JT-21.5

Measurement accuracy of the mandibular kinesiograph—A computerized study

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The use of electronic biomedical instrumentation has long provided the scientific basis for diagnosis and monitoring of a variety of body dysfunctions. Examples are the electrocardiograph (ECG) for diagnosis and monitoring of cardiac dysfunction, the electroencephalograph (EEG) for neurologic dysfunction, and the electromyograph (EMG) for monitoring muscle dysfunction.

Constant advances in high-technology electronic and computer sciences have now made possible instrumentation of comparable convenience and adaptability for diagnosing and monitoring mandibular dysfunction.

The transferral of quantitative measurement data from the mouth to precision measuring instrumentation and the question of the quantitative accuracy of the derived data has been a long-standing problem. Increments of fractions of millimeters can be significant in the study of occlusal problems. Techniques which wholly or partially use mechanical instrumentation have their limitations. Electronic technology offers alternatives for more expeditious, precise, and dependable measurement.[1-3]

THE MANDIBULAR KINESIOGRAPH (MKG)*

The MKG is an instrument designed for research and diagnosis of mandibular function/dysfunction. It electronically records mandibular incisor-point movements in three dimensions by tracking a magnetic field emanating from a 2.8 gm magnet lying in the inferior labial vestibule.[2] Measurement of vertical velocity is also provided by differentiating the vertical position signal.

The 100 gm sensor array, supported on the skull by a modified pair of eyeglass frames worn by the patient, electronically tracks the magnet attached to the mandibular incisors with a modified acrylic. This magnet is positioned to lie inferiorly in the labial vestibule. It is bisected by the midsagittal plane, with its magnetic axis parallel to the interpupillary line. The geometry of the magnetic axis precludes tracking errors for small differences in the parallelism (up to ±5 degrees). Lateral displacement of the magnetic point from the midsagittal (up to ±5 mm) is compensated for by the alignment of the sensors.

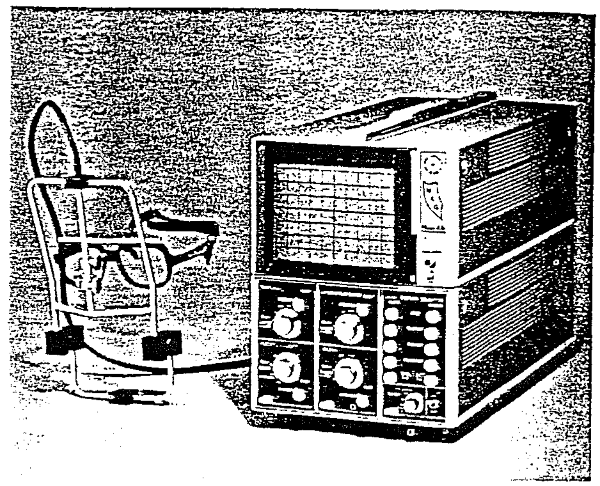

Fig. 1. Model K5-R mandibular kinesiograph.

The MKG interfaces with various display units, such as a paper strip chart recorder, magnetic tape deck, or a computer terminal in addition to the integral, built-in storage cathode-ray tube (CRT).

The choice of a number of calibrated magnifications (gain) from 1.2 to 62.5 magnification provides easily visualized orthogonal views of actual movement at the incisor point.

PURPOSE OF STUDY

The validity of data generated by any measuring instrument is dependent on the qualitative and

*Model K5-R Mandibular Kinesiograph, Myo-Tronics Research, Inc., Seattle, WA.

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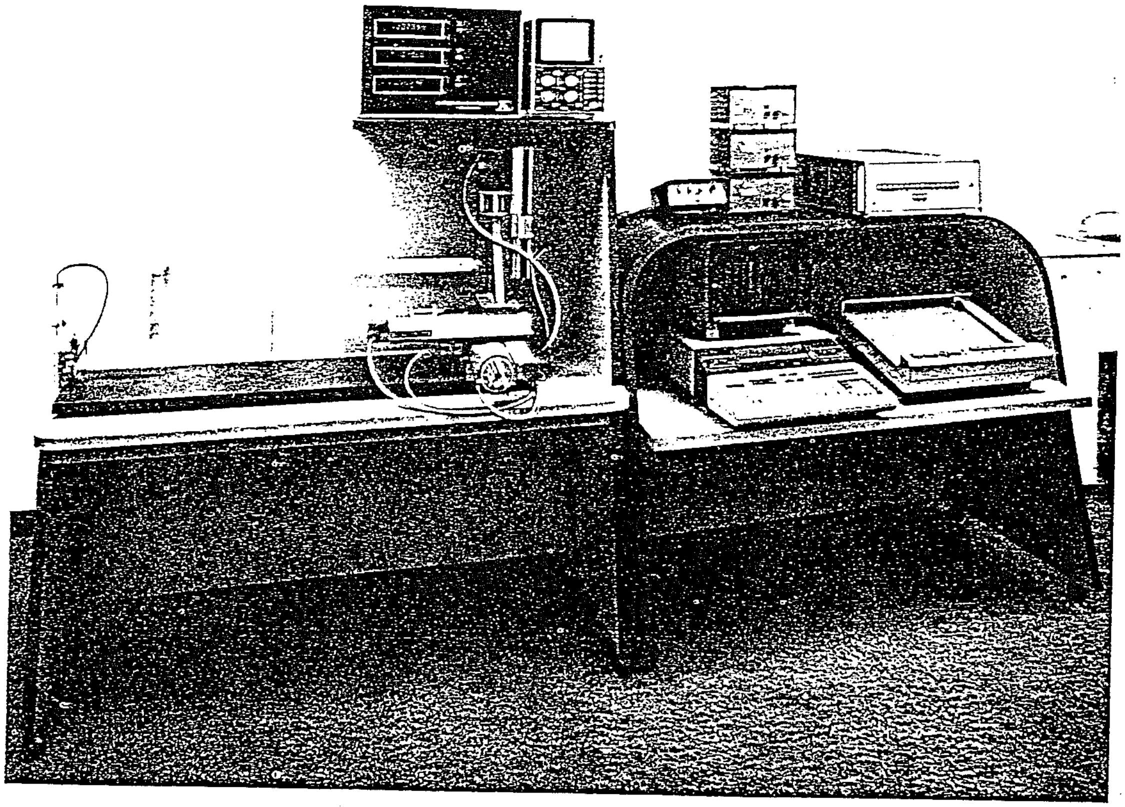

