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Kinetic properties of arm and hand movements as useful indices for evaluating the dexterity of dentists

Part 2 – Movements of the arm and hand during orthodontic bracket bonding

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Introduction

In order to evaluate an orthodontic clinician's hand skills, it is necessary to know the kinematic features of the hand and arm motions during clinical practice. Previous reports[1)~6)] documented that the smoothness and efficiency of the arm movements could be evaluated by using kinematical parameters, such as the motion duration, the dispersion, the peak velocity, the velocity profile, the jerk-cost and the movement trajectory. However, the motions made during the transfer of an orthodontic bracket differ from the motions described in previous reports, because this transfer requires high accuracy for positioning the attachment near the end-point of the motion, the force control to avoid damage to the teeth and quickness of motion.

In Part 1 of the present study, we compared the smoothness of displacement of the orthodontic bracket while it was transferred onto the tooth between those who had clinical experience in orthodontic practice and those with no such experience. The kinetic characteristics of the orthodontic bracket displacement trajectories were found to be explained by the peak tangential velocity, the phase duration and the normalized jerk-cost. There were significant differences in the kinetic properties of the attachment displacement between those with and without clinical experience. The kinetic properties of the hand and arm joint motions, however, were not investigated in that study.

The purposes of this part of the study were (1) to examine whether the skillfulness of hand and arm joint motions when transferring orthodontic brackets onto a tooth differ between those with clinical experiences in orthodontic practice and those with no such experiences relevant to dental practice, and (2) to identify the kinematic parameters which are considered to be useful for quantitatively evaluating the dexterity of dental practitioners in clinical orthodontics.

Finally, if the kinetic differences in hand and arm motion between the experienced clinicians and the unskilled individuals become apparent, practical methods for the orthodontic clinical training of unskilled students can be developed.

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Subjects

The subjects consisted of 41 adult females who were divided into two groups: an Experienced Group (20 females who had already completed the three-year university postgraduate program in orthodontics; mean age, 32 years, 6 months) and a Novice Group (21 females who had not completed or were not participating in the postgraduate program in orthodontics; mean age, 27 years, 4 months). All subjects were right-handed and had normal eyesight.

Finally, among the 41 subjects, we employed the data from 13 experienced clinicians and 17 novices who had successfully undergone recording for the motion of all markers during the task.

Methods

Each subject was asked to transfer a metallic orthodontic bracket (Victory Series™ Miniature Metal Bracket System, 3M Unitek Co., MN, U.S.A.) with tweezers onto the midpoint of the facial axis (FA points)[7] of an acrylic maxillary right permanent first premolar tooth of a phantom, with retracting of the corners of the mouth performed by the operator (Fig.1). The task was performed seven times, with a one-minute interval between each task.

Infrared-sensitive reflective markers with a diameter of 7 mm were adhered to the subjects' right-side shoulder, arm and hand, and a marker with a diameter of 4 mm was adhered to each bracket (Fig. 2). The center of the elbow joint was defined as the midpoint between the two markers adhered to the lateral and medial epicondyles. The center of the wrist joint was defined as the midpoint of two markers adhered to the radial and ulnar styloid processes[8]. The three-dimensional trajectories of each marker were recorded simultaneously at a sampling frequency of 100 Hz with a motion tracking system (OQUS Motion Capture Unit, Qualisys, Gothenburg, Sweden). An L-shaped reference structure with four spherical markers was placed on the desk, and was used for calibration.

A 30th-order Fourier series approximation fit to the time serial data of the lateral, anteroposterior and vertical displacements of each marker for each cycle was performed. The functions x(t), y(t) and z(t), corresponding to the time series of the lateral (x), anteroposterior (y) and vertical (z) marker displace-

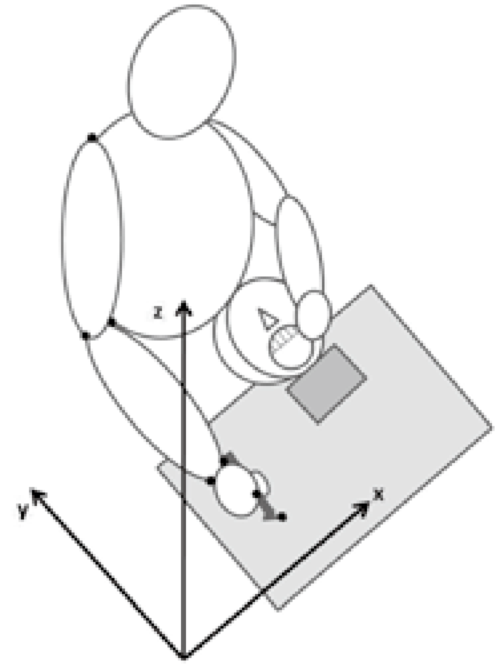

Figure 1. The experimental setup for monitoring the transfer of an orthodontic bracket. Seven reflective markers were placed on the right shoulder, elbow, wrist, hand and an orthodontic bracket.

