# A MECHANICAL MODEL FOR DETERMINING THE RESULTANT FORCES AND MOMENTS APPLIED TO MOLAR TEETH BY SYMMETRIC AND ASYMMETRIC CERVICAL TRACTION

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# INTRODUCTION

The use of extraoral traction for anchorage control and as a means of applying distal force during orthodontic treatment has become somewhat routine in the orthodontic profession. Various designs are available for the clinician to choose from depending on the desired result. Clinical preference and experience with the varied facebow designs and directions of pull allow the orthodontist to make the selection in each individual case.

The effectiveness of various types of extraoral traction has been investigated largely through the use of theoretical models and rigid body biomechanics. These mathematical models along with investigators clinical impressions have given the orthodontist a feel for the various forces delivered by each type of configuration of facebow and direction of pull. The accuracy of the data derived from theoretical models is often questioned due to the use of rigid body biomechanics on a non-rigid body. Several investigators have constructed mechanical models to directly measure forces delivered by headgears. These mechanical models have for the most part been designed to measure antero-posterior and medio-lateral forces.

The intent of this project is to continue to work on a mechanical model to evaluate headgear forces as done in similar projects by Marenda[1] and Birdwell.[2] The model to be used was designed and constructed by Dr. Birdwell and this will be a continuation of that research project. This model allows measurement in the antero-posterior, medio-lateral, intrusive-extrusive, and the moments associated with these various forces referred to as tip and torque. The mechanical model was completed by Birdwell, however there is considerable work in calibration and possibly some design changes that are needed prior to realizing any meaningful data from the effort.

This project will involve the calibration of the above mentioned mechanical model along with any beneficial design changes that are needed to produce an accurate working model. A bilaterally symmetrical facebow design with a simulated cervical pull will be tested along with several unilateral designs. The forces involved may then be evaluated as to the effectiveness of unilateral action in asymmetric designs and the magnitude of undesirable forces can be discerned.

## REVIEW OF THE LITERATURE

The use of extraoral anchorage dates back to Norman Kingsley who is credited for being the first American to use a headcap in 1867.[3] Edward Angle experimented with what he called the "Occipital Bandage" in the late 1880's and he found it useful in cases of maxillary protrusion.[4] His views changed over the next two decades and by the turn of the century he had virtually stopped using extraoral appliances. In the early 1900's Calvin Case[5] was advocating the benefits of the use of extraoral anchorage and was promoting its use. Despite Case's efforts, Angle's influence at this time and his promotion of intermaxillary traction as a means of anchorage led to the abandonment of extraoral anchorage for nearly 30 years.

The use of extraoral anchorage was revived after cephalometric studies had shown some of the undesirable effects of intermaxillary traction. At this time, orthodontists were searching for a way to move maxillary teeth distally without the mesial movement of the mandibular teeth, and they turned to extraoral appliances. Oppenheim[6] reported in 1944 of a patient he treated with extraoral force, that he felt had efficiently moved the maxillary molars distally. His cephalometric analysis showed that the molars had not been tipped distally but were upright. The most important study in the resurgence of extraoral anchorage was published in 1947, when Kloehn[7] discussed his use of extraoral anchorage and described the fabrication of a facebow and the use of his design. Kloehn later outlined in detail his use of extraoral anchorage and advocated the ease of its construction and its applications in clinical practice.[8] Since this time extraoral anchorage in orthodontic treatment has become widely accepted and its use routine in many orthodontic practices.

Variations in extraoral appliances became apparent as its use increased, one of these being the asymmetric or unilateral facebow design. In January 1953, J. Phillip Baldridge[9] presented a report to the Midwestern Component of the Angle Society entitled, "Construction and Use of Unilateral Headcap With Report of Cases". Baldridge introduced the design of a facebow that he proposed would deliver more force to one of the maxillary first molars that it was attached to than the other. The facebow was similar to the Kloehn design with a conventional inner bow but the outer bow was soldered offset to the inner to the side that the greater force was desired. He presented two cases in which his unilateral headcap was used (class II subdivision type cases) and the models showed the finished cases in a class I molar relationship without the use of intermaxillary elastics. This paper created quite a discussion about whether or not there was more force exerted on the side of the offset. This discussion stimulated others to design various types of unilateral facebows. A year later Block presented a report to the same society entitled "An Analysis of Midline and Offcenter Extra-oral Force".[10] He evaluated three headgear designs all with identical inner bows made of .045 inch stainless steel, and two with Baldridge-type soldered offset unilateral outer bows and one bilaterally symmetrical Kloehn outer bow. He performed both a theoretical analysis and a mechanical analysis in which he measured the relative amounts of elastic stretch to determine whether there was a difference in force distribution. The soldered offset facebows showed greater elastic stretch on the terminal end of the inner bow that was closest to the solder joint than the opposite side. From this he concluded that the side closest to the offset did receive the greater force. This same analysis showed that the bilateral facebow did not deliver a significant unilateral force. Block's findings agreed with Baldridge's and he concluded that the soldered offset facebow could deliver a greater force to one molar attachment that to the other.

In 1958 Haack and Weinstein[11] published the results of a study on the mechanics of centric and eccentric cervical traction. They felt that some previous studies had been inaccurate and had shown a misunderstanding of the fundamental laws of forces and equilibrium and had only added confusion to the topic. They studied the mechanics involved through both a theoretical and laboratory model. Theoretically they felt that the prime consideration for an appliance to deliver eccentric cervical traction was the angle formed by the ends of the elastic straps tangent to the neck. These angles must be manipulated in such a way that the bisector of that angle passes closer to the molar on which the greater force is desired. Haack and Weinstein produced this clinically by making one arm of the outer bow longer than the other. However, in doing this they introduced a lateral component of force which they cautioned should be kept small, but they did not describe how to accomplish that.

Their analysis of the soldered offset type of facebow showed it to be similar to the bilaterally symmetrical facebow and concluded that it would produce similar forces on both terminal molars. This went against the earlier work of Baldridge and the theoretical analysis offered by Block. Haack and Weinstein felt that the earlier workers had erred in not recognizing an important fundamental principle of mechanics which states, "In a statically determinate problem, the internal configuration of a rigid body does not affect the distribution of the external forces on the body". They established that no matter where a rigid attachment of the outer bow to inner bow of a facebow is placed, if the tractional forces are equal in magnitude and direction of application with respect to the midsagittal plane, the reactionary forces on both right and left molars will be equal.

Haack and Weinstein followed their theoretical evaluation of three facebow designs by evaluating them using a laboratory model. Their model utilized a dentiform model of the upper arch with buccal tubes attached to the first molars and two Richmond tension gauges which were attached to the inner bow of the headgear just anterior to the buccal tubes. They tested a bilateral symmetrical facebow, a power arm unilateral facebow, and a soldered offset unilateral facebow. Their experimental results substantiated their theoretical results. Both the bilaterally symmetrical and soldered offset facebows delivered similar forces to the molars and the power arm unilateral facebow delivered a greater force to one molar than the other.

Drenker[12] followed Haack and Weinstein's study with another evaluation of unilateral facebow design in 1959. He used trigonometry and algebra to evaluate a bilaterally symmetric facebow, a power arm unilateral facebow, and a soldered offset unilateral facebow. His findings substantiated those of Haack and Weinstein in that the soldered offset unilateral facebow acted as the bilaterally symmetrical facebow, while the unilateral power arm facebow did deliver a greater force to one side. He also concluded that the force difference between sides could be increased if the long arm of the power arm facebow is bent out away from the patient's face. He also recognized that undesirable lateral forces also came into play with the unilateral design.

Baldridge was still not convinced that his offset headcap exerted the same force on both molars because he had success with unilateral action clinically. Therefore, he decided to do his own laboratory testing of his original design and a power arm unilateral facebow. His testing was simple as he placed open coil springs on the inner bow of the patient's headgear to which their was a soldered stop to keep the spring from sliding forward. As the headgear was activated on the patient the springs were measured and compared with their length prior to activation. Baldridge's study showed that the power arm facebow did compress the spring on the favored side more than the other while the soldered offset design did not compress one coil more than the other. Therefore, he concluded that his design did not deliver a unilateral force and that the power arm facebow was the appliance of choice for obtaining unilateral forces to maxillary molars.[13]

Marenda[1] in 1965 constructed a more sophisticated mechanical model to test the various headgear designs than had been used up to this date. This model consisted of molar tubes mounted on cylinders which were fitted into the inner races of two standard bearings. These model teeth had wires in all four directions, 90 degrees from one another and were mounted onto glass plates. When the headgear was activated the model teeth would move on the glass plates and were then centered to their original positions by adding weight to buckets which were attached to each of the four wires off of the molar teeth. Once these teeth were returned to their original positions the weight in each of the buckets off of the four different wires was measured to evaluate the force needed to center the simulated teeth. Marenda tested five different headgear designs one bilaterally symmetrical and four asymmetrical. All of the facebows were constructed with .063 inch stainless outer bows and .045 inch stainless steel inner bows. Each test was repeated ten times with a different magnitude of force applied to the headgear ranging from 100 to 1100 grams. His results showed that the offset soldered unilateral facebow design provided a unilateral action throughout the entire force range. The power arm design worked best when the long arm was bent out from the midsagittal plane and achieved the greatest unilateral action when used in the commonly used force ranges. It was also shown that at the higher force ranges there is a tendency for the unilateral designs to act more nearly to the symmetrical design. These results were in contradiction to Haack, Weinstein and Drenker's theoretical models concerning the offset soldered facebow design and Marenda concluded that rigid body mechanics were not valid when considering headgear designs. The diameters of the wires used in his headgear designs created flexion of inner and outer bows upon activation and can therefore not be considered as static for mathematical analysis.

During this same time period other investigators were designing mechanical laboratory models using strain gauge transducers to evaluate facebow forces. In 1960 Zwemer was the first to use strain gauges in a study of facebow forces. He used 120-ohm strain gauges mounted on either side to two stainless steel spatulas to which had been soldered .045 inch stainless steel tubes. These strain gauges were connected to a strain gauge analyzer and recorder. The system was calibrated and five facebow designs were tested. The symmetrical designs produced symmetrical forces while the unilateral designs produced the following forces when loaded with 100 gm.; 1) the eccentrically hinged asymmetric bow delivered 73-26 gm, 2) the eccentrically soldered bow delivered 53-47 gm, 3) the power arm type delivered 60-40 gm.[14]

Since Zwemer's initial use of strain gauge analysis of orthodontic forces other systems have been devised. In 1973, Burstone, Koenig, and Solonche reported that they had designed and fabricated an orthodontic force transducer system.[15] This system utilized strain gauges and was capable of measuring all forces and couples acting on a tooth in three planes of space. Burstone and others in 1976,[16] developed a strain gauge transducer model for evaluation of a clinical appliance in a two-tooth segment. This model employed the use of six strain gauge bridges and was capable of measuring forces directed axially along a tooth, in a direction creating rotational torque and in tipping or bending movements.

