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Comparative Analysis of Two Transpalatal Arch and Lingual Arch Activation Methods

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Abstract

Introduction: The TPA and LA can be activated in two ways: the "shape-driven method," in which the appliance is intended to correspond to the final tooth position, and the "force-driven method," in which the appliance is designed to ensure that the force system delivered at the start is consistent with the planned tooth movement. In the present investigation, both approaches were quantitatively evaluated in vitro using typodont teeth and multi-axis force torque transducers in all three dimensions.

Result: In the TPA first order activation, the shape-driven activation group exhibited a considerably greater Mx (moment on X axis) measurement than the force-driven activation group despite similar Fy (force on Y axis) readings. In the TPA second order activation, the shape-driven activation group exhibited a considerably greater Fx (Force on X axis) value than the force-driven activation group despite similar My (moment on Y axis) readings. In the TPA third order activation, the shape-driven activation group showed a significantly greater Fy (force on Y axis) measurement than the force-driven activation group despite similar Mx (moment on X axis) readings.

Conclusion: Both TPA and LA activated using the force-driven method exhibited lesser unintended side effects in first second and third order forces and moments than the shape-driven method.

Keywords: Force-Driven Method, Shape-Driven Method, Transpalatal Arch, Lingual Arch Activation.

Introduction

The transpalatal arch (TPA) is a commonly used appliance in clinical orthodontics treatment [1]. Many different designs have been developed and tested including the Goshgarian type [2], the Zachrisson type [3], the removable type [4], the "Precision lingual arch" [5,6], The "Butterfly Arch TPA" [7], etc. TPA and LA (Lingual arch) can be used passively for anchorage[8] or actively for tooth movement in first order [4, 9, 10], second order [11, 12] and third order[13]. Although TPA and LA are very versatile and can be used to move tooth efficiently in many conditions, unwanted tooth movements can result from less than ideal initial activations.

The TPA and lingual arch can be activated with two methods [14]. The first method is "shape-driven method", where the appliance wire is fabricated to the ideal arch shape when it is passive. The wire is then elastically bent and placed into the maligned brackets for activation. Although this is straightforward and easy to fabricate, this activation usually brings large unnecessary initial moments to the teeth, thus results the undesirable side effects of round tripping movements of the teeth.

The second activation method is "force-driven method". To eliminate the unwanted side effects of the shape-driven method, and to give tooth the desired initial force system, a "force-driven method" has been developed. In this method, correct starting force is prioritized over establishing the ideal final tooth position. This initial force-driven activation can be achieved theoretically with computer calculation based on beam theory and iterative methods, it can also be achieved in five steps at chair side clinically. The first step is to choose the desired force system, the second is to passively shape the appliance's arch to match the position of the teeth, the third is to simulate shaping the appliance by the deactivation force system, the fourth is to permanently deform the appliance to be identical to the simulated deactivated shape, and the fifth is to perform a trial activation in the mouth to ensure that there are no unwanted moments. Theoretically, by first delivering the correct force system within the ideal force level zone, this force-driven activation method is more effective than the shape-driven method since the tooth can move directly to the desired position without needless wriggling or negative consequences.

This work aims to quantitatively compare the "force-driven activation method" and the "shape-driven activation method" in vitro. We compared the forces and moments in all three dimensions. The Burstone way of activation can be supported or disproven by comparing the force systems of the two approaches at the beginning and determining which is nearer to the ideal. The physician will have the option of consciously selecting the approach that best fits the given case scenario.

Methodology

In this in vitro study, typodont was used initially for the setup. Anatomically rooted metal teeth from Kilgore™ International Inc. was used for the typodont. The maxillary permanent first molars were cemented with molar bands from Ormco™, and precision lingual hinge caps from Ormco™ were welded to the molar bands. Removable TPA linked to the molars was made from 0.032''x0.032'' TMA burstone arch form from Ormco™, and removable LA linked to the molars was made from 0.032''x0.032'' TMA burstone arch form from Ormco™. After typodont setup, teeth were bonded to steel rods with J-B Weld™ 8280 Steel Reinforced Epoxy, and the steel rods were linked to multi- axis

force torque transducers Nano17 from ATI Industrial Automation™, Apex, NC. The signals were acquired with NI USB-6229 data acquisition device from National Instruments™, and analyzed in a computer with OFM F/T DAQ™ software. With this setup, the forces and moments can be captured and measured in all three dimension for evaluation.