Fig. 2. Computerized electronic positioning system.

quantitative reproducibility and accuracy of the measuring device.

The purpose of this study was to assess the validity of the data supplied by the MKG by testing the accuracy of both the raw MKG data and the corrected data by means of precise measurements throughout the entire range of functional mandibular movement.

The accuracy of the MKG trace patterns in the vicinity of occlusion had previously been mathematically computed and reported as within 0.1 mm. For wider mouth openings, where geometric divergence became greater, computer corrections had then been written on the basis of the mathematic expression, in Fortran and Basic languages. From the results, a printed table of corrected measurements was also compiled.[1]

SCOPE OF STUDY

The scope of this report is limited to: (1) description of a computerized electronic testing instrumentation sytem capable of measuring and recording position accuracy to within 0.01 mm, (2) quantitative accuracy of both the raw MKG data and the computer corrected data (determined by testing against the measurements established by the computerized electronic positioning system), and (3) quantitative accuracy capabilities of a dedicated microcomputer correction system developed to eliminate the need for a general purpose computer.

Four models of the MKG are currently available for use in: (1) clinical diagnosis (Model K5), (2) general research (Model K5-R), (3) computer-aided research (K5-C), and (4) a dual-magnet capability (K3-A) with two 1.9 gm magnets placed buccally to the second molars where they detect minute rotations occurring around an anteroposterior axis. However, since all models are essentially comparable in function, this report is limited to the testing of the K5-R (Fig. 1).

MATERIAL AND METHODS

Description of computerized electronic test system

A computerized, electronically driven positioning system was used to move the MKG oral magnet in

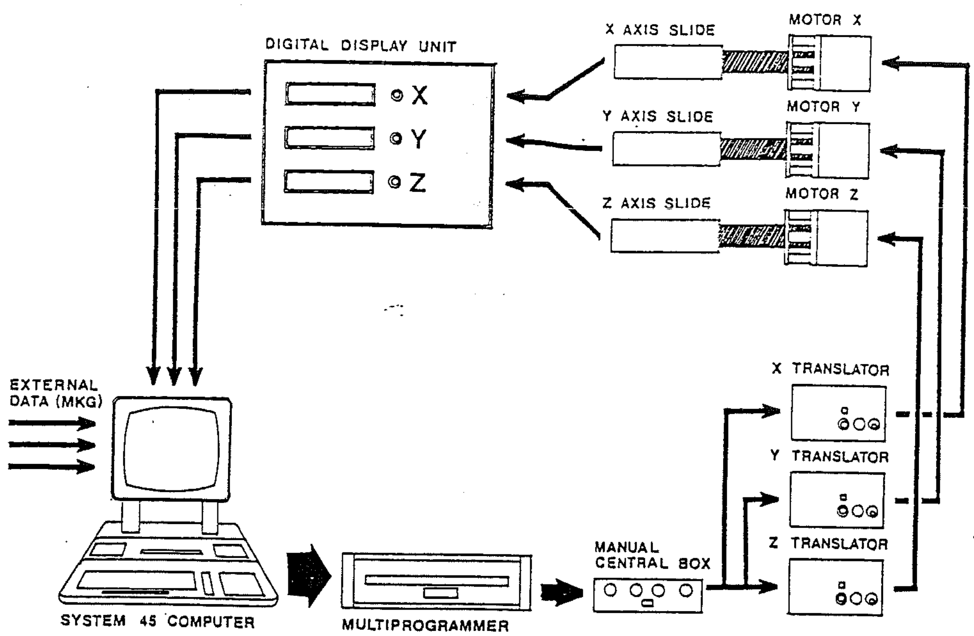

Fig. 3. Block diagram of positioning system.

increments of 0.01 mm so that these known movements could be compared with the MKG outputs. Additional tests were performed to isolate and measure any inaccuracy resulting from operator errors or external interference.