Houghton in 1977,[17] fabricated a strain gauge transducer system that was used to determine the distal and lateral forces delivered to the terminal ends of the inner bows of ten variously design facebows. He tested nine unilateral and one bilateral facebow and found that only the power arm unilateral facebow and the swivel offset unilateral facebow were effective in delivering a clinically significant unilateral distal force. The Kloehn bilateral facebow, the spring attachment unilateral facebow, and the soldered offset unilateral facebow were not effective in delivering a clinically significant unilateral distal force. Houghton also found that every facebow that is effective in delivering unilateral distal forces also delivers a net lateral force having a direction running from the inner bow terminal receiving the greater distal force toward the inner bow terminal receiving the lesser distal force. The magnitude of this net lateral force increased as the unilateral effectiveness of the facebow design increased.

Kaprelian reported in January 1982,[18] of a facebow design to minimize this undesirable lateral force on the inner bow terminal receiving the lesser distal force. He suggest the use of a swivel just anterior to the first molar on the side that does not need to be moved and reports that this acts as a lateral force breaker to prevent lateral expansion on that side. This is a clinical article and the use of the swivel has not yet been tested with a mechanical model.

In summary, as this review suggest, there appears to be many controversies over the design of unilateral facebows and the analysis of the forces they produce. Various investigators have been unable to agree on the theoretical analysis of unilateral headgear action and the mechanical models have advanced from crude non-scientific methods to very technical strain gauge transducer force analyzers. These advanced mechanical models are needed and will be very helpful in the evaluation of new concepts and designs of unilateral headgear systems.

## MATERIALS AND METHODS

A mechanical model capable of measuring the forces delivered to the molar teeth by various headgear designs was designed and constructed by Birdwell in 1987.[2] This model was used in this project as a continuation of what was started last year. The main concern and effort of this project was to accurately calibrate all of the forces and moments applied to the simulated molar teeth. The mechanical model is capable of measuring the forces in the antero-posterior, medio-lateral, and intrusive-extrusive directions. It will also allow the measurement of the moments applied in the mesio-distal and bucco-lingual planes commonly known as tip and torque.

Dr Birdwell's model was designed with a series of eight vertical pieces of feeler stock arranged in a series of two tiers from which each simulated tooth was suspended by two horizontal pieces of feeler stock. To each of the vertical segments a large strain gauge (8.3mm X 4.7mm) was applied and these were configured to measure the forces produced in the antero-posterior and medio-lateral directions. The horizontal segments were arranged in a cross pattern and each segment had four strain gauges applied to it (photo. #1). These segments were used to measure intrusive-extrusive forces along with moments in the mesio-distal and bucco-lingual directions.

The 32 strain gauges were connected to a switching mechanism as a full bridge in ten different Wheatstone bridge configurations. The switching mechanism also provided a balancing resistor for each of the ten bridge configurations involved which made for ease in balancing the bridges (photo. #2). The switching mechanism was connected to a Sanborn Strain Gauge Amplifier, so that, the Wheatstone bridge configuration, which was acting as transducer, could have excitation voltage applied to it. The transducer takes this excitation voltage and returns a signal voltage to the Strain Gauge Amplifier and the difference is interpreted by the Sanborn Amplifier and is reflected with a galvanometer deflection (photo. #3). The stylus deflection is recorded on paper and can be used to find the direction and magnitude of the load applied to that particular Wheatstone bridge. For a more detailed description of the position of the gauges, the Wheatstone bridge configurations and the complete mechanical model refer to Birdwell's paper.[2]

The dimensions used on the machine were constucted to simulate the average orthodontic patient. The horizontal strain gauges and feeler stock used to measure the moments were placed 12mm apical to the molar tubes. This figure was used to approximate the average distance from the buccal tubes to the center of rotation of an upper first molar. The antero-posterior dimension from the molar tubes to the swivel pulleys from which the force is applied is 80mm. These swivels were also placed 13mm inferior to the simulated maxillary molar occlusal plane so as to simulate cervical traction (photo. #4). Intermolar distances were 61mm from buccal tube to buccal tube and 47mm from the center of one tooth to the center of the other tooth.

The main emphasis of this project was to attempt to calibrate as accurately as possible each of the Wheatstone bridges so that meaningful data could be obtained when testing various facebow designs. Calibration of each bridge was started by balancing the full bridge by using an internal capacitor and resistor in the Sanborn Amplifier, and the balancing resistor in the switching device. A platform with various pulleys was constructed so that ligature wire leads coming off of an .045 inch wire that was placed in the molar tubes were as horizontal as possible to these pulleys. The effort was made to keep the pull as straight and as level as possible so that the force delivered at the molar was the same as the weight that was hung from the wire over the pulley (photo. #5). The simulated molars had both a buccal tube and a tube cemented on the distal so that medio-lateral forces could also be calibrated in this same manner. The moments were calibrated by hanging a weight off of an .045 inch wire that was placed in either the distal or buccal tube 12mm from the center of the tooth either mesio-distally or bucco-lingually (photo. #6). Calibration in the extrusive direction was done by hanging weights directly off of the simulated teeth. The calibration of the model in the prior project had been made in only one direction as it had been assumed that the galvanometer deflection would be equal for the same force in either direction. However, meaningful data was not obtained in the prior study and that may have been part of the problem. The other problem in the prior study was that only several weights, from three to six per Wheatstone bridge, were used for calibration. In the current study all Wheatstone bridges were calibrated in both possible directions except for the intrusive-extrusive force which was only calibrated in the extrusive direction as would be expected from cervical traction. Each of the bridges was calibrated through a series of 10-23 weights. It was felt that through these tedious calibration procedures that the accuracy of the model would be much improved over the previous study.

The calibration data was analyzed through the use of a regression analysis. A regression analysis was done on the data from each Wheatstone bridge in both directions (table #1). Stylus deflections were always measured as positive numbers and the direction of deflection was noted as to the force direction applied. The various regression lines were plotted on graphs as the galvanometer deflection for each applied force. The individual data points were also placed on the graphs (graphs #1-10). As the headgear designs are tested the resultant forces can be calculated from the regression lines using the linear equation:

$$Y=ax + b$$

Where Y is equal to the galvanometer deflection, a is the x-coefficient or slope of the line, x is the applied force, and b is the constant or y intercept. Solving for the applied force (x) we obtain:

$$X=\frac{y-b}{a}$$

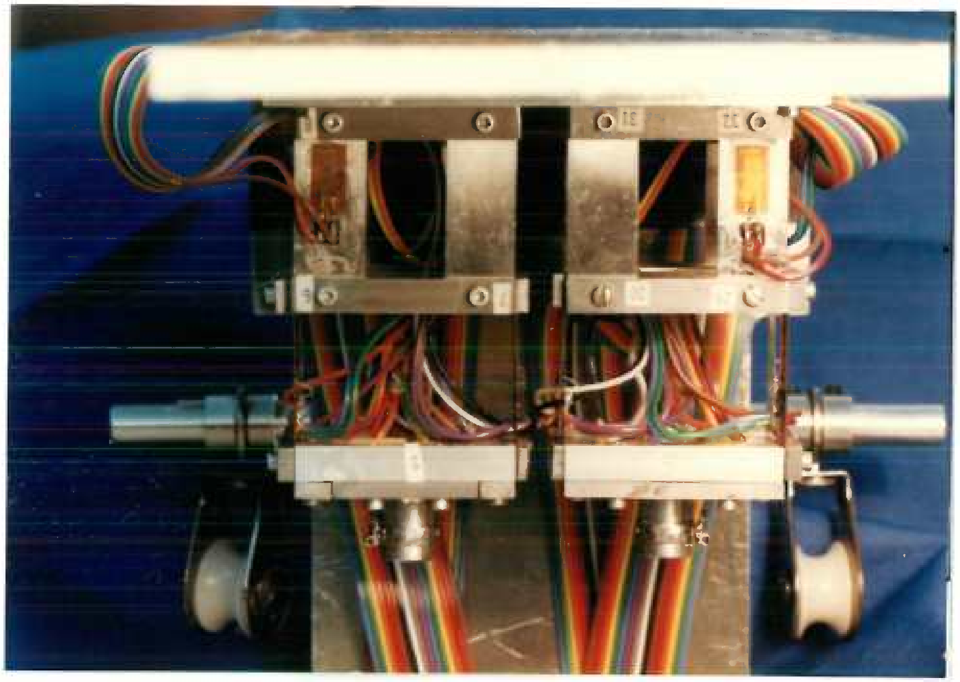
This formula and the regression analysis for each of the Wheatstone bridges can now be used to solve for the forces that each of the headgear designs deliver.

Four headgear designs were tested; a bilaterally symmetrical facebow, a eccentrically hinged facebow with power arm asymmetric outer bow, and two similar power arm facebows (photo. #7). The bilaterally symmetric and eccentrically hinged unilateral facebow were tested as to all forces and moments that the model was capable of measuring. The two power arm type facebows were fabricated identical to each other except that one had a "stress breaking" swivel placed just anterior to the molar on the inner bow on the side of the short outer arm. These were only tested for forces delivered in the antero-posterior and medio-lateral directions, as was needed to try to determine if the swivel was effective in reducing undesirable lateral forces.

All facebows were constructed as to have the outer bow level with the inner bow. The symmetric headgear was made as symmetrically balanced as possible using graph paper. Each facebow was tested by placing the inner bow (made as passive as possible) into the buccal tubes of the simulated molar teeth and then having a tractional force of 400 gm. applied to each side. The force was transmitted by a weight of lead shot in a bucket that was attached to the outer bow by a hook and a fine ligature wire. These wires were fed over two pulleys positioned 4.5 inches apart so as to simulate a neckstrap (photo. #8).

To minimize slight fluctuations in the galvanometer and friction in the setup each headgear design was tested five times for each Wheatstone bridge that was evaluated. The five galvanometer deflections measured were then averaged and the mean was then used to calculate the resultant force or moment. Due to the difficulty, if not impossibility of making a completely passive inner bow, the Sanborn Amplifier was balanced after placement of the facebow to negate forces inherent in the inner bows themselves. The tractional force was then attached and the buckets were pulled down to increase the force and then released and each pulley was tapped several times to release as much friction as possible and to center the hinged asymmetric facebow on the model.