With TPA or LA appliances attached to the lingual slots, the teeth were removed from the typodont for independent measurements. As the lingual slots positions were different from the transducers' measuring point, a moment was measured by the transducer when pure force and no moment were applied to the lingual slot point. To make the calculation easier and to make the measurement meaningful, calibration files were generated for each transducer to make sure when forces are applied at the lingual slot, all moments in three dimension were zero. These specific calibration files were loaded into the software for all the following measurements so the data collected below were true forces and moments at the points of the lingual slots.

Positive or negative forces in X, Y, Z direction are defined as following: X axis is defined as the straight line perpendicular to the coronal plane. The direction toward anterior is defined as positive, and the direction toward posterior is defined as negative. Y axis is defined as the straight line perpendicular to the sagittal plane. The direction toward left is defined as positive, and the direction toward right isdefined as negative.

Z axis is defined as the straight line perpendicular to the transverse plane. The direction toward upward is defined as positive, and the direction toward downward is defined as negative. Then according to the right hand rule (Figure 4), positive moments direction was defined as the right thumb direction when the right fingers point in the direction of the first vector direction, and then curled towards the second vector.

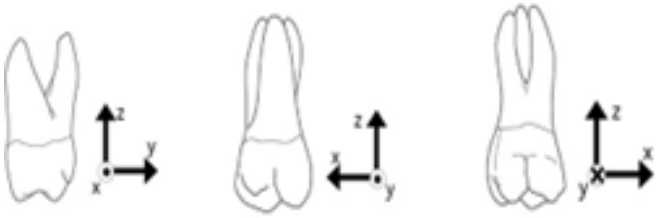


Figure 1. Axis definition for maxillary right first molar. (Mesial, lingual and buccal views)

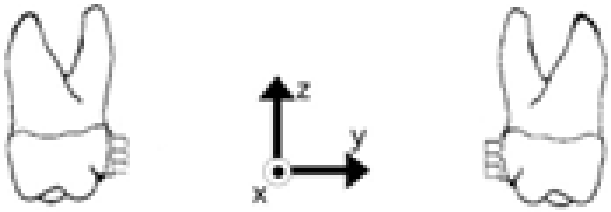


Figure 2. Axis definition for maxillary molars. (Mesial view)

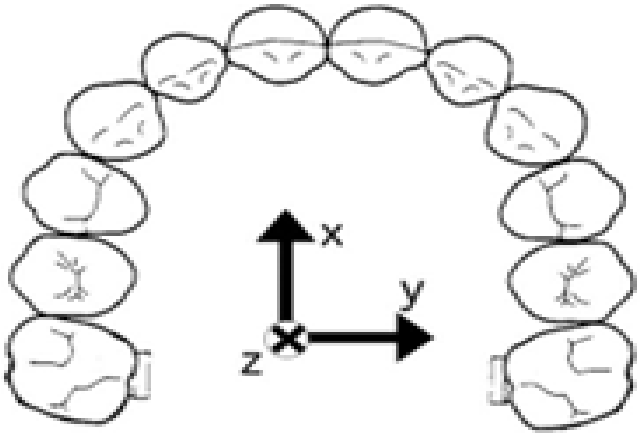


Figure 3. Axis definition for maxillary dentition.

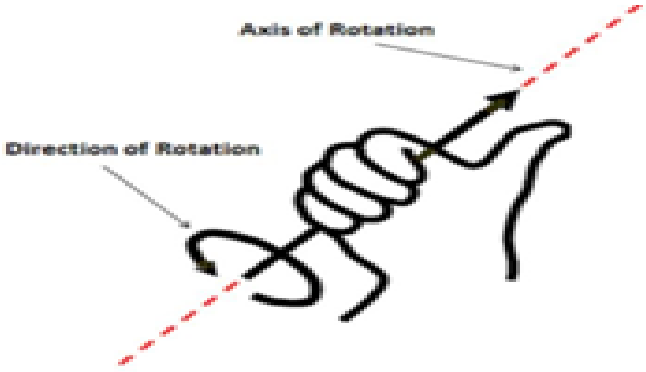


Figure 4. Right hand rule for moment axis.