The test system was designed to: (1) simulate three dimensional movements occurring at the incisor point during function. Incisor point movement was selected because that is where mandibular movement is greatest,[5] so that both movement and errors are most apparent; (2) measure, with a resolution of 0.01 mm, three dimensional movements of a magnetic test point as it changes position in space; (3) play back previously recorded movements (i.e., cause the positioning system to precisely repeat movements); (4) constantly computer-test the positioning gear to ensure optimum accuracy to 0.01 mm and perform self-correction if necessary; and (5) ensure that the positioning system causes no magnetic interference with the magnetic test point.

To accomplish these specifications, three orthogonally arranged dove-tail slides* were each independently driven by a stepping motor† in X,Y, and Z directions. Each motor moved electronically in increments of 0.01 mm, controlled by a translator unit† under computer command. The computer was a Hewlett Packard System 45* with a flexible disk memory (Fig. 2).

The computer transferred control information and position-related data to a 6940B multiprogrammer unit,* which in turn converted this information to a format suitable for each motor translator (Fig. 3). The computer is capable of commanding movement of the positioning system to any point within a cubic volume 150 mm per side. To verify whether a certain command was performed, and to observe the precision involved, six-digit electronic glass scales† optically measured the displacement of each slide with a precision of 0.01 mm and constantly monitored the movements of each dimension (Fig. 2). The readings, which constituted the coordinates of the test point in space, were then transferred to the computer and simultaneously displayed on the large digital unit.† The information transferred to the computer was then checked against the original command during an execution interruption. The comparison check determined whether self correction techniques were necessary to ensure the 0.01 mm precision required of the system.

To test the tracking accuracy of the MKG, the computerized positioning system electronically moved an MKG magnet in increments of 0.01 mm,

*Setco Industries, Inc., Cincinnati, OH.
†Superior Electronic Co., Bristol, CT.

*Hewlett Packard, Loveland, CO.
†Anilam Electronics Co., Miami, FL.

in three orthogonal dimensions: X, Y, and Z (lateral, anteroposterior, and vertical, respectively). As the computerized system recorded the movement of the magnet which it controlled, the MKG simultaneously tracked the same movements. Both outputs were fed into the computer. The computer compared the MKG outputs with those of the positioning system and plotted the two on an X-Y recorder in superimposition.

Correction by general purpose computer

The raw MKG data were then corrected by the Hewlett Packard System 45 computer using the existing correction program. The computer-corrected results were in turn compared with, and plotted against, the known positions provided by the electronic positioning system.

Correction by dedicated microcomputer

Recent advancements in electronic technology, specifically the development of the microcomputer, have made low-cost digital processing feasible. Thus, a separate goal of this project was to determine whether the geometric correction program could be provided by a dedicated microcomputer device that would correct MKG data in real-time at a fraction of the cost of a general-purpose computer system.

An instrument was designed and produced using a microprocessor with 8 bit (0.4%) resolution, that reproduced (in real-time) the same geometric correction as the Hewlett Packard computer system. An additional benefit of dedicated microcomputer application is user convenience. The device connects directly to the MKG, and the corrected data is viewed instantaneously on the CRT.

CONTROL OF VARIABLES

Locating MKG to avoid ferromagnetic interference

In accordance with the caution advised in the operating manual, care was taken to avoid positioning the MKG in proximity to sources of electromagnetic or ferromagnetic interference.[6]

Head movement cancellation system

Because the craniomandibular muscles continuously posture the head while the mandible is functioning, the need for restriction of head movement while monitoring mandibular movement tends to compromise the functional validity of the data.[7]

Because it is important not to restrict the head movements that are a characteristic part of function,

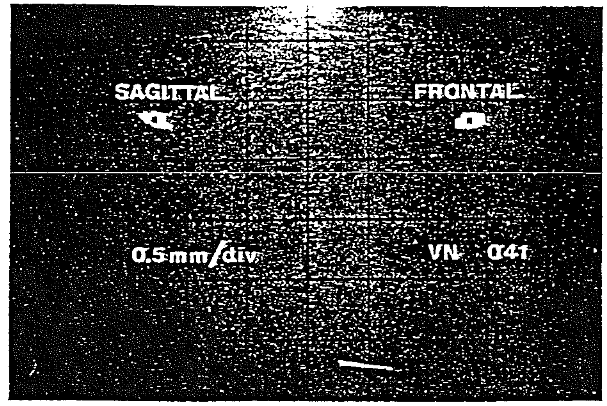

Fig. 4. Movement artifact produced by sensor array assembly and earth's magnetic field.

a separate transducer, mounted above and away from the magnet sensing system, monitored changes in head position relative to the earth's or other ambient magnetic fields, transmitting the information into a cancellation system built into the MKG.

To test whether the cancellation system was effective, and to determine the extent to which functional head movement might be affecting the data on mandibular movement, the magnet was attached securely to the midline of the *maxillary* incisors on five subjects. Output from the MKG then reflected any failure of the circuitry to cancel the influence of the earth's magnetic field or other ambient magnetic influence, as well as errors that might be introduced by movement of the sensor assembly on the skull.