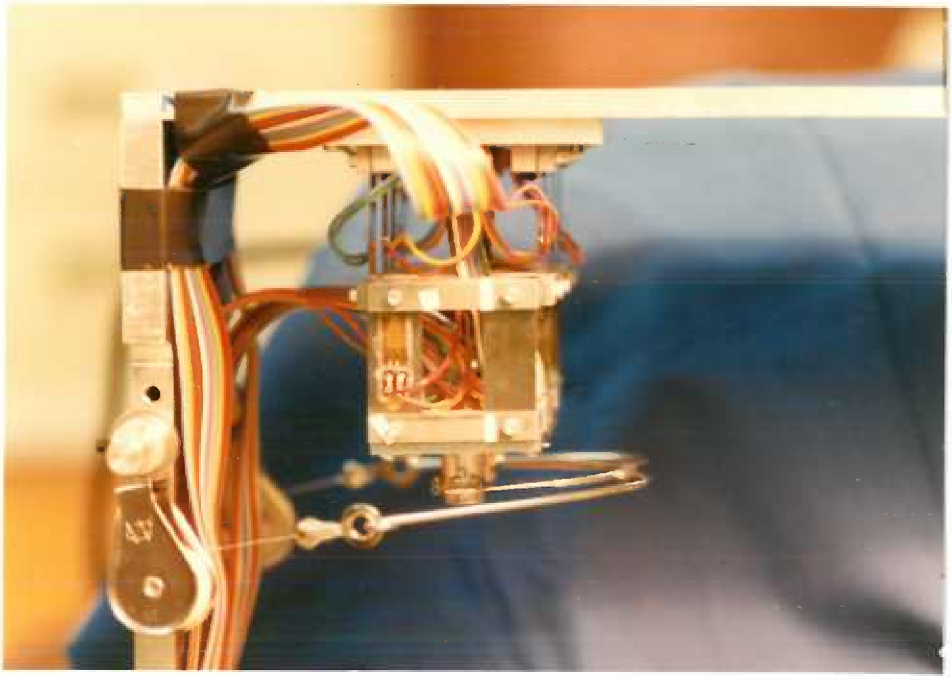
The bilaterally symmetrical facebow and the eccentrically hinged asymmetric facebow were tested as to forces in the antero-posterior, medio-lateral and intrusive-extrusive directions. They were also tested as to their moments in the bucco-lingual (torque) and mesio-distal (tip) directions. The two power arm facebows were tested in the antero-posterior and medio-lateral directions only.



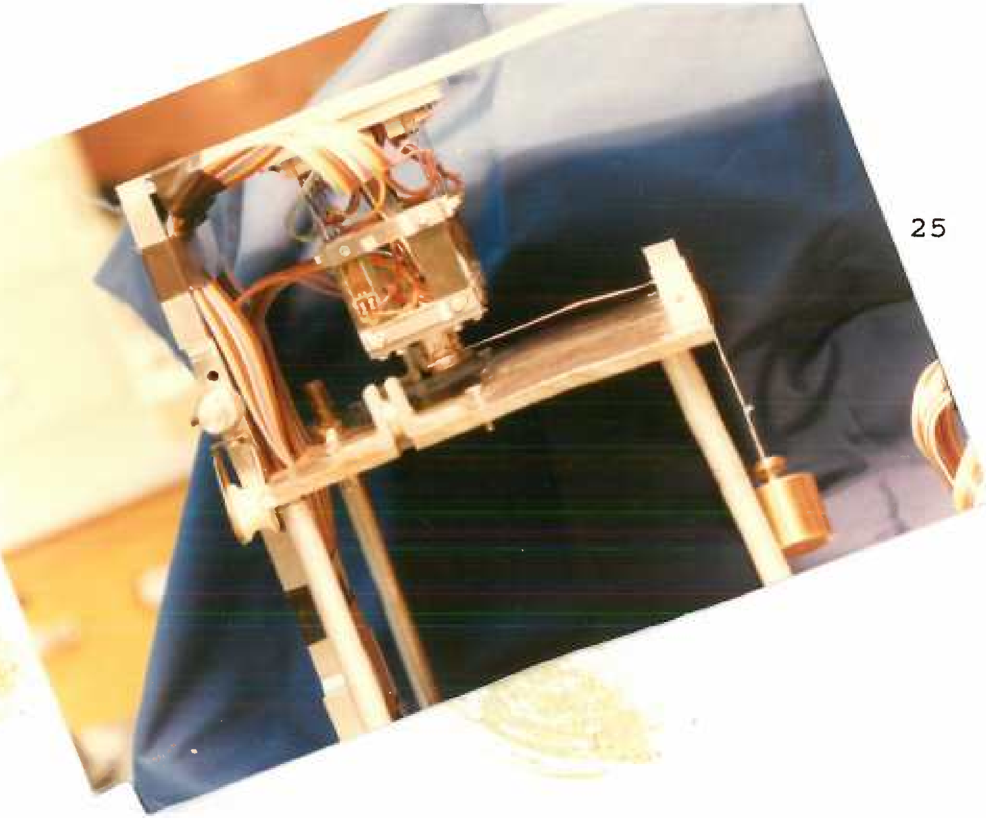
Photograph #1: Anterior view of two tiers that hold strain gauges and simulated molar teeth.

Photograph #2: Switching mechanism

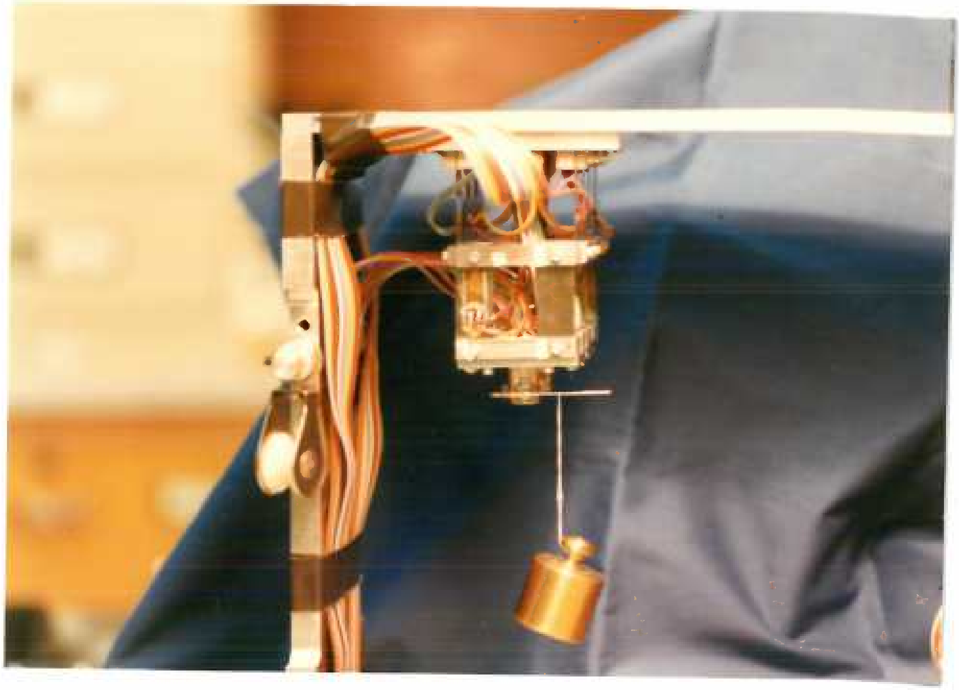
Photograph #3: Sanborn Strain Gauge Amplifier



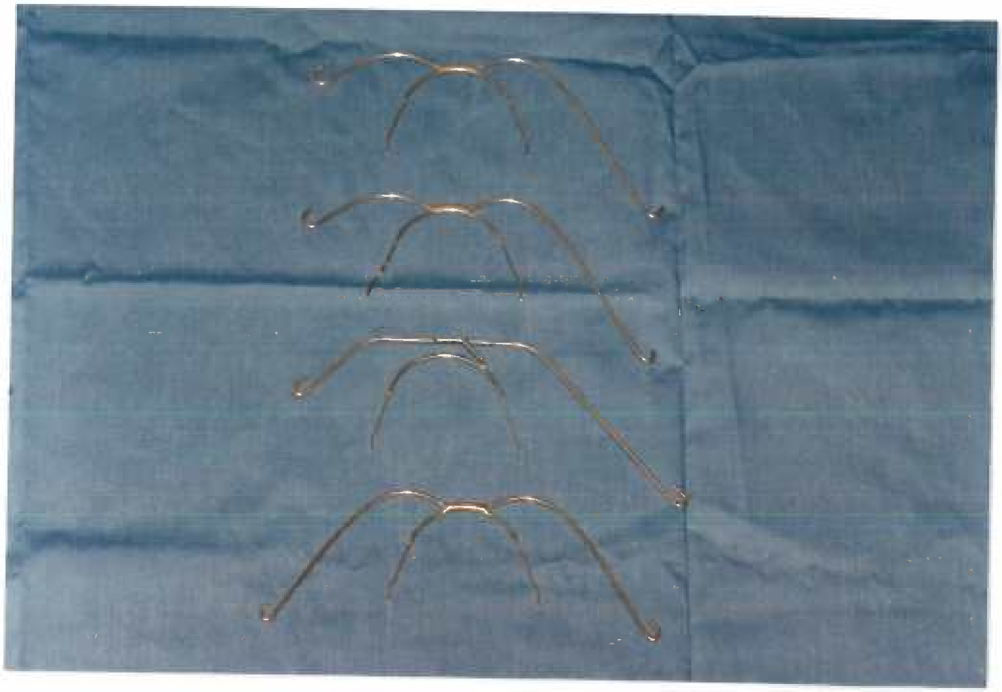
Photograph #4: Right lateral view of Headgear Force Analyzer.



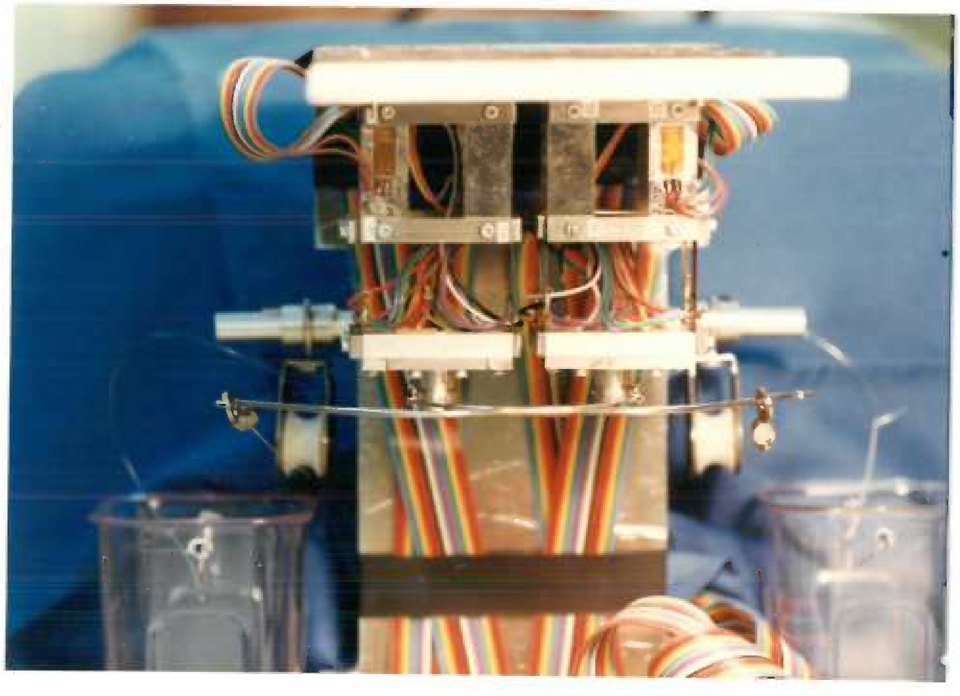
Photograph #5: Anterior calibration of right simulated molar.



