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A Study to Expand the Linear Range of the Mandibular Kinesiograph

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INTRODUCTION

The clinical recording of mandibular movements has been attempted as early as the late nineteenth century.[1] However, until recently the basic requirements for recording jaw movement have not been met. Ideally, in order to describe the position of movement of a solid body in space, a minimum of three reference points which do not lie on the same straight line is required. Any technique which locates a point on the jaw does not necessarily locate the jaw position. Thus, absolute location of jaw position requires a minimum of three jaw points and six coordinates, i.e., 6 degrees of freedom. Such location involves complexity in recording and interpretation.[2]

The development of a commercially available magnetic sensing device made it possible to monitor jaw positions and movements in the dental office.[3] Some problems in hardware and software exist with its use: nonlinearity throughout normal jaw opening range and absence of generally accepted clinical correlates of function and dysfunction.

A number of studies have been done using the Mandibular Kinesiograph as a jaw movement tracking system.[3) 3) 5) 6) 7)] Among the studies, however, only a few authors have mentioned the extent of nonlinearity of the system. A mathematical model has been demonstrated which achieves linearity with a small range of jaw movements.[4) 6) 7)] The need for expanding the linear range of the jaw movement tracking system is obvious: many functions of the masticatory system involve a wide range of movement, e.g., temporomandibular joint clicking may occur in a vertical dimension during wide jaw opening. The objective of this study was to expand the scope of linearity of the Mandibular Kinesiograph.

LITERATURE REVIEW

This review will cover briefly: (1) review of previous studies on mandibular movements; and (2) review of other studies using the Mandibular Kinesiograph as a jaw movement monitoring system.

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1. MANDIBULAR MOVEMENT STUDIES

There have been many intra-and extraoral devices which have been employed for recording manibular movements. It has included simple graphic tracing devices[8], kinematic methods (cine-fluorographic, cineradiographic, mechanical and photographic techniques), and also recent sophisticated electronic techniques. Most techniques have been concerned with physiological mandibular movements and little is known about masticatory movements in patients with functional disturbances. Although these techniques have provided valuable information, it should be kept in mind that whatever is put into the mouth it will affect the masticatory system in some way. Some of the studies will be discussed below.

Pbotograpbic Tecbnique

As early as the late nineteenth century, the photographic method was used to study mandibular movement. Luce[1] fastened a silver bead to a wooden pin which was inserted between the inferior central incisors and then he photographed the reflection of the sunlight from the beads. His recording of mandibular movements was discussed only with regard to movement of the mandible in the sagittal plane. This movement area is quite similar to what is now known as border movement. Another early photographic study was done by Ulrich.[9] He traced points in fixed connection with the mandible by means of a splint, an extension which carried reflective silver balls. Tracings of the path of moving jaw were constructed from the curves obtained by exposing the photographic plate while the balls were brightly lighted. He found large variations in the patterns of opening and closing, as well as forward and lateral movements, and the instantaneous axes for such movement. Hildebrand's work[10] can be regarded as the first serious study of the nature of mastication using a photographic technique. His photographic system consisted of markers on the teeth which were photographed from the front and also using a mirror to show the movements in the sagittal plane. His study showed that in the frontal plane the jaw glided slightly with some lateral movement and then gradually opened to a third of the maximum opening position. The mandible was then moved obliquely, cranially and laterally and usually to the side having the most favorable articulation. It was impossible, in his investigation, to differentiate parts of the masticatory cycles as into a crushing phase and a grinding phase. In the study of mandibular movements in mastication, Kurth[11] used the graphic method to trace mandibular movement. Stroboscopic photographs were then utilized to determine the direction of the movement of the incisor point on the three planes. The results showed that a masticatory stroke was posterior to centric relation and was not within the confines of the gothic arch. He concluded that all masticatory endeavor ended in centric relation. Beyron[12] studied Australian aborigines who chew with their lips apart during mastication. Simple cinematography of the central incisors enables the chewing cycle to be observed directly. He found that the preferred chewing side was on that side where the greatest number of teeth were in contact during lateral glide. He accepted the possibility that actual tooth contact might not occur if there was a very thin film of food between the teeth. However, with the photographic technique it was difficult to establish whether true occlusal contact occurred or whether the teeth were separated by a thin film of food. In a kinesiologic study the mandibular movements were analyzed partly by electromyography and partly by cinematography (Ahlgren[13]). The chewing cycle form was classified into seven groups. The subjects who had normal occlusion showed a more regular chewing pattern. Patients with malocclusion demonstrated chopping. reversed, contralateral, and irregular chewing patterns. There was no direct relationship between the type of occlusion of the teeth and the pattern of masticatory movement. Hickey et al.[15] inserted a steel pin directly into the mandibular condyles to a depth of about 1 cm. Small lights, which were placed on the end of the incisor wires and one on a rigid wire directly above the condyle pin, were photographed in three dimensions using three synchronously running motion picture cameras. They claimed that the tracing error was ±0.17 mm. They stated that the condyles and teeth were in the centric occlusion position during swallowing and the teeth contacted in centric occlusion.