Alignment of sensor array to intercuspal position

The intercuspal position provides the most repetitive, stable reference[8] from which mandibular movements originate and to which they return. An essential prerequisite for use of the MKG is that the sensor array be nulled to the intercuspal position.[6]

The 100 gm sensor array, supported by a pair of modified eyeglass frames, is aligned to the skull and the magnet. Since the signal amplifiers are direct current-coupled, the MKG screen is used (at 25 × magnification) to electronically monitor whether the sensor array is aligned precisely to the intercuspal position. Total set-up time in the hands of an experienced operator is approximately 5 minutes.

To test the accuracy and reproducibility of sensor array alignment, the sensor array was remounted 10 different times over a period of 2 weeks by three different, experienced operators.

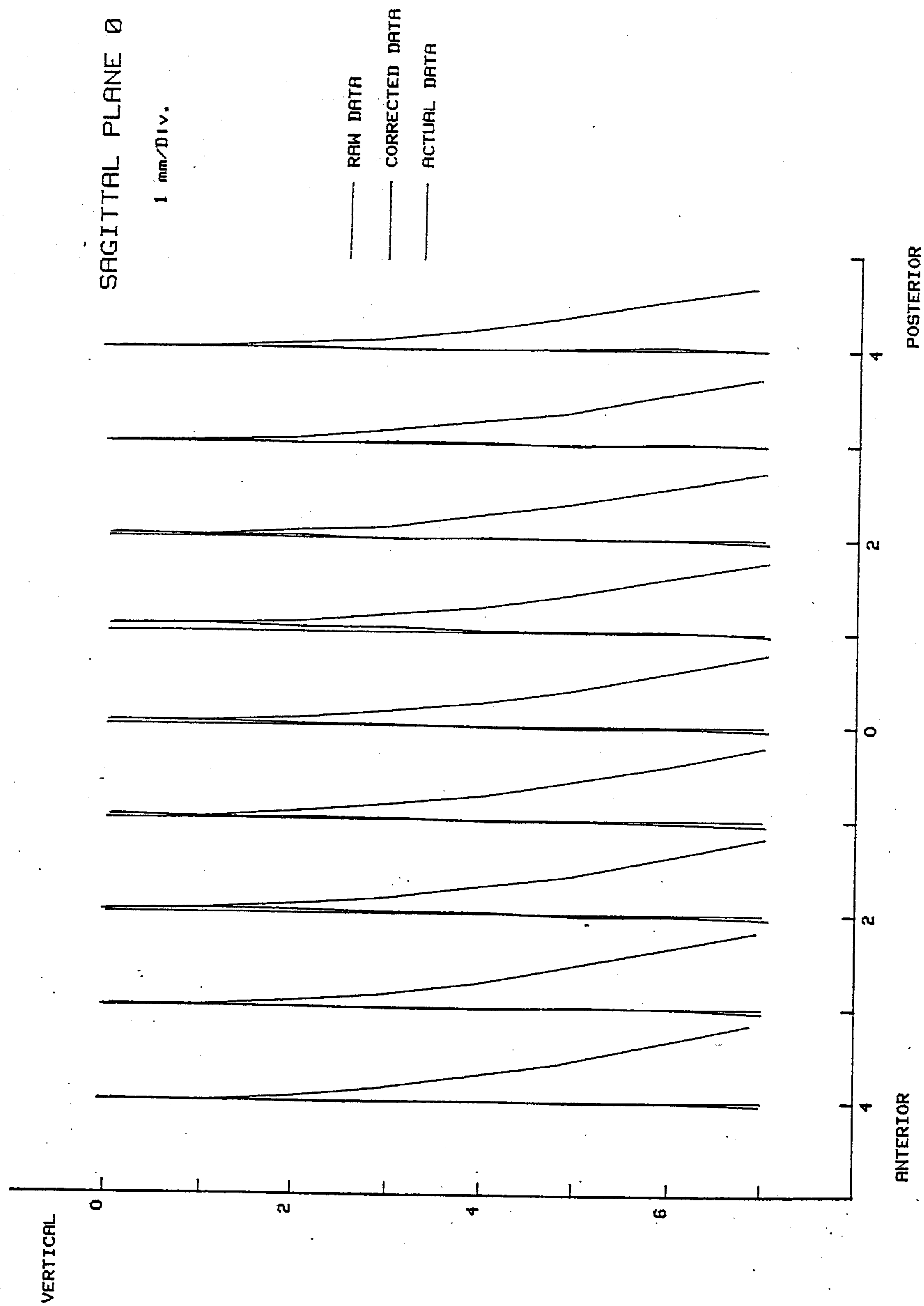

Fig. 5. Saggital plane raw and corrected data plotted by computer.