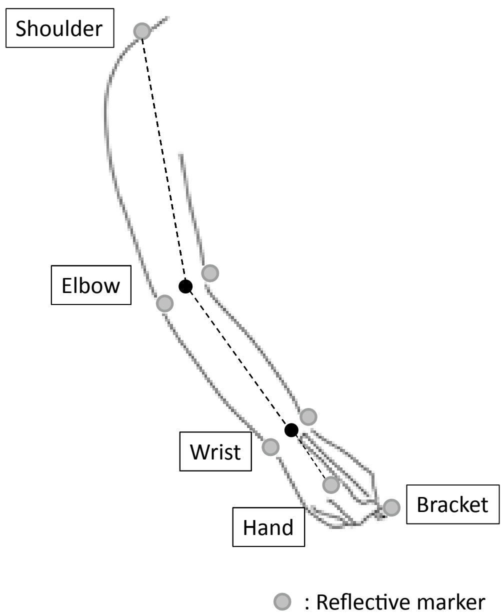

Figure 2. The joint coordinate system. The joint centers are dark.

ment data were obtained. The tangential velocity TV (t) and tangential acceleration TA (t) were calculated for each cycle.

In order to compute the entire duration of each phase, the time points at the start and end of each task were determined in the three-dimensional displacement trajectory of the bracket. The peak tangential velocity was calculated for a velocity profile generated from the recorded data to define the acceleration and deceleration phases. The kinetic characteristics of the bracket, the hand and each joint motion were quantified using normalized jerk-costs (NJC) in each phase, the time integral of the squared jerk (jerk-cost) normalized by the distances moved and durations of the movements[3]. In addition, we examined the symmetrical properties of the velocity profile using an index which calculated the duration of the deceleration phase relative to the entire phase. This meant that closer the obtained rate was to 0.5, the more symmetrical and bell-shaped was the observed velocity profile.

The linear distance (LD) and the actual bracket movement distance between the start and the end position were obtained. The actual movement distance was normalized by the LD and the movement time, respectively.

Finally, the adduction angle of the elbow and the wrist joint projected onto the XY-plane, YZ-plane and XZ-plane was also calculated for each subject.

The Mann-Whitney U test was used for the inter-group comparisons of these kinematic variables for the arm movement. Values of $P < 0.05$ were considered to be significant.

Results

The entire phase durations and the deceleration phase durations were significantly shorter ($P < 0.05$) in the Experienced Group than in the Novice Group for each joint (Table 1). In both groups, the duration of the deceleration phase was longer than that of the acceleration phase.

No significant difference was found for the peak tangential velocity between the two groups for each joint. The mean NJCs in the deceleration phase and the entire phase calculated for the Experienced Group were significantly greater ($P<0.001$) than those for the Novice group, except for the elbow joints. The Experienced Group showed significantly more symmetrical velocity profiles ($P<0.05$) than the

Table 1. The inter-group comparisons of the mean values calculated for the phase durations, as well as the peak tangential velocities, the normalized jerk-costs (NJCs) and the symmetrical properties of the velocity profile.

	Phase duration (s)						Peak tangential velocity (mm/s)	Normalized jerk-cost					Ratio of the dec./entire phase duration	
	Entire phase		Acc.phase	Dec. phase				Entire phase		Acc.phase	Dec. phase			
1 (bracket)														
Experienced Group	1.18	**	0.40	0.80	**		963.6	4891.9	**	42.7	1166.7	**	0.67	*
Novice Group	1.42		0.40	1.03			954.3	13360.1		40.6	4574.8		0.72	
2 (hand)														
Experienced Group	1.18	**	0.41	0.78	**		649.6	4426.7	**	45.9	964.2	**	0.65	*
Novice Group	1.42		0.42	1.00			619.0	11278.4		52.6	3458.5		0.70	
3 (wrist joint)														
Experienced Group	1.18	**	0.40	0.78	**		432.9	4373.3	**	42.7	1034.0	**	0.67	*
Novice Group	1.42		0.40	1.01			405.2	11289.2		45.6	4387.9		0.71	
4 (elbow joint)														
Experienced Group	1.18	**	0.44	0.77	*		123.3	16289.9		413.1	3578.0		0.64	
Novice Group	1.42		0.45	0.97			152.2	30599.3		1307.8	18286.8		0.69	
5 (shoulder joint)														
Experienced Group	1.18	**	0.46	0.75	*		30.2	13140.2	*	700.1	3242.1		0.63	
Novice Group	1.42		0.47	0.93			33.1	80587.6		884.9	22067.1		0.66	