Radiographic Technique

Cinefluorography is the making of a motion picture record of an image seen on a fluoroscopic screen. Klatsky[16], employing a radiographic machine, special fluoroscopic screen, and a motion picture camera, obtained eighty pictures in the exposure time of five seconds. He experimented with a series of foods to show the influence of the physical properties of foods on human masticatory function. He found that the harder a food is, the more powerful the bite must be; the more fibrous a food is, the longer mastication must be. In the study of the physiology of the stomatognathic system[17], a cinefluorographic technique was used. A strain gauge was used at the same time to record the vertical motion. It was found that chewing activity was influenced by the constantly changing consistency, shape and size of the bolus, by its taste, and even by the state of the subject's emotions. Berry and Hoffman[18] reported studies of condyle activity using a cineradiographic method. They photographed an electronically intensified image. A sound motion picture camera was used to take pictures of the radiographic images. They used a bone conduction microphone to record occlusal sounds and clicking joints. No conclusion was given for their study. In addition, they did not mention about errors in reading and plotting.

Mechanical Technique

Boswell[19] showed two kinds of mechanical devices (Mandibulograph, Mandibuloscope) in his article concerning occlusion and complete denture. No description was made for the devices. However, he indicated the physiologic action of the mandibular mechanism as cyclic movement and the cycles had their termini at centric occlusion. The Gnatho-thesiometer was an apparatus which Posselt[20] used for registering position of a lower jaw. His apparatus consisted of a inverted cast of the lower jaw and a shaft attached to it, which was placed in different positions in relation to inverted upper cast. He measured differences between various positions of the lower jaw at three points. He stated that the apparatus was used for registration of the contact movement areas of all three measuring points, analysis of the Bennett movement, and observation of the variation of the inclination of the condyle path. Zola and Rothschild[21] followed mandibular movements with the Condylar Thesiograph which traces and records condylar positions. It is basically a lightweight hinge bow which has separate right and left sections attached to the mandible by cementation to the buccal surfaces of a lower molar. In their experiments 68 percent of the power closure recordings were in the hinge axis position. Gibbs et al.[22] have studied mandibular movements with the Case Gnathic Replicator. This system records jaw motion with six incremental transducers mounted between an upper maxillary reference bow and a lower jaw mounted face bow. They claimed that the maximum measuring error was 0.13 mm and the maximum error for reporducing jaw motion was 0.25 mm. As the clutches, which attached the measuring instrument to the teeth, were cemented to the labial surfaces of the anterior teeth, it is doubtful whether jaw movements were influenced by the apparatus and by the subject who certainly was aware of his being observed.

In the study of the sagittal condylar movements of the clicking TMJ, Willigen[23] employed a pantograph with two floating-circle movement scanners to determine the positions of the photoreceptors in the sagittal planes which were attached to the ends of the two facebows. In his study he found at the moment of the clicking sound clearly perceivable deflections in the proceeding movement pattern in the dysfunction patients with clicking joints.

Electronic Technique

Telemetry:

A method has been developed for incorporating radio transmitters into complete dentures for the study of masticating and nonmastcating contacts of the occlusal surfaces.[24] Gold occlusal surfaces were cast and arranged to occlude on dentures. Any area or combination of areas might be selected to send a signal upon contact with opposing areas. It was speculated that tooth contact in chewing varied with the individual and with the type and arrangement of cusp form. Two miniaturized radio transmitters, embedded in acrylic bridgework and fixed to the patients' natural dentition were used to broadcast tooth contact patterns.[25] Transmitter 1 signaled in intercuspal contact position only and transmitter 2 signaled any possible contact of the antagonistic gold crown. There was an extremely long duration of the sliding pattern during swallowing. There was no clear-cut relationship between tooth contact pattern and EMG pattern of the mandibular elevators.