Results

Results of comparison in this group are summarized in Tables 1, ,2,3, 4 andFigures 5, 6, 7, 8.

Table 1: 3D Force comparison in TPA first order activation for maxillary right first molar. No activation, shape driven activation and force driven activation are compared. Mean, Standard Deviation, ANOVA and Post hoc results are included.

TRANSDUCER 1	PT1	ST1	FT1	PT1	ST1	FT1	PT1	ST1	FT1
Measurement	Fx (N)	Fx (N)	Fx (N)	Fy (N)	Fy (N)	Fy (N)	Fz (N)	Fz (N)	Fz (N)
appliance 1	-0.018	0.123	0.146	0.001	-1.385	-1.023	-0.032	-0.122	-0.023
appliance 2	-0.001	-0.054	0.085	-0.040	-1.136	-1.126	0.044	-0.011	0.097
appliance 3	0.026	0.106	0.079	0.001	-1.192	-1.208	0.030	0.091	0.106
appliance 4	0.001	-0.074	-0.001	0.034	-1.228	-1.056	0.028	0.040	0.015
appliance 5	0.002	-0.004	0.098	0.003	-1.093	-1.031	-0.016	0.034	-0.064
appliance 6	-0.036	0.030	-0.061	0.048	-1.326	-1.362	-0.002	0.030	0.028
appliance 7	-0.021	0.037	-0.031	0.034	-1.115	-1.151	-0.013	-0.013	-0.131
appliance 8	0.024	-0.086	-0.020	-0.017	-1.355	-1.169	0.008	0.135	0.078
appliance 9	0.001	0.019	-0.144	-0.004	-1.020	-1.179	-0.009	0.143	0.045
appliance 10	0.004	0.129	-0.145	-0.007	-1.217	-1.291	-0.051	0.013	0.090
Mean	-0.002	0.022	0.001	0.005	-1.207	-1.160	-0.001	0.034	0.024
Standard deviation	0.019	0.079	0.101	0.026	0.120	0.110	0.030	0.078	0.077
ANOVA PSF	NS			$			NS		
POST HOC PS	NS			$			NS		
POST HOC PF	NS			$			NS		
POST HOC SF	NS			NS			NS		

Table 2: 3D Force comparison in TPA first order activation for maxillary left first molar. No activation, shape driven activation and force driven activation are compared. Mean, Standard Deviation, ANOVA and Post hoc results are included

TRANSDUCER2	PT1	ST1	FT1	PT1	ST1	FT1	PT1	ST1	FT1
Measurement	Fx (N)	Fx (N)	Fx (N)	Fy (N)	Fy (N)	Fy (N)	Fz (N)	Fz (N)	Fz (N)
appliance 1	0.068	-0.102	-0.133	-0.011	1.425	0.980	0.045	0.108	0.078
appliance 2	0.006	0.100	-0.128	0.032	1.147	1.159	-0.023	-0.028	-0.122
appliance 3	-0.006	-0.079	-0.126	-0.016	1.205	1.158	-0.036	-0.105	-0.186
appliance 4	-0.058	0.114	0.055	-0.006	1.291	1.103	-0.010	-0.030	0.019
appliance 5	0.011	0.004	-0.114	0.008	1.107	0.981	0.011	0.002	-0.044
appliance 6	0.047	-0.032	0.071	-0.065	1.288	1.394	0.006	0.008	-0.028
appliance 7	0.056	0.017	0.007	-0.046	1.050	1.222	-0.008	-0.027	0.064
appliance 8	-0.123	0.165	-0.036	0.014	1.378	1.235	0.001	-0.148	-0.012
appliance 9	0.003	0.051	0.152	0.003	1.056	1.206	0.051	-0.221	-0.042
appliance 10	0.001	-0.098	0.151	-0.014	1.316	1.376	0.014	-0.062	-0.103
Mean	0.000	0.014	-0.010	-0.010	1.226	1.181	0.005	-0.051	-0.038
Standard deviation	0.056	0.094	0.114	0.028	0.133	0.140	0.027	0.091	0.082
ANOVA PSF	NS			$			NS		
POST HOC PS	NS			$			NS		
POST HOC PF	NS			$			NS		
POST HOC SF	NS			NS			NS		