(*: $p < 0.05$, **: $p < 0.001$)

Table 2. The inter-group comparisons of the mean values calculated for the movement distance and the normalized movement distance.

	Experienced Group (n=13)	Novice Group (n=17)	p value
Linear distance (LD) between start and end position (mm)	413.7	412.7	0.967
Actual movement distance (mm)	443.5	459.9	0.020
Normalized movement distance by LD	1.08	1.12	0.017
Normalized movement distance by movement time	381.0	313.1	0.002

Table 3. The inter-group comparisons of the mean values calculated for the adduction angle of the wrist and elbow joints projected onto the XY- , YZ- and XZ-planes.

	Novice Group (deg.)	Experienced Group (deg.)	p value
Wrist joint			
projection onto xy plane	55.5	65.3	0.140
projection onto yz plane	60.7	66.2	0.800
projection onto zx plane	39.7	29.7	0.014
Elbow joint			
projection onto xy plane	13.6	18.2	0.245
projection onto yz plane	26.1	39.4	0.281
projection onto zx plane	11.9	7.8	0.043

Novice Group, except in the elbow and shoulder joints.

The actual bracket movement distance was significantly shorter (P=0.02) in the Experienced Group than in the Novice Group (Table 2). The movement distance normalized by the movement time observed in the Experienced Group was significantly greater (P=0.002) than that observed in the Novice Group.

The adduction angles of the wrist and the elbow joint projected onto the ZX-plane observed in the Experienced Group were both significantly smaller (P=0.01, wrist joint; P=0.04, elbow joint) than those observed in the Novice Group (Table 3). However, there were no significant differences in the adduction angles of the wrist and the elbow joint projected onto the XY- and YZ- planes between the two groups. In both groups, the degree of adduction in the wrist was greater than that observed in the elbow joint.

Discussion

Previously, the orthodontic clinical skills have generally been evaluated by the treatment results[9),10)]. However, in the actual clinical situation, smoothness of the hand and arm motion is required for successful treatment, and this 'hand skill' should be evaluated during orthodontic clinical education.

The hand and arm movements have previously been evaluated using various parameters[1)~6)]. Those with skillful motion show more symmetrical velocity profiles[1),2)] and lower jerk-costs[3)~6)]. In order to clarify the kinematic features of the motion in each joint while transferring a bracket, we employed the phase duration, the peak tangential velocity, the NJCs and the symmetrical properties of the velocity profile as parameters in this study. In addition, to compare the efficiency of the motion, the actual bracket movement distance was also evaluated.

In the present study, the bracket transferring motion observed in the Experienced Group was associated with lower NJCs, a shorter motion duration, a more symmetrical velocity profile (Table 1) and a shorter movement distance (Table 2) than those observed in the Novice Group. These findings indicated that the clinically experienced orthodontists could transfer the bracket onto the tooth more smoothly and efficiently than the novices.

Furthermore, significant differences (P<0.001) in the NJCs between the Experienced Group and the

Novice Group were observed in the deceleration phase. During the bracket transferring motion, high accuracy at the end-point of the motion was required. In addition, force control was also required to prevent tooth damage. We suggest that the kinematic control of the transferring motion has been developed by clinical practice, so that the experienced person could transfer the bracket smoothly even near the end-point of the motion. In other words, clinical practice is associated with repetitive motion. Our results are in agreement with those of previous studies indicating that the smoothness of motion was improved by the repetition of the motion[11), 12)].

In this study, we evaluated not only the end effects of the motion, but also the motion of each joint in order to clarify their relationships. The arm joint coordination system has been well studied[13)~16)]. In ball-throwing, it is known that the intersegmental dynamics are strongly influenced by the joint angular velocity and the angular acceleration in order to increase speed[14)] and the motion of the proximal (shoulder) joint produces an assistive interaction torque for the distal (elbow) joint[15), 16)]. However, little is known about the relationship between the joint coordination system and the dexterity of hand motion when transferring objects.