Photograph #6: Calibration of right distal crown tip.



Photograph #7: Four facebows tested (from top to bottom); 1) power arm without swivel 2) power arm with swivel 3) asymmetrical hinged 4) bilaterally symmetric



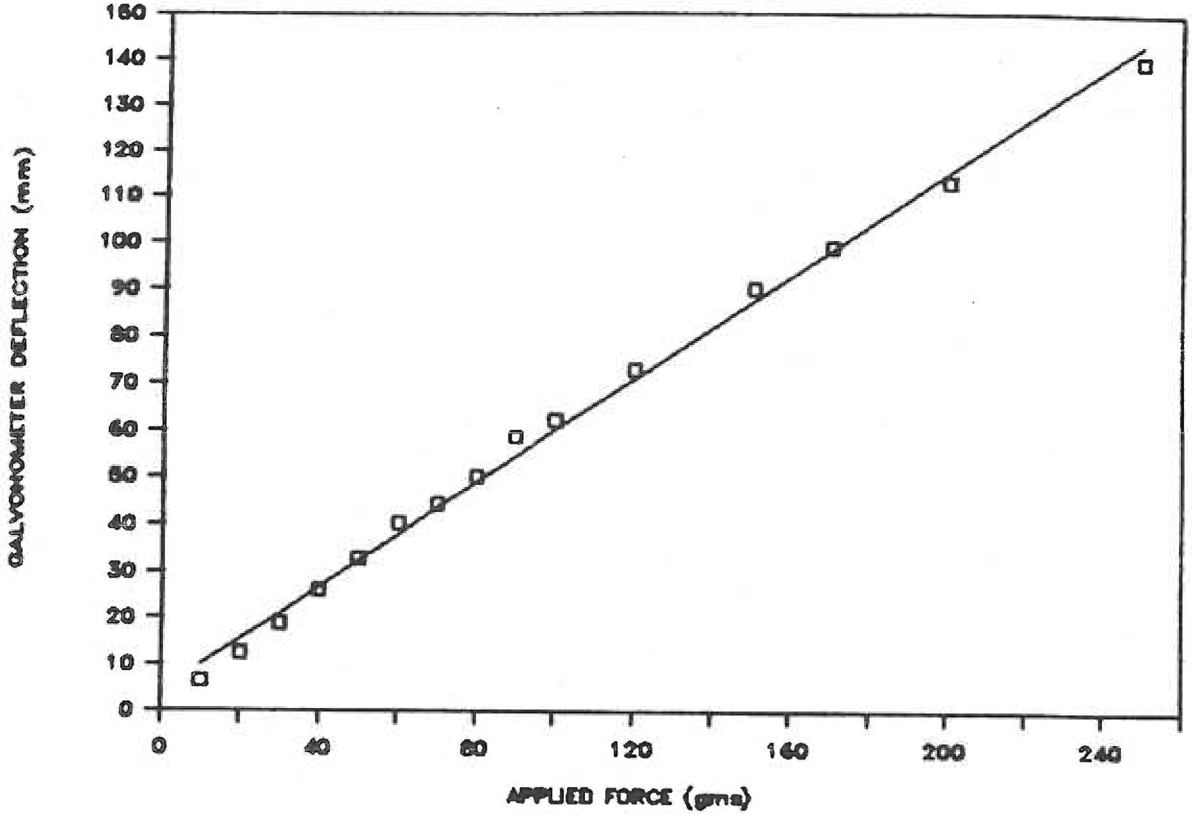
Photograph #8: Anterior view of Headgear Force Analyzer prior to activation

## TABLE 1: WHEATSTONE BRIDGE CALIBRATIONS - REGRESSION ANALYSIS

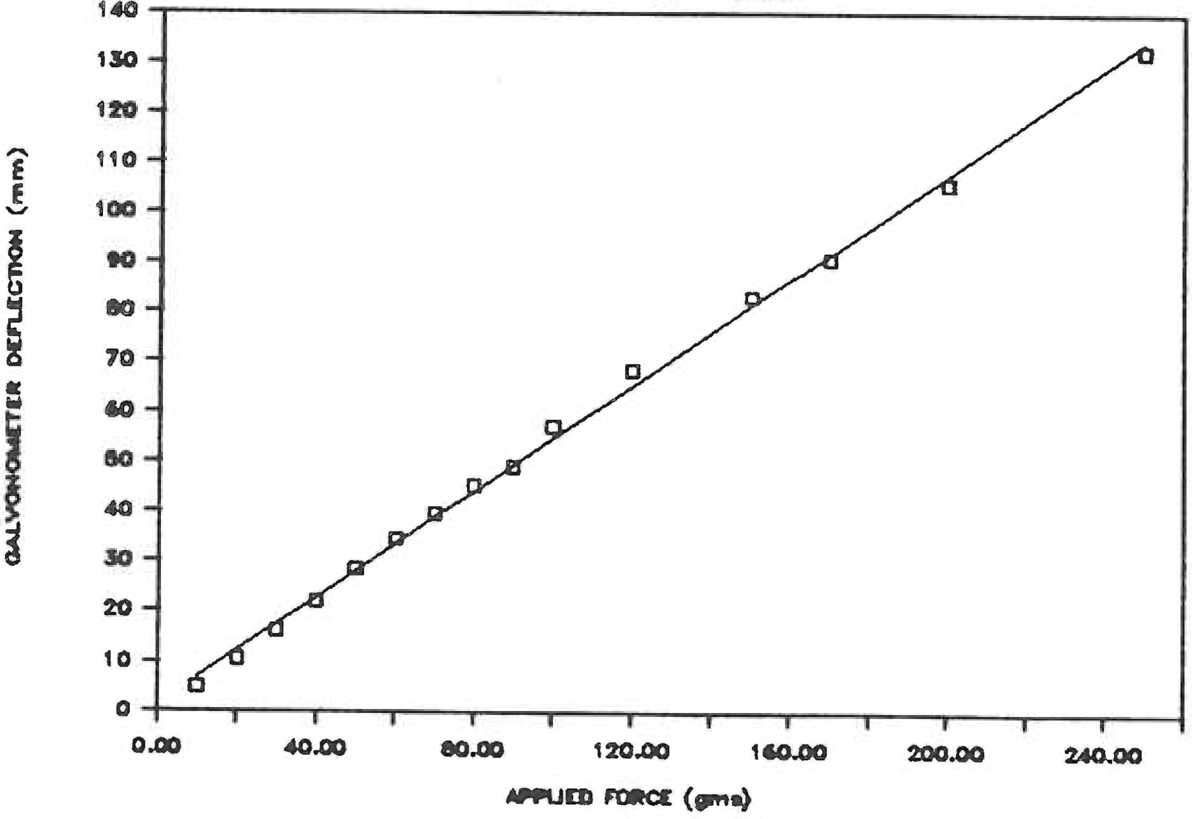
| Wheatstone bridge # Force or moment measured | Y - Intercept | Std Err of Y Est. | R Squared | No. of Observations | Degrees of freedom | X Coefficient | Std Err of Coef |
|---|---|---|---|---|---|---|---|
| WSB #1 Left lingual crown torque | 1.73 | 1.70 | .998 | 15 | 13 | .53 | .0065 |
| WSB #1 Left buccal crown torque | 4.46 | 2.48 | .996 | 15 | 13 | .56 | .0095 |
| WSB #2 Left distal crown tip | 9.23 | 3.76 | .997 | 10 | 8 | .44 | .0083 |
| WSB #2 Left mesial crown tip | 6.44 | 4.15 | .988 | 15 | 13 | .25 | .0075 |
| WSB #3 Left extrusive force | -.22 | .158 | .999 | 19 | 17 | .063 | .0003 |
| WSB #4 Left posterior force | 3.80 | 5.10 | .994 | 18 | 16 | .35 | .0070 |
| WSB #4 Left anterior force | 10.17 | 6.02 | .991 | 18 | 16 | .36 | .0083 |
| WSB #5 Left lateral force | 8.28 | 2.82 | .994 | 17 | 15 | .41 | .0078 |
| WSB #5 Left medial force | 2.54 | 6.05 | .97 | 16 | 14 | .39 | .017 |

## TABLE #1 CONT'D

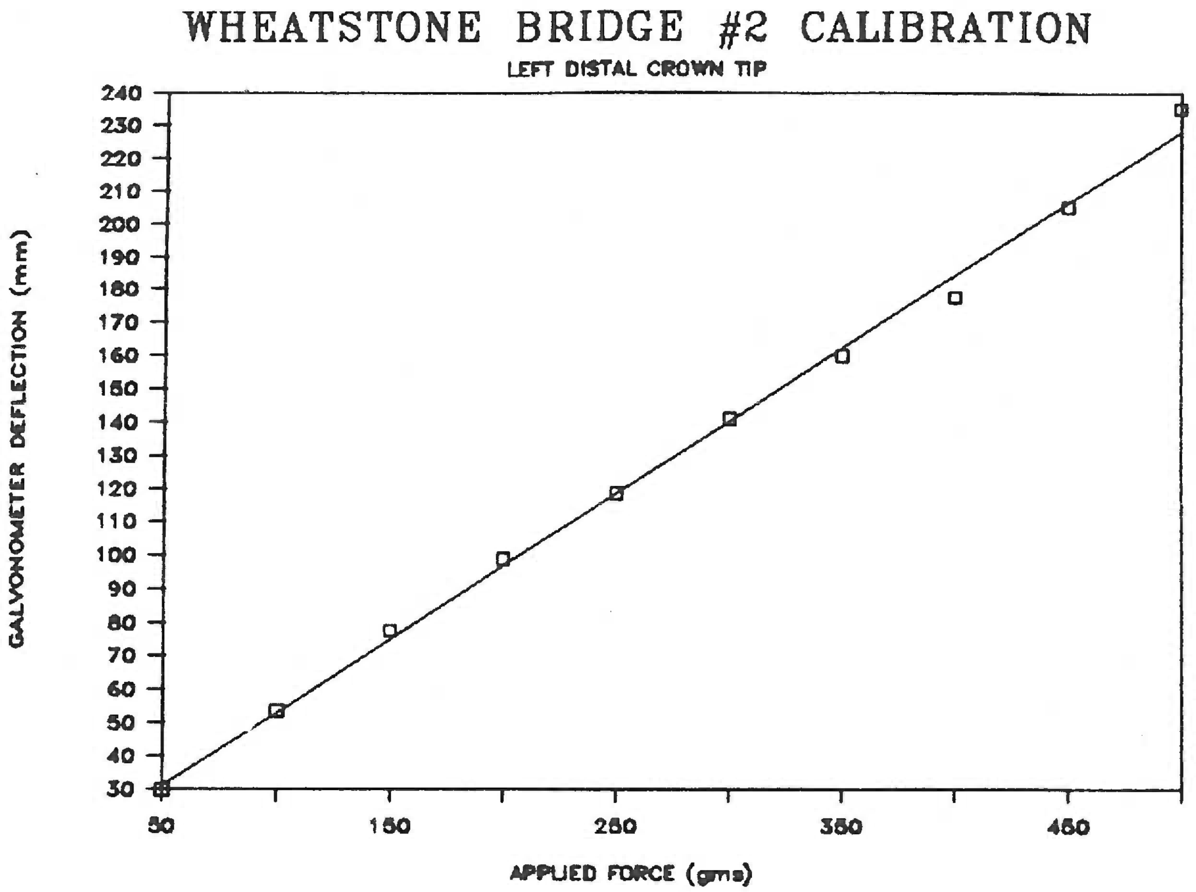
| Wheatstone bridge #<br>Force or moment measured | Y - Intercept | Std Err of Y Est. | R Squared | No. of Observations | Degrees of freedom | X Coefficient | Std Err of Coef |
|---|---|---|---|---|---|---|---|
| WSB #6 Right buccal crown torque | 0.83 | 2.81 | .994 | 17 | 15 | .41 | .0078 |
| WSB #6 Right lingual crown torque | 4.13 | 1.44 | .999 | 17 | 15 | .48 | .0040 |
| WSB #7 Right distal crown tip | 10.1 | 5.39 | .997 | 10 | 8 | .61 | .0119 |
| WSB #7 Right mesial crown tip | 3.10 | 1.57 | .999 | 23 | 21 | .40 | .0024 |
| WSB #8 Right extrusive force | -.30 | 0.15 | .999 | 17 | 15 | .05 | .0004 |
| WSB #9 Right posterior force | 10.8 | 4.76 | .992 | 18 | 16 | .29 | .0065 |
| WSB #9 Right anterior force | -4.4 | 4.09 | .994 | 18 | 16 | .30 | .0056 |
| WSB #10 Right lateral force | -2.4 | 4.75 | .991 | 19 | 17 | .42 | .0098 |
| WSB #10 Right medial force | -4.0 | 3.10 | .996 | 17 | 15 | .43 | .0066 |