Table 3: 3D Force comparison in TPA first order activation for maxillary right first molar. No activation, shape driven activation and force driven activation are compared. Mean, Standard Deviation, ANOVA and Post hoc results are included

TRANSDUCER 1	PT1	ST1	FT1	PT1	ST1	FT1	PT1	ST1	FT1
Measurement	Mx (Nmm)	Mx (Nmm)	Mx (Nmm)	My (Nmm)	My (Nmm)	My (Nmm)	Mz (Nmm)	Mz (Nmm)	Mz (Nmm)
appliance 1	-0.028	6.237	0.084	-0.029	-0.378	0.302	-0.003	-0.624	-0.277
appliance 2	-0.076	6.892	0.082	-0.016	0.349	-0.022	-0.032	-0.770	-0.607
appliance 3	0.010	7.183	0.227	0.003	-0.140	0.364	0.040	-0.328	-1.411
appliance 4	-0.070	6.611	0.086	0.046	0.025	-0.217	-0.021	-0.620	-0.555
appliance 5	0.014	6.440	-0.266	-0.063	-0.072	-0.178	-0.044	-0.560	-0.727
appliance 6	-0.038	6.463	0.143	-0.024	-0.203	-0.048	0.008	-0.666	-1.197
appliance 7	0.021	6.722	-0.310	-0.093	-0.038	-0.090	0.022	-0.919	-0.856
appliance 8	-0.003	5.710	-0.042	-0.033	0.171	-0.144	0.078	-0.869	-0.285
appliance 9	-0.019	6.578	0.368	0.024	0.000	-0.170	-0.005	-0.552	-0.986
appliance 10	-0.025	6.229	0.225	-0.029	0.307	0.455	-0.003	-0.671	-0.894
Mean	-0.021	6.507	0.060	-0.021	0.002	0.025	0.004	-0.658	-0.780
Standard deviation	0.034	0.403	0.214	0.040	0.225	0.250	0.036	0.169	0.367
ANOVA PSF	$			NS			$		
POST HOC PS	$			NS			$		
POST HOC PF	NS			NS			$		
POST HOC SF	$			NS			NS		

Table 4: 3D Force comparison in TPA first order activation for maxillary left first molar. No activation, shape driven activation and force driven activation are compared. Mean, Standard Deviation, ANOVA and Post hoc results are included

TRANSDUCER 1	PT1	ST1	FT1	PT1	ST1	FT1	PT1	ST1	FT1
Measurement	Mx (Nmm)	Mx (Nmm)	Mx (Nmm)	My (Nmm)	My (Nmm)	My (Nmm)	Mz (Nmm)	Mz (Nmm)	Mz (Nmm)
appliance 1	-0.028	6.237	0.084	-0.029	-0.378	0.302	-0.003	-0.624	-0.277
appliance 2	-0.076	6.892	0.082	-0.016	0.349	-0.022	-0.032	-0.770	-0.607
appliance 3	0.010	7.183	0.227	0.003	-0.140	0.364	0.040	-0.328	-1.411
appliance 4	-0.070	6.611	0.086	0.046	0.025	-0.217	-0.021	-0.620	-0.555
appliance 5	0.014	6.440	-0.266	-0.063	-0.072	-0.178	-0.044	-0.560	-0.727
appliance 6	-0.038	6.463	0.143	-0.024	-0.203	-0.048	0.008	-0.666	-1.197
appliance 7	0.021	6.722	-0.310	-0.093	-0.038	-0.090	0.022	-0.919	-0.856
appliance 8	-0.003	5.710	-0.042	-0.033	0.171	-0.144	0.078	-0.869	-0.285
appliance 9	-0.019	6.578	0.368	0.024	0.000	-0.170	-0.005	-0.552	-0.986
appliance 10	-0.025	6.229	0.225	-0.029	0.307	0.455	-0.003	-0.671	-0.894
Mean	-0.021	6.507	0.060	-0.021	0.002	0.025	0.004	-0.658	-0.780
Standard deviation	0.034	0.403	0.214	0.040	0.225	0.250	0.036	0.169	0.367
ANOVA PSF	$			NS			$		
POST HOC PS	$			NS			$		
POST HOC PF	NS			NS			$		
POST HOC SF	$			NS			NS		