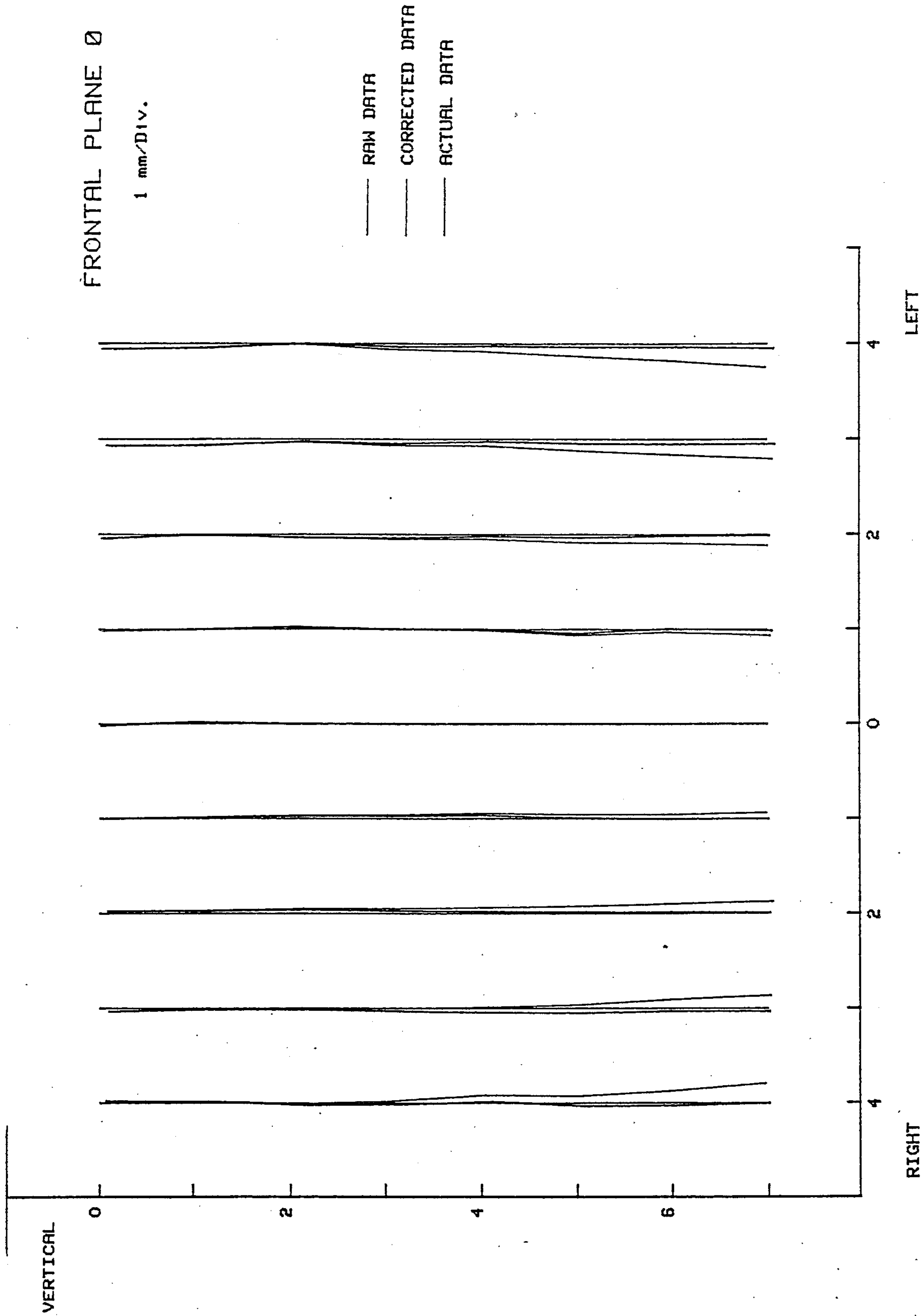

Fig. 6. Frontal plane raw and corrected data plotted by computer.