Hall effect devices:

A system for continuously measuring the occlusal vertical dimension based on the principle of the "Hall effect" was devised.[26] The Hall device generates a continuous output that varies in inverse proportion to the magnetic field strength, as long as current is maintained through the sensing element. This system measured the distance of sagittal jaw opening with an accuracy of 0.177 mm±0.1 mm through an opening of up to 5 mm. No results were provided for their study. Lemmer et al.[27] described the movements of a point on the jaw as recorded in two dimensions in each of three planes, i.e., forntal, horizontal, sagittal plane. The device consisted of a small magnet central incisor teeth and three pairs of Hall-effect ttansducers. They reported that since the translation and rotational components of the displacements were not separable on their apparatus, the movements of the magnetic point on the mandible could not be fully described.

Opto-electronic devices:

Gillings[2)] developed the Photoelectric Mandibulography and his device recorded continuous functional jaw movements in three dimensions. He used a light attached to the lower jaw and photocells held on a frame fixed to the head to locate in space the position of a point on the stationary or moving jaw. His device had limited anterior-posterior linearity owing to mechanical limitations. He claimed that a change in jaw point position of less than 100 microns could be readily detected in any of the three planes of movement. Speech was impaired by the device, since they hold the lips from 5 to 10 mm apart. He did not mention how accurate his device was.

In a clinical pilot study using a method known as the Selspot system, Karlsson[28–] used light emitting diodes (LED) and a photodetector system. One LED was placed intraorally and one on the forehead, the latter acting as reference. By using two detectors and a reference system, the three-dimensional coordinates of a movement could be calculated. The detector nonlinearity was about one per cent. He suggested that by using three reference diodes the test person would be allowed to move his head in all direction without any influence on the monitoring of the real mandibular movements in three dimensions. Another study using Selspot system was carried out by Joss and Graf[29)]. Individually made plastic splints which carried two infrared-light emitters were fixed to the subjects' upper and lower teeth. Two cameras were placed to look from 45 degrees left and right so that they provided all information for the three-dimensional movement pattern of the incisal point. It was reported that the resolution of the system was better than 1/100 mm. In the Selspot system, although they claimed that the system could be used very easily by anyone, it seemed to be too complex to be operated by any electronic novice.

2. THE MANDIBULAR KINESIOGRAPH

Jankelson et al.[3)] introduced the Mandibular Kinesiograph which sensed the spatial location of a permanent magnet that was mounted on the mandibular incisors. The system provided an accuracy of 0.1 mm for resolution of mandibular positions in the vicinity of occlusion. At a vertical opening of 20 mm, the geometric error was approximately±3 % in the vertical, ± 5.7 % in the anteroposterior, and 0 % in the lateral. There was, however, a corresponding error in the lateral channel of about± 6 % when the mandible was deviated 10 mm left or right at a 20 mm vertical opening. In the study of a computer-based system for the simultaneous measurement of muscle activity and jaw movement during mastication, Hannam et al.[4) 5)] used the Kinesiograph to record jaw displacement in three planes. For the calibration of the system, a magnet was moved systematically in a three dimensional lattice. Calibration curves where constructed for each of the three planes of movement enabling a linearizing program to be written for the computer so that, after sampling, the displacement data would be automatically corrected. It was possible to measure to an accuracy of± 0.25 mm, anywhere within a cube 2 cm wide, by 2 cm deep, by 4 cm in height. Jankelson[6] examined the validity of the data supplied by the Kinesiograph. A computerized, elecronically driven positioning system was used to move a magnet in increments of 0.001 mm in three dimensions so that these known movements could be compared with the Kinesiograph outputs. The data showed tha "clinical space", defined as an area within 4 mm to the right and left of, 4 mm anterior and posterior to, and 0 to 7 mm inferior to the intercuspal position, was least affected by geometric divergence. The calibrated range of the Kinesiograph was measured from the null point (intercuspation) vertically 26 mm, 11 mm anterior, 11 mm posterior, 11 mm to the right and left. Within this calibrated test range, the computer program corrected the data to within 1.5 % of the exact values. Stohler and Ash[7] studied habitual chewing with the techniques of electromyography and the Mandibular Kinesiograph. The validity of data from the Kinesiograph was assessed with a positioning device. Data streams were linearized with the conversion routine. The error of the formula was 0.0±2 mm under work-bench conditions and 0.0±3 mm under dynamic conditions in an area within 7.5 mm to the left and right of, 5 mm anterior and posterior to, and 0 to 10 mm inferior to the intercuspal position.