Figure 5: 3D Force comparison in TPA first order activation for maxillary right first molar. No activation, shape driven activation and force driven activation are compared. Mean, Standard Deviation of each group are marked

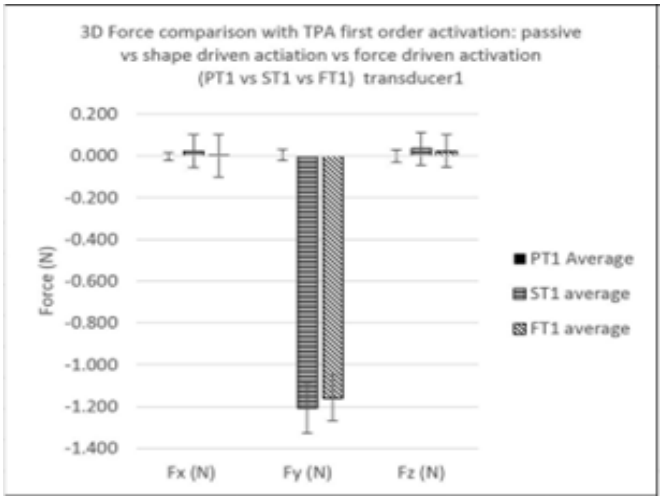


Figure 6: 3D Force comparison in TPA first order activation for maxillary left first molar. No activation, shape driven activation and force driven activation are

compared. Mean, Standard Deviation of each group are marked

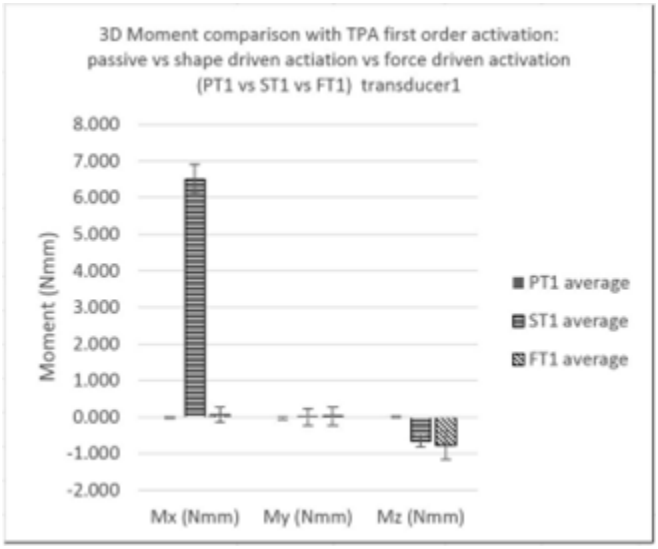
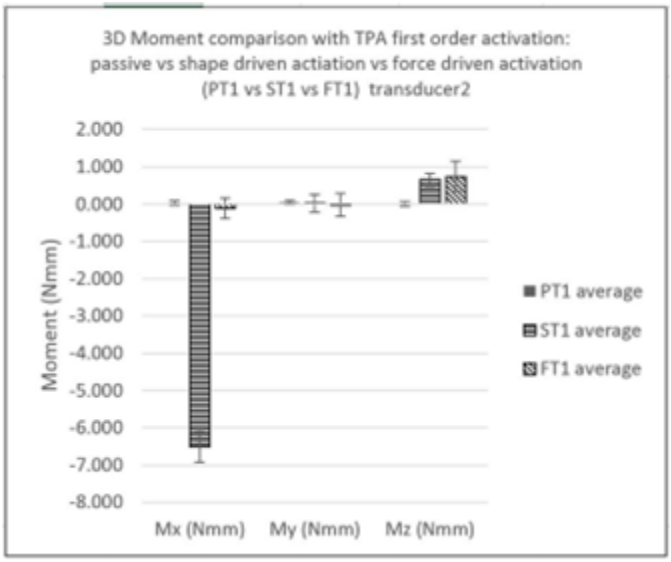