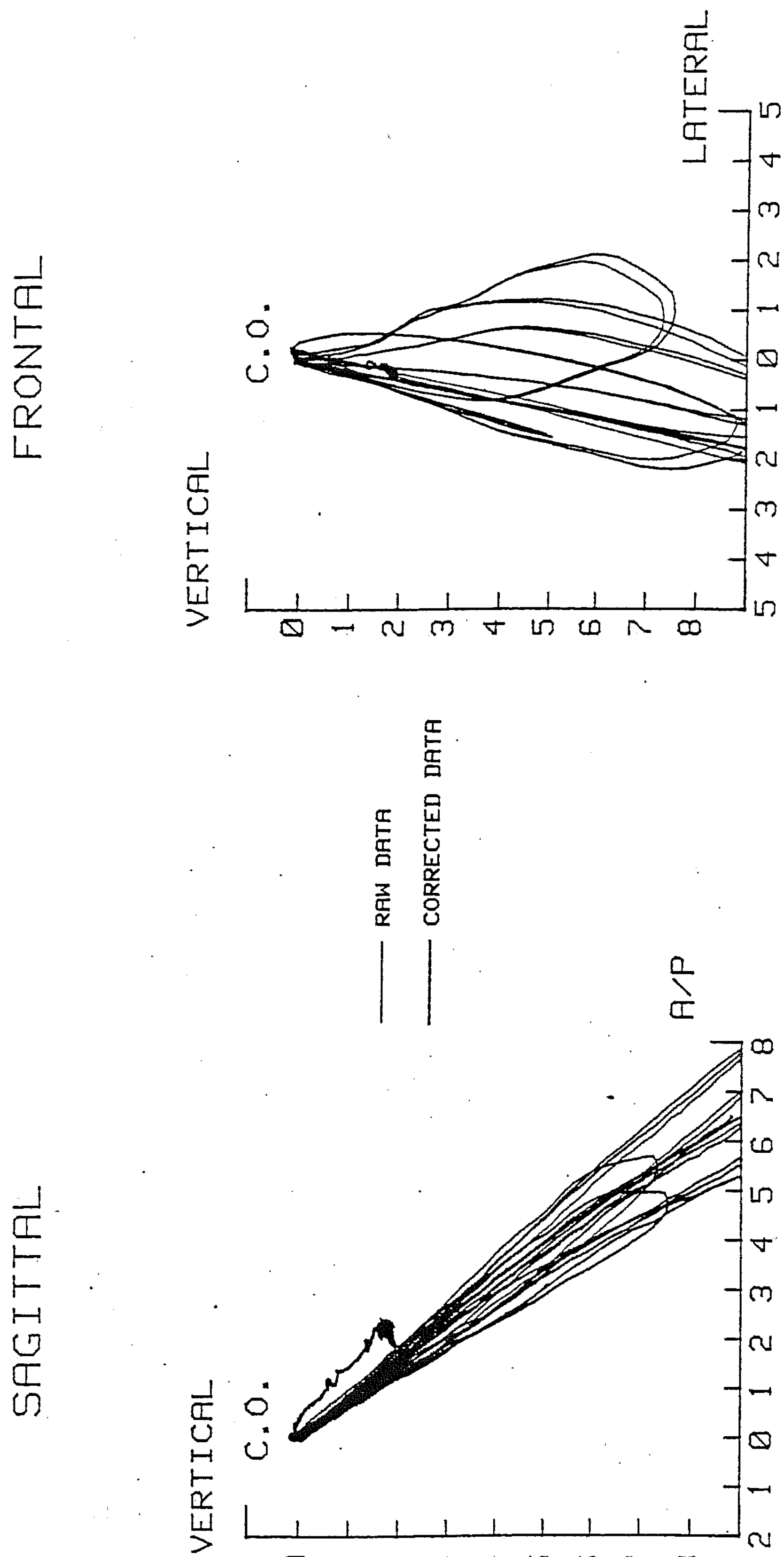

Fig. 7. Typical chewing sequence followed by voluntary retrusion to centric relation.

Accuracy characteristics of clinical space

The most critical research and diagnostic area is the space in the vicinity of occlusion. Information regarding rest position, interocclusal space, intercuspal position, centric occlusion parafunction, and centric relation are all derived within this space.

Hence a primary concern is the integrity of the data within the volume of "clinical space," defined here as an area within 4 mm to the left and right of, 4 mm anterior and posterior to, and 0 to 7 mm inferior to the intercuspal position. The data reported here also establish that it is this "clinical space" which is least affected by geometric divergence.

Accuracy characteristics at wider mouth openings

As the MKG K5-R tracks the more wide-ranging movement at wider mouth openings beyond clinical space, the influence of geometric divergence becomes increasingly greater. To compensate for this increase of geometric divergence in the raw MKG traces, a computer correction program was developed. The measurement accuracy of the MKG was then tested using the computerized electronic positioning system described above, to its resolution of 0.01 mm. Order of accuracy of the computer-corrected traces was further determined with the computerized testing system.

RESULTS

Head movement

In the tests described that were used to determine what effect functional head movement might have on the data, the recorded error induced by head/sensor array movement combined was less than ±0.1 mm. A sample record is shown in Fig. 4.

Alignment of sensor array

In each trial performed by the three experienced operators, the computerized tests of the accuracy and reproducibility of electronic sensor alignment showed that the null point was replicated within ±0.025 mm.

Accuracy within clinical space

The qualitative integrity of the raw MKG trace patterns throughout clinical space is shown in Figs. 5 and 6. No discontinuities existed. Quantitatively, in a typical slide from centric occlusion to centric relation (1.7 mm), the raw MKG data deviated only 0.05 mm (less than 2%) from exact reproduction (Fig. 7). The only significant error in the raw data resulted from the geometric distortion which caused a skewing of the trace posteriorly as the mouth opened wider. The largest, three-dimensional error of the raw data was 0.83 mm (8%). The computer-corrected data was accurate to within 0.1 mm (1.5%). Geometric distortion of both raw and corrected data approaches zero as the mandible approaches centric occlusion (the null point).

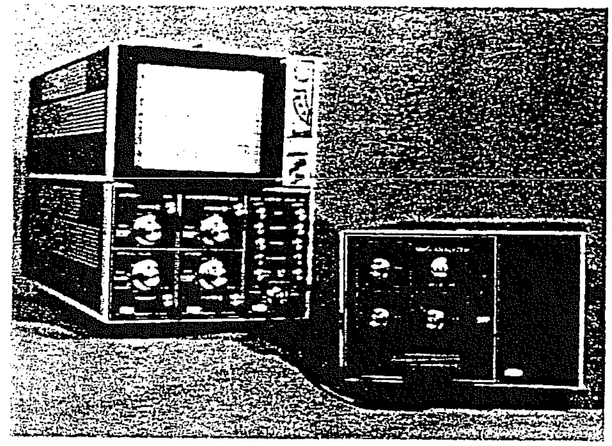

Fig. 8. Microcomputer-based correction instrument interfaced with the MKG.

