes.)	Moment (gr-mm)	UR1 Force sys.	UL1 Force sys.
3.204!6.408#	≈0	•• -115.128	≈0	+115.128	↻	↺
2.99!6.408	+0.959	-62.334	-1.567	+47.45	↻↓	↑↺
2.776!6.408	+1.863	-65.096	-2.4113	+41.128	↻↓	↑↺
2.562!6.408	+2.647	-67.86	-3.2556	+34.804	↻↓	↑↺
2.348!6.408	+3.491	-70.62	-4.0999	+28.48	↻↓	↑↺
2.134!6.408	+4.307	-73.48	-4.9151	+22.266	↻↓	↑↺
1.920!6.408	+5.148	-76.24	-5.7566	+15.963	↻↓	↑↺
1.706!6.408	+5.989	-78.99	-6.5979	+9.660	↻↓	↑↺
1.492!6.408	+6.831	-81.74	-7.4392	+3.3582	↻↓	↑↺
♦ 1.278!6.408	+7.672	-84.49	-6.8845	+23.568	↻↓	↑↺
1.064!6.408	+8.513	-87.25	-4.7373	+16.211	↻↓	↑↺
0.850!6.408	+9.355	-89.99	-2.5902	+8.864	↻↓	↑↺
0.636!6.408	+10.196	-92.75	-4.4431	≈0	↻↓	↑
0.422!6.408	+11.037	-95.508	+1.7041	-7.188	↻↓	↑↻

Table-3. Various force systems produced by different V-bend positions.
• = the difference between forces applied to the bracket wings.
•• = Clockwise moments are indicated by "-" and counterclockwise moments are indicated by "+".
= Center V-bend position moving towards UR1.
♦ = the beginning stages of intrusion (with angulation change)

The sensitivity of the v bend placement is obvious in table 3 making it difficult to apply. On the other hand, increasing the inter-bracket distance decreases the sensitivity.

There are situations when a V bend can be applied to align two adjacent teeth. A complete knowledge of the force systems involved in this situation is needed to explain or overcome the side effects. Considering the V-bend principle, some recommendations have been provided for the placement of the T-loop.[21] It is our duty as a clinician to find out the exact behavior of the wire we use when applying bends in it.

Conclusion

The present article based on a 3D FEM research provided the clinician with practical points in placing V-bends between two adjacent teeth and making it clear that differences between materials from mechanical point of view, manufacturing, and handling necessitates a complete knowledge of handling the exact material we are applying if a desirable result is expected.

References:

1. Marcotte M. Biomechanics in orthodontics. Philadelphia B.C.Decker 1990, Chap 1.
2. Ronay F, Kleinert W, Melsen B. Burstone CJ. Force system developed by V-bends in an elastic orthodontic wire. AJO/DO 1989;96:295-301.
3. Geramy A. Harmonious translation of the Cres in different tooth movements while the force is remained constant. Journal of Dentistry, Shiraz University of Medical Sciences 2002:3(1-2); 59-65.
4. Geramy A. Faghihi SH. Secondary trauma from occlusion: 3D analysis using Finite Element method. Quintessence Intl.2004; 35.835-843.
5. Geramy A. Moment/Force ratio and the center of rotation alteration: 3D analysis by means of the F.E.M. J. Dent. Shiraz University of Medical Sciences 2000; 1(2); 26-34.
6. Geramy A. Alveolar bone resorption and the center of resistance modification: 3D analysis by means of the F.E.M. AJO/DO 2000; 117.399-405.
7. Geramy A. Initial Stress Produced in the Periodontal Membrane by Orthodontic Loads in the presence Of Alveolar Bone Loss of Varying Extent: Three dimensional analysis using Finite Element Method. European Journal of Orthodontics.2002; 24:21-33.
8. Geramy A. Stress Tensor Modification in alveolar Bone resorption: 3D analysis using FEM Journal of Dentistry, Shiraz University of Medical Sciences 2002:3(3-4); 39-49.
9. Geramy A. Cervical Headgear Force System: 3D analysis by means of the finite element method. J. Dent. Shiraz Univ. of Medical sciences 2001; 2(1); 21-30.
10. Geramy A. Optimization of unilateral overjet management: 3D analysis using finite element method. Journal of the Angle Orthodontist2002; 75(6):585-592.
11. Geramy A, Morgano S. Finite element analysis of three designs of an implant-supported molar crown. J Prosthetic Dent2004; 92:434-40.
12. Geramy A. Sharafodding F. Abfraction: 3D analysis using Finite Element Method. Quintessence Intl 2003; 34: 526-533.
13. Burstone CJ, Koenig HA. Force systems from an ideal arch. AJO 1974; 65:270-89.
14. Burstone CJ, Koenig HA. Creative wire bending. The force system from step and V-bends. AJO/DO 1988; 93: 59-67.
15. Siatkowski RE. Force system analysis of V-bend sliding mechanics. JCO 1994; 28 (9):539-46.
16. Ash MM. Dental anatomy, Physiology, and Occlusion, Ed 6. Philadelphia; Saunders, 1984 P118-29.
17. Melsen B. Current controversies in orthodontics. Chicago, Quintessence pub. Co. 1991 Chap.7.
18. Nanda R. Biomechanics in clinical orthodontics. Philadelphia; W.B. Saunders Co. 1997 Chap 9, 11.
19. Mulligan T. Common sense mechanics. J Clinic Orthod 1980; 14:265-72.
20. Dellinger EL. A histologic and cephalometric investigation of premolar intrusion in the Macaca speciosa monkey. AJO1967; 5:325-55.
21. Yang TY, Baldwin JJ. Analysis of space closing springs in orthodontics. J Biomech 1974; 21-8.