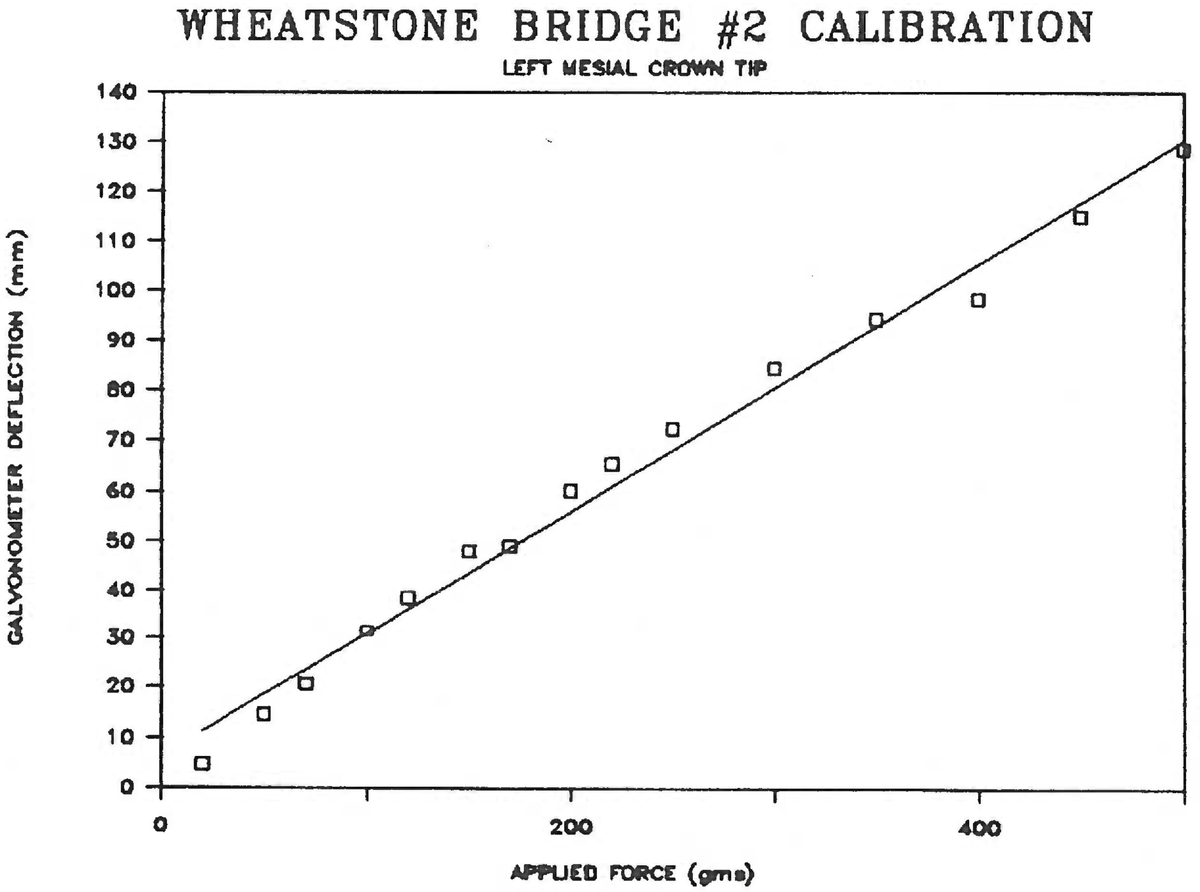

WHEATSTONE BRIDGE #1 CALIBRATION

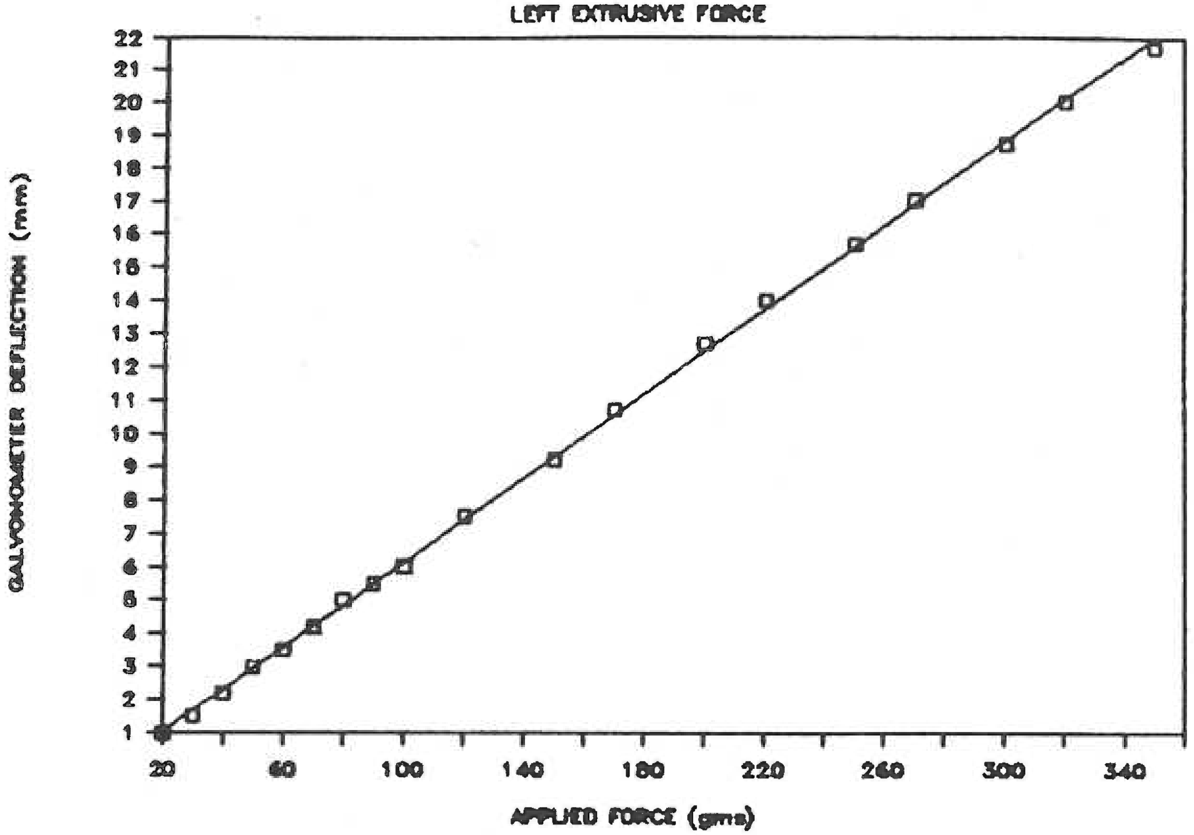
LEFT BUCCAL CROWN TORQUE


WHEATSTONE BRIDGE #1 CALIBRATION

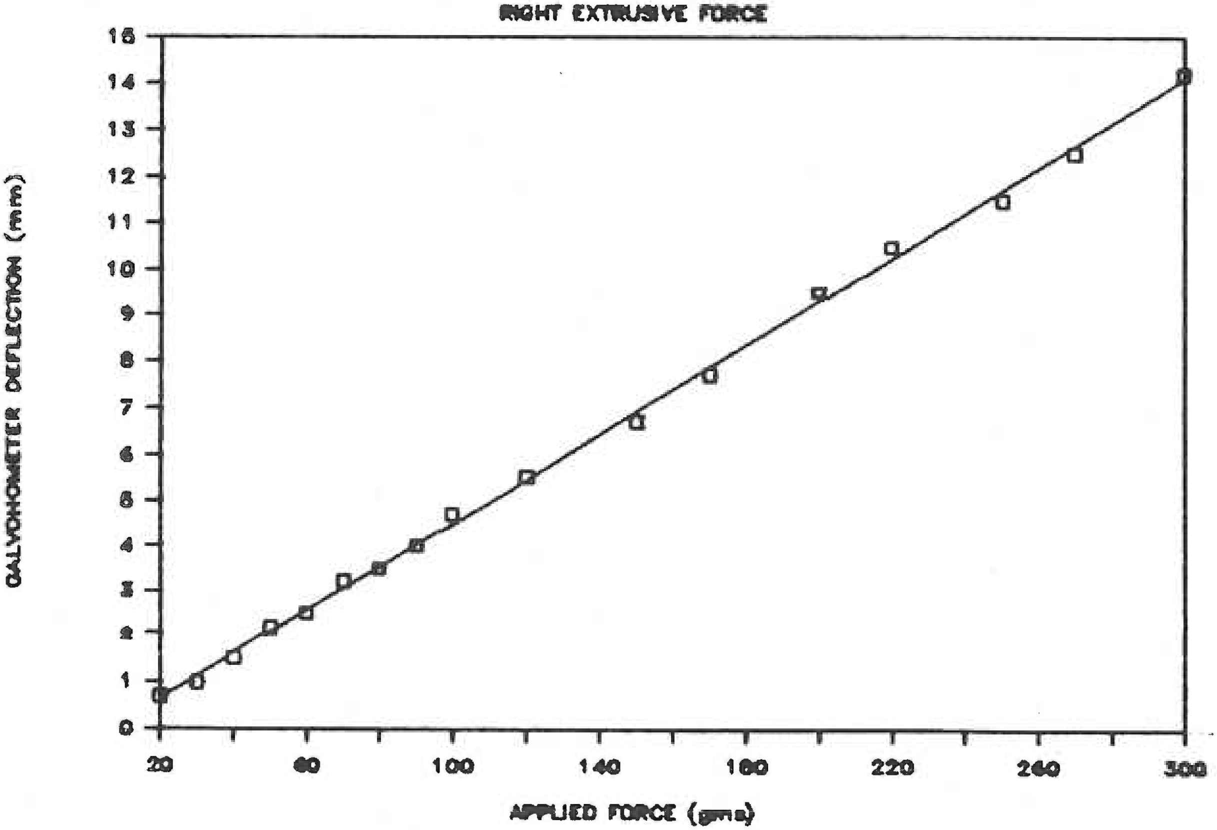
LEFT LINGUAL CROWN TORQUE


WHEATSTONE BRIDGE #2 CALIBRATION
LEFT DISTAL CROWN TIP
GALVONOMETER DEFLECTION (mm)
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
50
150
250
350
450
APPLIED FORCE (gms)


WHEATSTONE BRIDGE #2 CALIBRATION
LEFT MESIAL CROWN TIP
GALVONOMETER DEFLECTION (mm)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
200
400
APPLIED FORCE (gms)