Table I. Error analysis of mastication recordings within "clinical space"

	Mean ($\bar{x}$) (mm)	SD (s) (mm)	Variance (s^2) (mm)
Vertical	0.098	0.070	0.005
Anteroposterior	0.267	0.198	0.039
Lateral	0.039	0.028	0.001
Three-dimensional	0.286	0.211	0.045

Accuracy of raw output at wider than functional openings

Quantitative measurement of wide-opening, wide-ranging movements requires geometric correction.

Since the error is a constant function determined by the geometry of the sensor array, the correction program makes it feasible to provide accurate data throughout the range of possible jaw movement. The calibrated range of the MKG is measured from the null point (intercuspation) open vertically 26 mm, 11 mm anterior, 11 mm posterior, 11 mm to the left and 11 mm to the right. Within this calibrated test range, the computer program corrects the data to within 1.5% of the exact values, which provides a "worst-case" error less than 0.5 mm for a 30 mm movement. This correlates closely with the findings of Hannam et al.[9]

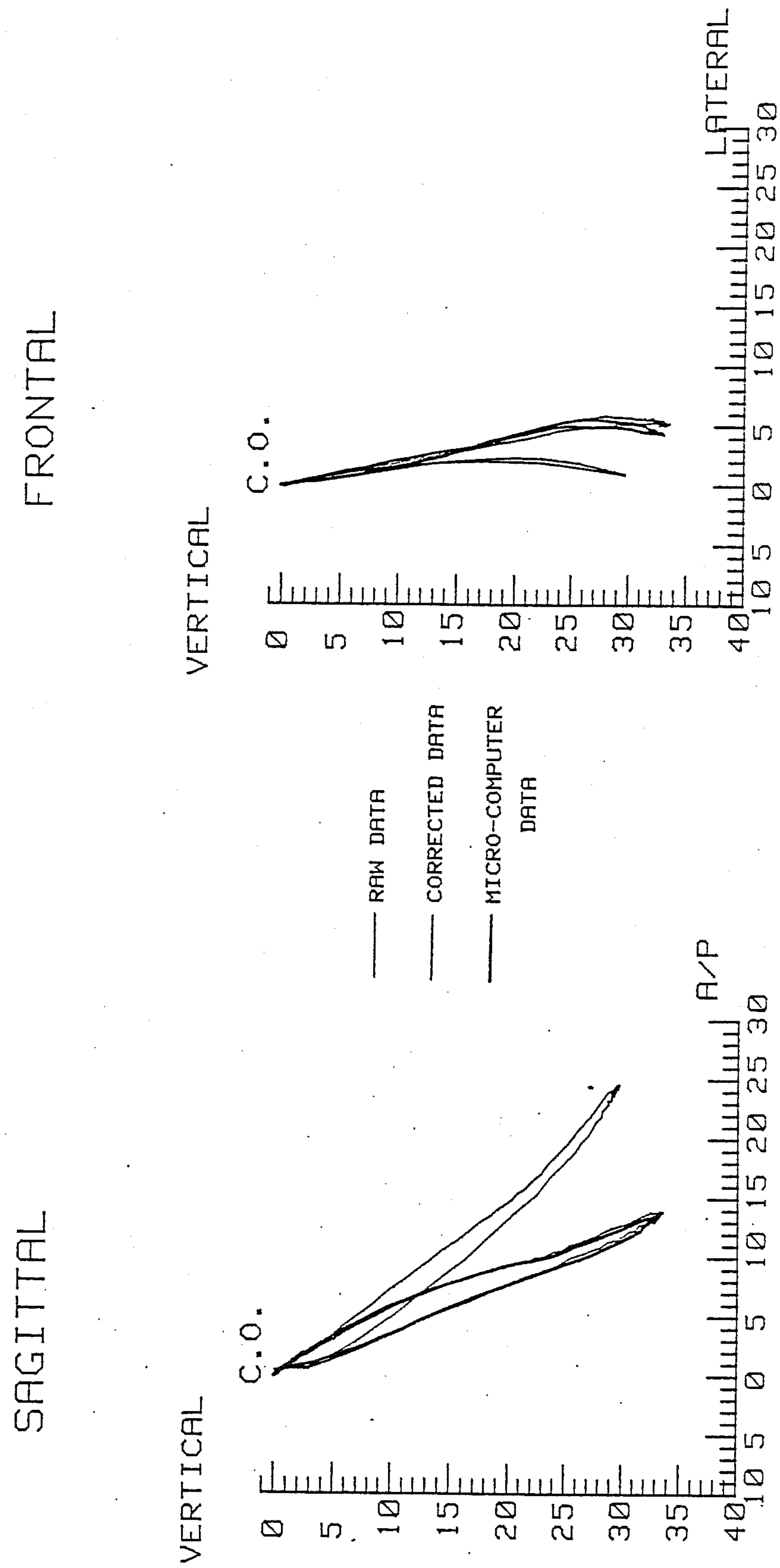

Fig. 9. Comparison of data corrected by the Hewlett Packard System 45 general purpose computer and the same data corrected by a microcomputer.

In a real-life recording, the geometric error is considerably smaller because the extreme limits tested go beyond the range of functional movements. To establish what real effect could be anticipated, random samples of actual jaw positions were taken during function. These samples were corrected and the errors averaged. The mean, standard deviations, and variance for the chewing data are presented in Table I.