Kim[30)] examined the validity of the Kinesiograph output using a nonferromagnetic mechanical positioning device within working range of a 3 cm wide by 4 cm deep by 5 cm high three dimensional lattice. In order to devise a formula which can be used to predict case values of actual positions by measured values from the Kinesiograph, regression analysis was performed. The statistical analysis showed that observed values and actual values were strongly correlated. However, high correlation does not necessarily mean perfect predictability of the formulated linear model. It was concluded in that study that the inherent nonlinearity of the system output keeps its application within measurements of a limited range of jaw movements.

METHODS

The outputs (in Voltages) from the Kinesiograph are not directly and equally proportional to displacement of the magnet. To provide absolute values for the Kinesiograph, this study was mainly devoted to develop software for a computer system that interfaces with the Kinesiograph.

The set-up for the Kinesiograph followed the same procedure described elsewhere.[30)] The magnet was placed in space with a non-ferromagnetic mechanical positioning device. Three micromanipulators were arranged so that the magnet could be moved in linear steps of 5 mm through three planes parallel to the frame work carrying the sensors within a 3 cm wide by 4 cm deep by 5 cm high three-dimensional lattice. Both the Kinesiograph outputs and actual movements were stored in the computer.

Raw data file has 6 variables, i.e., X, Y, Z for actual values and VV, AP, LL for observed values in each line of data file. When the magnet moved in linear steps of every 5 mm within a 3 cm wide by 4 cm deep by 5 cm high three dimensional.lattice, 693 data points were achieved. Each data points have 3 variables for actual values and 3 variables for observed values. The basic idea of new approach was to associate actual values and observed values and to name each data point with the given actual and observed values. In order to do that, raw line file was rearranged so that new file consists of nine sheets of data files. Each sheet of paper contains 7 by 11 data points and it represents a slice cut from the data matrix. How, one can easily visualize the observed values data matrix with the actual values along the coordinate axes. With this format it is not difficult to locate a point with three observed values once the actual values are provided.

However, the final goal was to deduce acutal values from provided observed values. The data file was reorganized so that observed values were used as coordinates to create an actual values data matrix. Here, actual values can be searched out by applying the given observed values, on variable at a time. First, one out of nine sheets of data matrix would be selected for the proper observed value and then the actual values could be located by crossing other two observed values. A computer program was specially written to deal with this work.

The computer program will do the following: it will read the values of X, Y, Z, VV, AP, LL from line 1 to line 693. And it will read the given values of A, B, C. And then it will compare, first, the values of VV and A.. If the absolute values of the output is smaller than error bound, it will take the line numbers of VV and will compare the values of AP of same line number with the values of B. Again if the values of |AP-B| is smaller than error bound, next it will compare the values of |LL-C|. In short, the program has a loop which will continue to read and compare the values of VV, AP, LL, and A, B, C until it finally comes up with one or more line numbers with which the absolute values of the differences fall within the given error bound. For the result, it will write input data and output data as well.

RESULTS

·To associate actual values and observed values, new line file was rearranged so that the observed values matrix could be visualized with the actual values along the coordinate axes. In the second transformation, the file was reorganized in order for observed values to be used as coordinates to create the actual values data matrix. Here, actual values could be determined by applying the observed values. A computer program was written to do this work.

Table 1 shows the sample result of the first transformation of raw line file. There are nine layers and each layer represents 7 by 11 matrix of observed values in volts. In Table 1 the "LAYER: 15" shows the position of the slice in terms of antero-posterior relation, i.e., 15 mm anterior to the reference point (zero point). In the edges, X values (actual) and Z values (actual) are arranged. X values for first line is 25 and the last one is-25 with the same interval of 5 between each row. Z values very from 15 to-15 with the interval of 5 between each column.