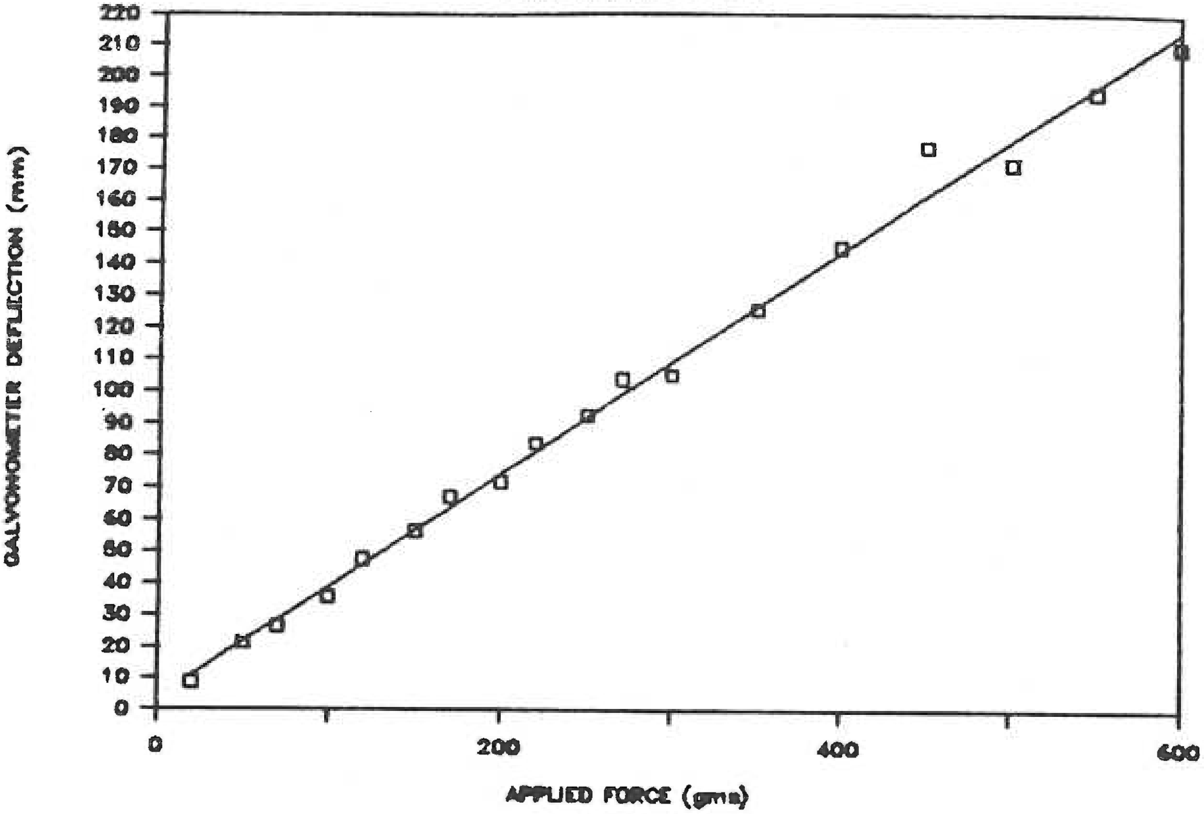
WHEATSTONE BRIDGE #3 CALIBRATION



WHEATSTONE BRIDGE #8 CALIBRATION

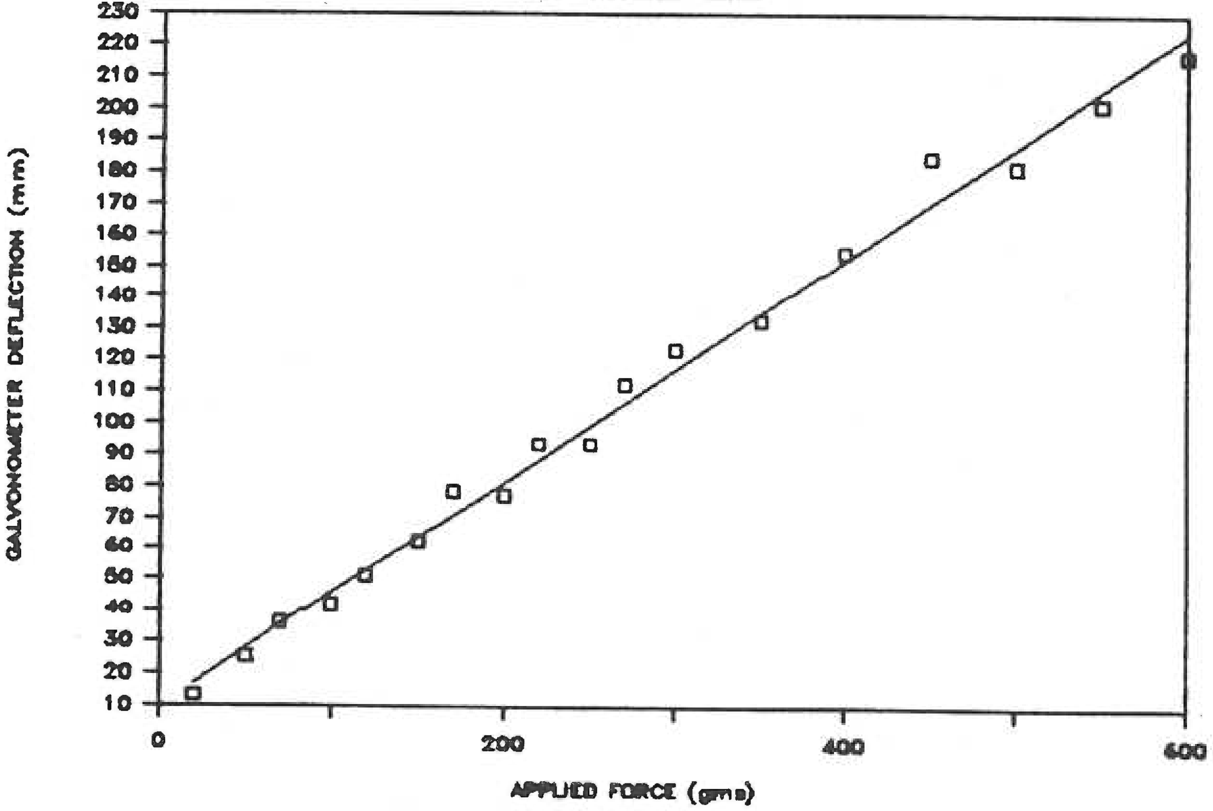
WHEATSTONE BRIDGE #4 CALIBRATION

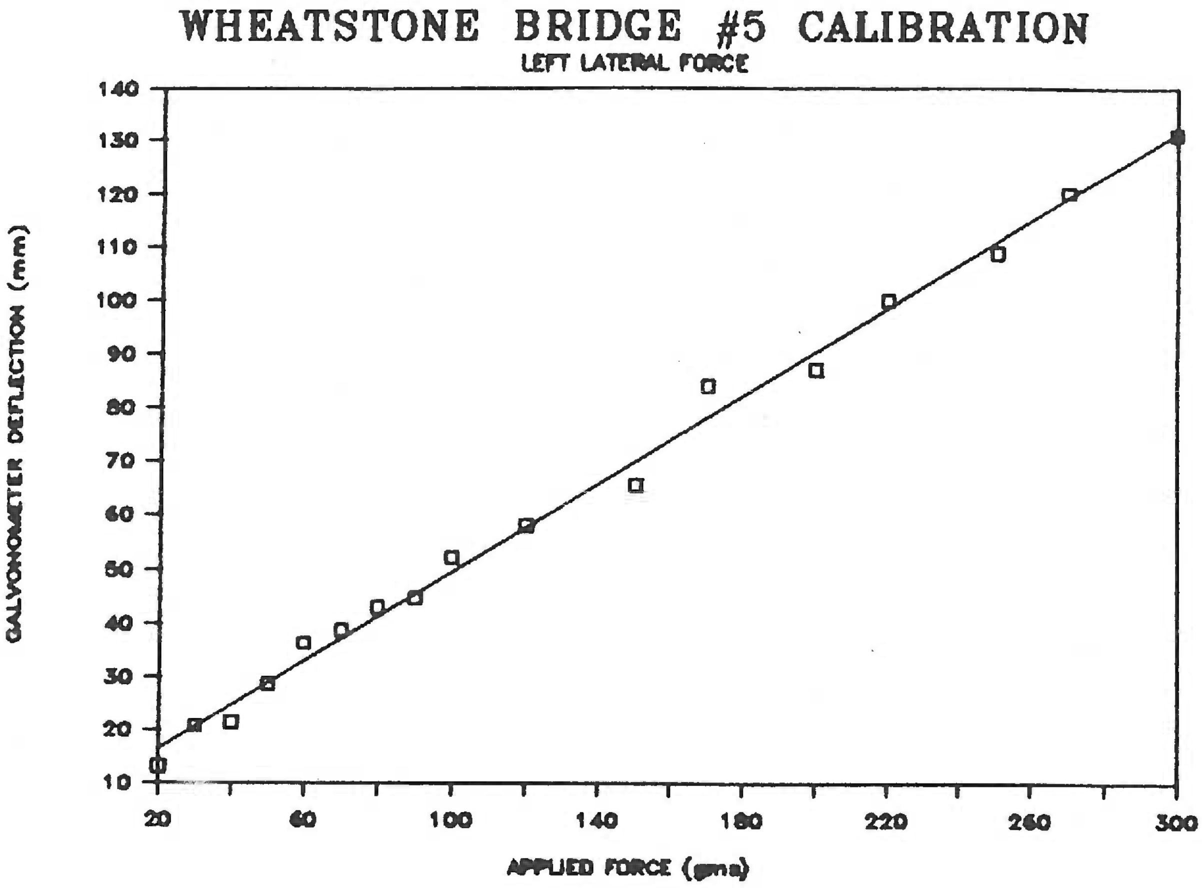
LEFT POSTERIOR FORCE

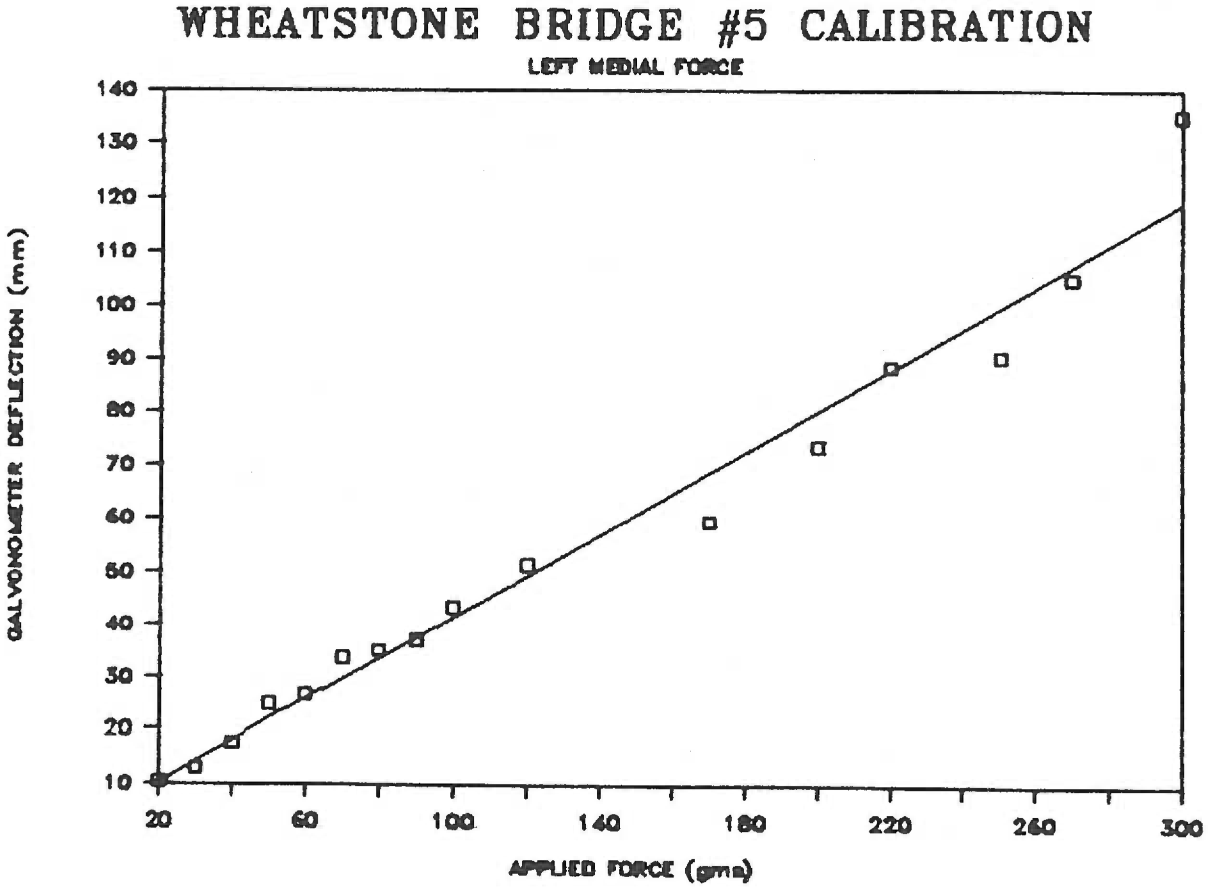