DISCUSSION

Now that the MKG is being used increasingly in research and diagnosis of mandibular function/dysfunction,[9-12] the experimental measurement data reported above should provide the researcher and the diagnostician the factual basis needed for evaluating the accuracy of the retrieved data. The extent to which variables affect the data was monitored and is here reported.

In the evaluation of clinical instrumentation, convenience and practicality of use are important considerations. The short, average set-up time of 5 minutes that we experienced in the tests for sensor alignment, repetitive to within ± 0.025 mm prior to recording, is a measure of the practicality of the instrumentation for retrieving a variety of research data from large populations and for user convenience in everyday clinical diagnoses of mandibular dysfunction and occlusal problems.

A number of variables are involved in the problem of tracing mandibular movements. One variable is induced by the range of head movements that naturally accompany mandibular function. In the MKG, the electronic head movement cancellation system reduced the effect on the data to less than 0.1 mm. Elimination of the need to fix the head not only allows convenience and flexibility, but also enhances the validity of the data.

Within the area of clinical space, where most diagnostic data is derived, departure from the linearity and quantitative accuracy ranged from 0 mm at intercuspation to 0.5 mm at worst error. This order of accuracy is both qualitatively and quantitatively adequate for research and diagnostic use. When a need for further correction arises, computer processing further reduces the worst error anywhere within the clinical space to 0.1 mm.

When recording at wider mouth openings beyond clinical space, geometric skewing of the data increases; computer processing, however, effectively cancelled the skewing effects.

A heuristic effect of this investigation was the development of a competent, dedicated microcomputer system that interfaces with, and then becomes an integral part of the MKG (Fig. 8). This development eliminates the need for larger general-purpose computers while retaining their capabilities. The X-Y plot of the microcomputer-corrected data traces directly over the system-corrected data, showing the high precision with which the low-cost device emulates the parent system (Fig. 9).

SUMMARY AND CONCLUSION

Today's high-technology electronic and computer techniques have been applied to the long-standing problem of tracking mandibular movement and skeletal relation in research and diagnosis of mandibular function/dysfunction. The measurement established that within an area known as "clinical space" where most diagnostic data is derived, the linearity and quantitative accuracy ranged from an error of 0 mm at intercuspation to 0.5 mm at worst error. This order of accuracy provides data that is qualitatively and quantitatively useful for research and diagnosis without the need for further correction. Computer processing further reduces the worst error anywhere within the clinical space to 0.1 mm. Geometric skewing of the trace patterns that occur while taking data at mouth openings beyond clinical space (though not pronounced enough to affect the qualitative usefulness of the data) is readily corrected by computer processing. A microcomputer attached to the K5-R corrects the skew in real-time so that the data are displayed to an accuracy within 1.5% of exact values or a worst-case error less than 0.5 mm for a 30 mm vertical opening.

When tested against a computer-controlled electronic measuring system, the accuracy and linearity parameters of the trace patterns confirmed the validity of the MKG recordings as precise representations of mandibular movement at the incisor point.

REFERENCES

1. Cannon D. C., Reswick, J. B., and Messerman, T.: Instrumentation for the investigation of mandibular movements. Report No. EPC-4-64-8. Cleveland Engineering Design Center, Case Western Reserve University, 1964.
2. Jankelson, B., Swain, C. W., Crane, P. F., and Radke, J. C.: Kinesiometric instrumentation: A new technology. J Am Dent Assoc 90:834, 1975.
3. Lemmer, J., Lewin, A., and van Rensburg, L. B.: The measurement of jaw movement. J PROSTHET DENT 36:211, 312, 1976.
4. Theoretical Accuracy of the K-5 Mandibular Kinesiograph

(MKG). Myo-tronics Research, Inc., Seattle, Wash., Jan. 20, 1978.

5. O'Connel, A. L., and Gardner, E. B.: Understanding the Scientific Basis of Human Movement. Baltimore, 1976, Williams and Wilkins Co.
6. Mandibular Kinesiograph (MKG) Operating Manual. Myo-tronics Research, Inc., Seattle, Wash., 1976.

Jemt, T., Karlsson, S., and Hedegård, B.: Mandibular movements of young adults recorded by intraorally placed light-emitting diodes. J Prosthet Dent 42:669, 1979.

8. Strohaver, R. A.: A comparison of articulator mountings made with centric relation and myocentric position records. J Prosthet Dent 28:4, 1972.
9. Hannam, A. G., Scott, J. D., and DeCou, R. E.: A computer-based system for the simultaneous measurement of muscle activity and jaw movement during mastication in man. Arch Oral Biol 22:18, 1977.
10. Yamashita, A., and Inoue, H.: Mandibular Kinesiograph (MKG), the principles, directions and clinical application. J Dent Engin 41:1, 1977.
11. Mitani, H., Ueno, H., and Yamashita, A.: Prophylactic and Therapeutic Prosthodontics. Tokyo, Japan, 1979, Ihiyaku Publishers, Inc.
12. George, J. P., and Boone, M. E.: A clinical study of rest position using the Kinesiograph and Myomonitor. J Prosthet Dent 41:456, 1979.

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