Based on our results, the NJCs of the wrist joint in the Experienced Group were significantly ($P<0.001$) smaller than those in the Novice Group. In addition, the velocity profile of the wrist joint motion observed in the Experienced Group was more symmetrical than that observed in the Novice Group. However, there were no significant differences in the skillfulness of motion observed in the elbow and the shoulder joint between the two groups. This suggests that the skillfulness of the bracket transferring motion was highly influenced by the joint near the end effector.

We also found that the novices showed a greater adduction angle projected onto the XZ plane in the wrist and elbow joint than did the Experienced clinicians (Table 3). This suggested that, due to the large adduction angle during bracket transfer, the smoothness of the motion of the end-effector (bracket) was decreased in the novices. Meanwhile, the Experienced clinicians showed skilled movement of the end-effector, with a smaller angular change and smooth motion of the wrist and elbow joints. Thus, we concluded that the smoothness of each joint motion and the joint coordination obtained by practical training result in improvements of the dexterity of the hand motion.

By using the kinematic parameters adopted in this study, the outcomes of orthodontic clinical training focused on hand skills can be evaluated quantitatively. We intend to expand our research to establish an orthodontic clinical training system.

Conclusions

Skillful hand and arm joint motions when transferring orthodontic brackets were found in the Experienced Group. The kinematic parameters determined in this study would be useful for quantitatively evaluating dental students' dexterity in orthodontic postgraduate programs.

References

1) Morasso, P. (1981): Spatial control of arm movements. *Exp. Brain Res*, **2**, 223–227.
2) Uno, Y., Kawato, M. and Suzuki, R. (1989): Formation and control of optimal trajectory in human multijoint arm movement. Minimum torque change model. *Biol. Cybern*, **61**, 89–101.
3) Flash, T. and Hogan, N. (1985): The coordination of arm movement : An experimentally confirmed mathematical model. *J. Neuroscience*, **5**, 1688–1703.
4) Schneider, K. and Zernicke, RF. (1989): Jerk-Cost Modulations during the practice of rapid arm movements. *Biol. Cybern*, **60**, 221–230.
5) Hreljac, A. (1993): The relationship between smoothness and performance during the practice of a lower limb obstacle avoidance task. *Biol. Cybern*, **4**, 375–379.
6) Harris, CM. and Wolpert, DM. (1998): Signal-dependent noise determines motor planning. *Nature*, **394**, 780–784.
7) Andrews, LF. (1989): Composites. I: Straight-Wire, the Concept and Appliance. San Diego, Calif: L. A. Wells, 13–33.
8) Schmidt, R., Disselhorst-Klug, C., Silny, J. and Rau, G. (1999): A marker-based measurement procedure for unconstrained wrist and elbow motions. *J. Biomech*, **32**, 615–621.

9) Casko, JS., Vaden, JL., Kokich, VG., Damone, J., James, RD., Cangialosi, TJ., Riolo, ML., Owens, SE. Jr., Bills, ED. (1998): Objective grading system for dental casts and panoramic radiographs. *Am J Orthod Dentofacial Orthop,* **114**, 589–599.
10) Yang-Powers, LC., Sadowsky, C., Rosenstein, S. and BeGole, EA. (2002): Treatment outcome in a graduate orthodontic clinic using the American Board of Orthodontics grading system. *Am J Orthod Dentofacial Orthop,* **122**, 451–455.
11) Bhushan, N., Shadmehr, R. (1999): Computational nature of human adaptive control during learning of reaching movements in force fields. *Biol cybern*, **8**, 39–60.
12) Yashiro, K., Fukuda, T. and Takada, K. (2010): Masticatory jaw movement optimization after introduction of occlusal interference. *J Oral Rehabil,* **37**, 163–170.
13) Hollerbach, MJ. and Flash, T. (1982): Dynamic interactions between limb segments during planar arm movement. *Biol Cyber,* **44**, 67–77.
14) Oliver, GD., Dwelly, PM., Kwon, YH. (2010): Kinematic motion of the windmill softball pitch in prepubescent and pubescent girls. *J Strength Cond Res,* **24**, 2400–2407.
15) Feltner, ME. (1989): Three-dimentional interactions in a two-segment kinetic chain. II. Application to the throwing arm in baseball pitching. *Int J Sport Biomech*, **5**, 420–450.
16) Hirashima, M., Kudo, K. and Ohtsuki, T. (2003): Utilization and compensation of interaction torques during ball-throwing. *J Neurophysiol*, **89**, 1784–1796.