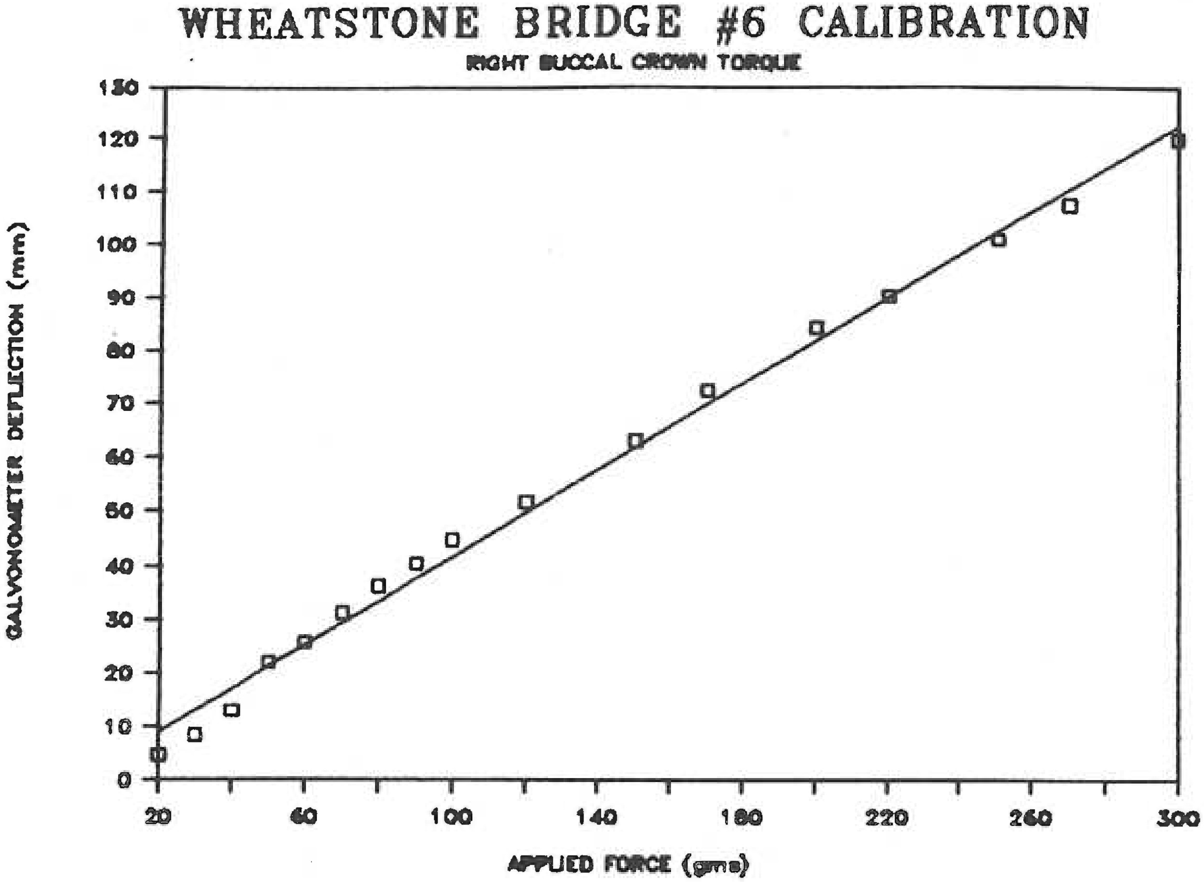
WHEATSTONE BRIDGE #4 CALIBRATION

LEFT ANTERIOR FORCE

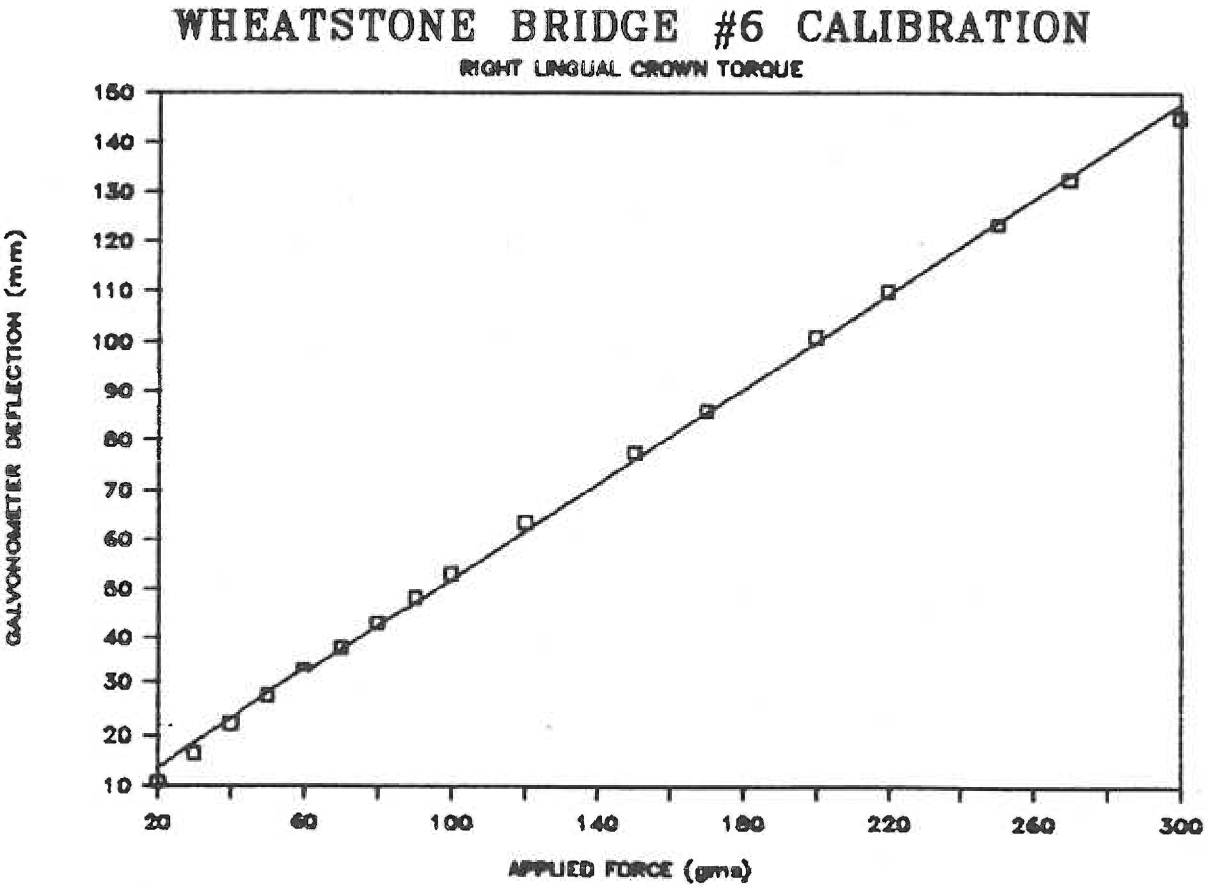



WHEATSTONE BRIDGE #5 CALIBRATION
LEFT LATERAL FORCE
GALVONOMETER DEFLECTION (mm)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
20
60
100
140
180
220
260
300
APPLIED FORCE (gms)