Table 2 and Table 3 are two samples of the results of resorting the outputs from the second transformation. In this case, actual values are in matrix form with the observed values along the coordinate axes at intervals of 0.25 (volts). Each layer has the range of .25 (volts) for LL values. For instance, Table 2 is for X variable which are within the range of -1.00 to -0.75 for the values of LL.

Table 4 shows a smaple of linearized jaw displacement data from high speed line printer.

Table 1. A sample printout of the first transformation.

	15			10			5			0			-5			-10			-15		
25	789	-635	176	1548	-848	156	1709	-783	80	1728	-740	55	1948	-702	36	1653	-811	14	498	-383	-20
20	510	-288	238	1136	-388	194	1290	-382	99	1312	-344	53	1505	-415	14	1233	-282	-26	238	217	-80
15	174	265	307	701	75	239.	852	0	119	876	30	53	1049	10	-6	819	215	-68	-73	822	-143
10	-194	813	375	264	484	290	408	317	143	423	341	54	594	376	-28	386	674	-108	-410	1364	-202
5	-570	1301	422	-173	835	323	-53	579	167	-27	577	59	117	686	-45	-57	1069	-141	-791	1852	-252
0	-959	1674	449	-623	1079	325	-519	740	184	-484	711	66	-339	887	-54	-485	1318	-141	-791	1852	-252
-5	-1346	1828	444	-1038	1163	322	-910	776	198	-934	722	77	-782	953	-56	-906	1405	-162	-1570	2038	-272
-10	-1736	1715	408	-1474	1080	304	-1428	684	207	-1375	616	84	-1227	876	-49	-1332	1290	-147	-1974	1739	-238
-15	-2105	1370	353	-1876	853	263	-1873	478	203	-1804	404	94	-1697	681	-36	-1723	1051	-119	-2386	1240	-181
-20	-2470	870	283	-2277	495	222	-2324	183	193	-2224	117	101	-2045	385	-13	-2130	672	-83	-2812	665	-114
-25	-2843	870	207	-2669	68	172	-2769	-166	180	-2671	-235	107	-2468	28	0	-2509	223	-43	-3246	76	-44

* (VV, AP, LL) in millivolts

Table 2. A sample of the result of second transformation (LL=−1.00 − −0.75).

		-15	-10		-5		0	5	5		
-20											10
		-15							5		
-20											10
					-10		-5		0		
-20											10
					-10		-5		0		
	-20										10
			-15							5	
		-15							5		
				-10				0			
						-5					
					-5						

Table 3. A sample of the result of second transformation (LL=−0.25 − 0).

																25			25		25	
																25		20	25	25		25
	-25		-20		-15								5		10		18	20		22		25
		-25					-10		-5		0						25	15		20		
		-25		-20		-15	-10			-5		0		5		10		15		25		25
		-25		-20												10	25			20	25	25
		-25				-15		-10		-5		0		5			25	15		22	25	
				-20												10			20		25	
		-25				-15		-10		-5		0		5		25	25	15	22	22		
		-25		-20		-15								5		15		20	20			
	-25			-20				-10		-5		0				15	18	20				
-25	-25					-15		-10				0		5	20	16						
-25	-25		-20			-10				-5					13							
-25		-20			-15		-10				0		5	11								
		-20		-15	-15		-10		-5	0		5	12	10								
				-15	-20	-10		-5		0												
											7											
							-5		0													

Table 4. A sample printout of linearized jaw displacement data

VV=-2367	AP=-2516	LL=-685
X=-20	Y=-25	Z=-15
VV=-1951	AP=-2425	LL=-836
X=-15	Y=-25	X=-16
VV=-1527	AP=-2371	LL=-941
X=-10	Y=-25	X=-15
VV=-1100	AP=-2356	LL=-970
X= ^{2}5	Y=-25	Z=-15
VV= -679	AP=-2386	LL=-923
X= 0	AP=-25	Z=-15
VV= -261	AP=-2453	LL=-809
X= 5	Y=-25	Z=-15
VV= 149	AP=-2562	LL=-645
X= 10	Y=-25	Z=-15

DISCUSSION

The masticatory systme is a complex interrelated system composed of the teeth, the muscles, the joints, the mucosa and the vascular and nervous system. Because of the inaccessibility of the central nervous system, most of the studies in human masticatory system have been limited to the analysis of peripheral correlates such as muscle activity, jaw movement and the forces involved.