Figure 7: 3D Force comparison in TPA first order activation for maxillary left first molar. No activation, shape driven activation and force driven activation are compared. Mean, Standard Deviation of each group are marked



In this comparison, horizontal expansion forces are given to the lingual slots of maxillary first molars for 7mm expansion. Forces comparisons in x, y, z axis are listed in table 1, 2, they are also drawn in figure 5, 7. The passive group shows minimal activation in all three axes, indicating a low force noise level in the system setup. There were no statistical significant differences in forces in x,y and z axis between shape-driven activation group and force-driven activation group.

Moment comparisons in x, y, z axis are listed in table 3, 4, they are also drawn in figure 6. The passive group shows minimal moment in all 3 axis, indicating a low moment noise level in the system setup. There are no statistical significant differences in moments in y and z axes between shape-driven activation group and force-driven activation group. There is a statistical significant difference in moments in x axis between shape-driven activation group and force-driven activation group, specifically, the shape-driven activation group has a 6.507+/-0.403 Nmm moment on the x axis for transducer 1 and a -6.506+/-0.417 Nmm moment on the x axis for transducer 2; in comparison, the force- driven activation group has a 0.060+/-0.214 Nmm moment on the x axis for transducer 1 and a -0.112+/-0.281 Nmm moment on the x axis for transducer 2.

Discussion

There are two ways to activate TPA and LA. The expected tooth position or arch form is created into the appliance in the first way, known as the shape-driven method. Clinically, several extraneous initial forces or seconds are discovered to occur after the activation, and round-tripping movements of the teeth are also not unusual. The second approach, called the force-driven approach, places more emphasis on the proper beginning force or moment. This approach seems counterintuitive, yet if used properly, it results in clinically less round-tripping and more effective movements.

As there have been only theoretical speculations in literature (12,14), this study could be the first to examine in vitro effects, systemically and quantitatively using sensitive transducers. These results may help clinicians choose an appropriate activation method for a

given specific case. In the PT1 vs. ST1 vs. FT1 comparison, the TPA was used to achieve a common orthodontic task: molar expansion. Both activation methods achieved reasonable expansion force of around 120g without significant and unnecessary forces in other directions. However, when the moments were considered, the shape-driven activation method revealed a significantly more positive moment in x axis, which by itself was a moment to rotate the crown lingually and root buccally. This could be a wanted or unwanted effects based on the specific clinic condition.[13]

As moment to force ratio is a useful indicator to describe the center of rotation (Crot), it was calculated for these two activations. The ST1 had an average Mx/Fy of - 5.456mm, while the FT1 had an average Mx/Fy of -0.045mm. This indicated that in the shape-driven activation group, the center of rotation was close to apex, and the molar would expand with controlled tipping movement. By comparison, in the fore driven activation group, the center of rotation was close to 1-2mm apical to center of resistance, and the molar would expand in an uncontrolled tipping pattern with crown moving buccally and root moving lingually. Again, this could be a wanted or unwanted effects based on the specific clinic condition. The buccal root torque "side effect" in the shape- driven method could actually be beneficial for some clinical scenario.[3]

Conclusion

TPA and LA activated in force-driven method had minimal side effects in the first, second and third order forces and moments. However, with shape-driven method, for the TPA first order activation, expansion had a buccal root torque side effect; for the TPA second order activation, distal crown tipping had a mesialization side effect and mesial crown tipping has a distalization effect; for the TPA third order activation, buccal crown torque had a constriction side effect; for the LA first order activation, expansion had a mesial buccal rotation side effect; for the LA second order activation, distal crown tipping had an extrusion side effect and mesial crown tipping had an intrusion side effect; for the LA third order activation, both activation methods had the same result with no side effects. As the targeted tooth movements can be helped or hindered by the side effects, clinicians can refer to the results to make the correct activations for the most efficient and effective tooth movements.

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