DISCUSSION

The masticatory system is a complex interrelated system composed of the teeth, the muscles, the joints, the mucosa and the vascular and nervous system. Because of the inaccessibility of the central nervous system, most of the studies in human masticatory system have been limited to the analysis of peripheral correlates such as muscle activity, jaw movement and the forces involved.[1-30)]

Many disturbances of the masticatory system are reflected as alterations of jaw position and movement, many involving only small change in dimension close to contact of the teeth, but others involve large dimensional change such as in yawning, singing and opening the mouth wide to incise large bite of food. Thus the clinical correlates of function or dysfunction require a system with a wide range of accuracy for measurement, but such requirements vary with the information desired and the type of dysfunction.

In the previous study[30] regression analysis was used to devise some kind of equation which could predict actual values using observed values. This approach was not so convincing for a wide range of movements. For this reason a process to provide absolute values for the output was attempted in a different approach.

The current system is good when the given values (A, B, C) are indentical with those of line file (VV, AP, LL). If a point within somewhere in a 5 mm cube is given, the computer program will find one or sometimes more than two points with three variables (X, Y, Z), or it may fail to search. To reduce this unwanted problem, a data matrix with a smaller interval between each data point could be used.

It is theoretically possible to retrieve absolute values without any error from the raw Kinesiograph data using algorithm adopted here in this study in contrast to certain errors inevitable in the other studies.[3) 4) 5) 6)] Still, there exist problems in processing the enormous amount of data and its expression. The only feasible way of solving the problems seems to be digital conversion of raw data. It is, however, prerequisite to have a fine positioning system which can move the magnet precisely in linear steps of, for instance, smaller than one hundredth mm while not affecting magnetic field created by the Kinesiograph since the accuracy of the proposed system depends totally upon the size of intervals between each data point. It needs to be mentioned that the outputs from the Kinesiograph should be stable and reproducible. For the better results, it is advisable to have a separate, electromagnetically shielded room in which all the measurements can be performed.

SUMMARY

The possibility of expanding the linear range of the Kinesiograph was studied using a non-ferromagnetic mechanical positioning device. The magnet was moved in linear steps of 5 mm through three planes parallel to the frame work carrying the sensors within working range of a 3 cm wide by 4 cm deep by 5 cm high three dimensional lattice and a matrix of 693 data points was achieved. For each data point, the three Kinesiograph outputs were associated with the values of actual position. Once three coordinates of observed values were known, actual values could be determined. A computer program was specially written in Fortran to deal with this work. Because each dat point was 5 mm apart from each other, there would be 480 cubes with 8 data points. Further refinement of the system is possible using a smaller interval between each data point. In conclusion, a theoretical model was presented which, by means of computer support, would allow the absolute measurement of jaw position over the entire range of functional jaw movements.

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=국 문 초 록=

Mandibular Kinesiograph에서의 선형범위 확장에 관한 연구

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Kinesiograph로 부터 얻어지는 자료의 선형범위를 확장하고자 하는 연구가 비철, 비자석성의 기구를 사용하여 수행되었다. 자석을 5 mm의 일정한 간격으로 자석감지장치가 달린 구조물에 평행하게 세 평면(frontal, horizontal, sogittal plam)을 통해 3 cm× 4 cm× 5 cm의 입체공간내에서 693개의 움직여서 만들어지는 자료점으로 항렬 (matrix)을 얻었다. 각각의 자료점에 있어서 Kinesiograph로부터 얻어진 관찰된 값과 움직인 실제값이 상과지어졌다. 따라서 관찰된 값의 세 상관계수를 알게되면 실제값인 세 계수를 얻을수 있게 됐다. 이 업무를 수행하기 위해서 컴퓨터 프로그램이 Fortran을 이용해서 특별히 쓰여졌다. 각 자료점이 5mm 서로 떨어져 있으므로 연구된 입체공간에는 각각 8개의 자료점을 가진 480개의 입방체가 존재한다. 따라서 각각 자료점간에 더 작은 간극을 마련할 수 있다면 보다 더 정밀한 계측이 가능할 것이다. 결론으로 컴퓨터의 도움으로 기능적 하악운동의 전체범위에 걸친 절대계측을 가능케 하는 이론적 모형이 제시되었다.