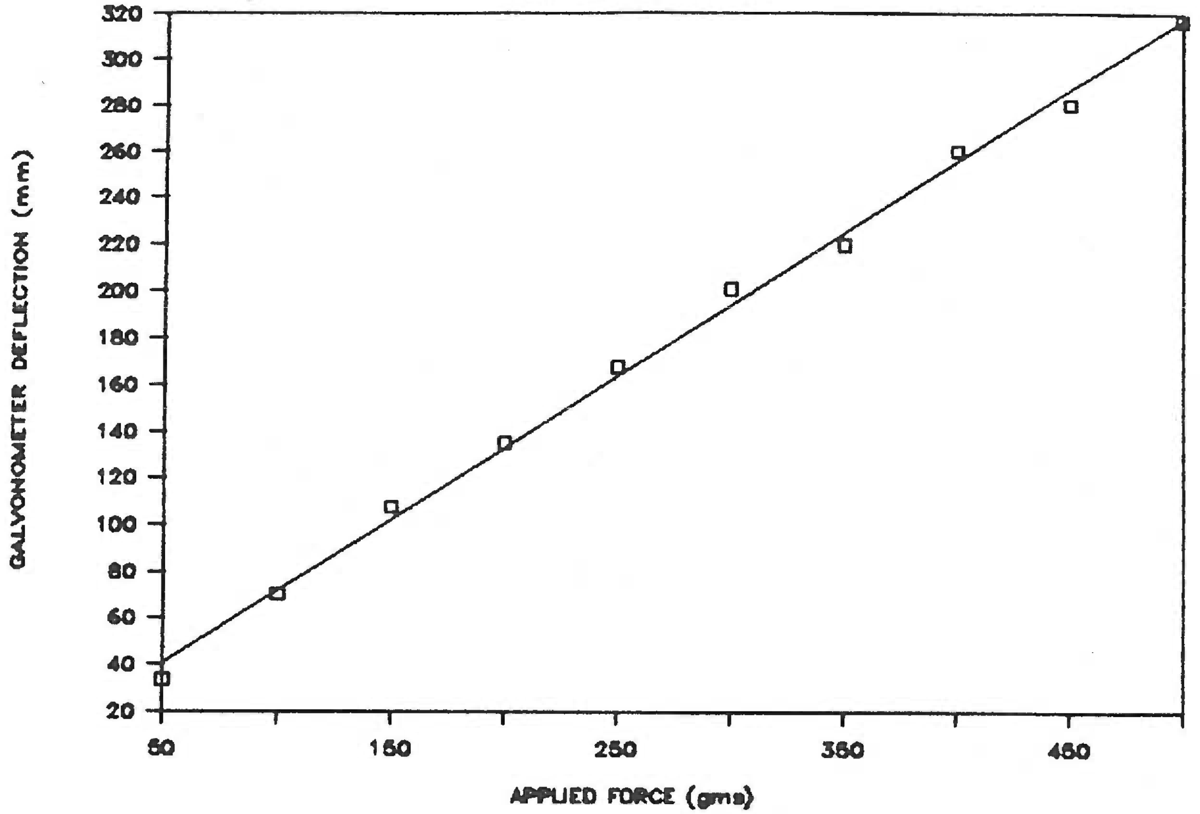

WHEATSTONE BRIDGE #5 CALIBRATION
LEFT MEDIAL FORCE
GALVONOMETER DEFLECTION (mm)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
20
60
100
140
180
220
260
300
APPLIED FORCE (gms)


WHEATSTONE BRIDGE #6 CALIBRATION

RIGHT BUCCAL CROWN TORQUE

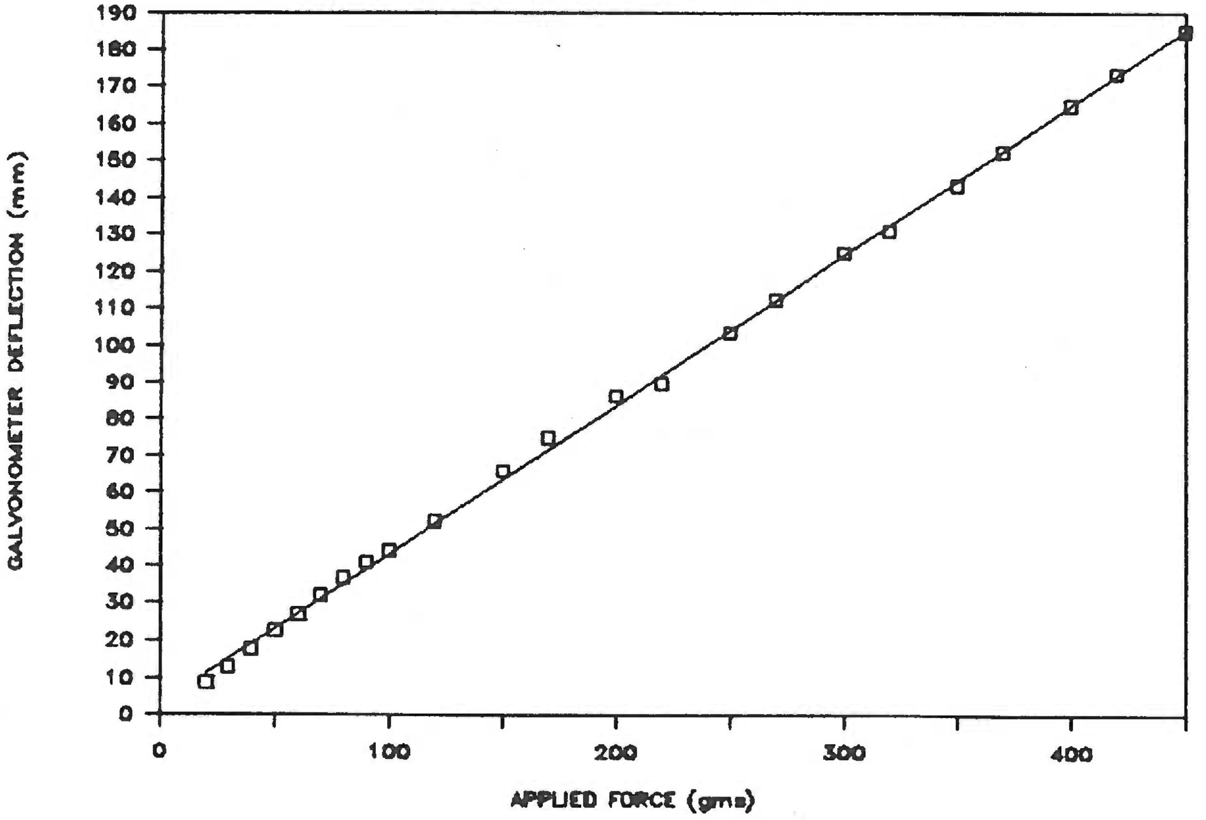

WHEATSTONE BRIDGE #6 CALIBRATION

RIGHT LINGUAL CROWN TORQUE



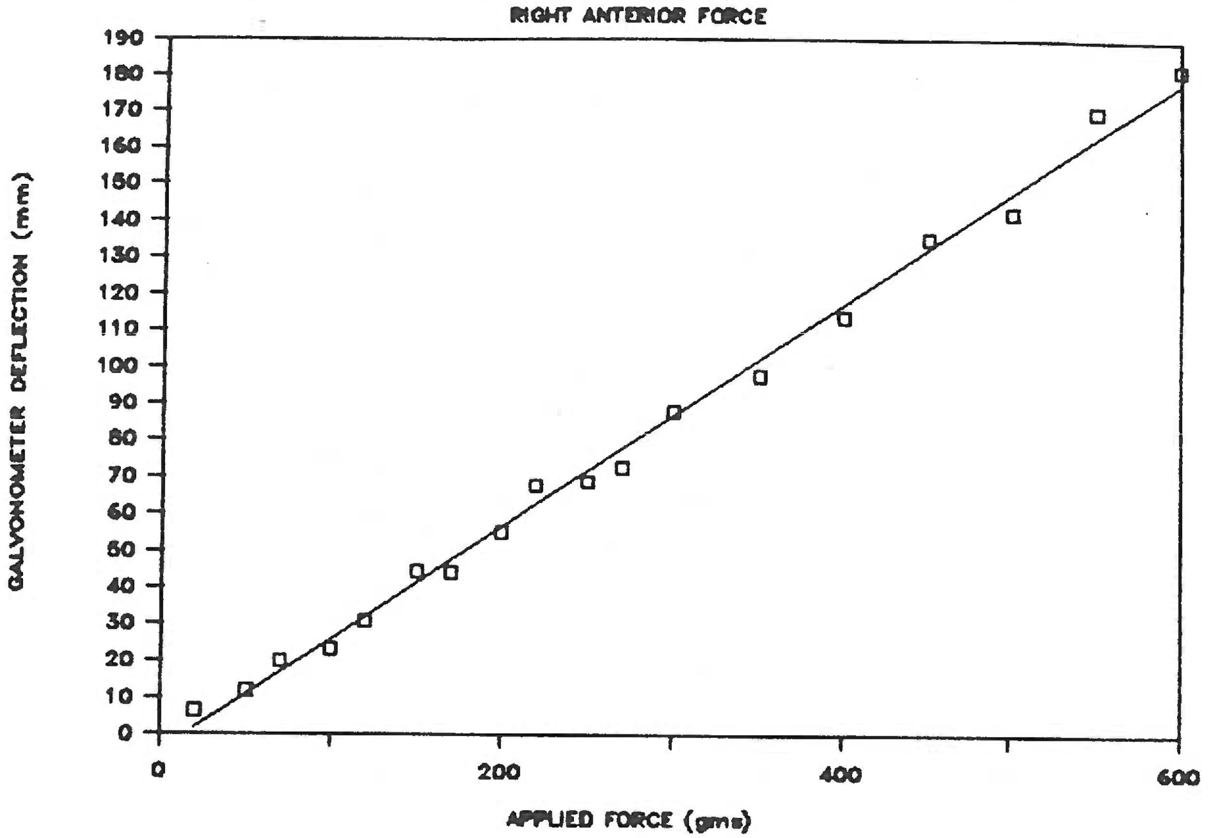
WHEATSTONE BRIDGE #7 CALIBRATION

RIGHT DISTAL CROWN TIP

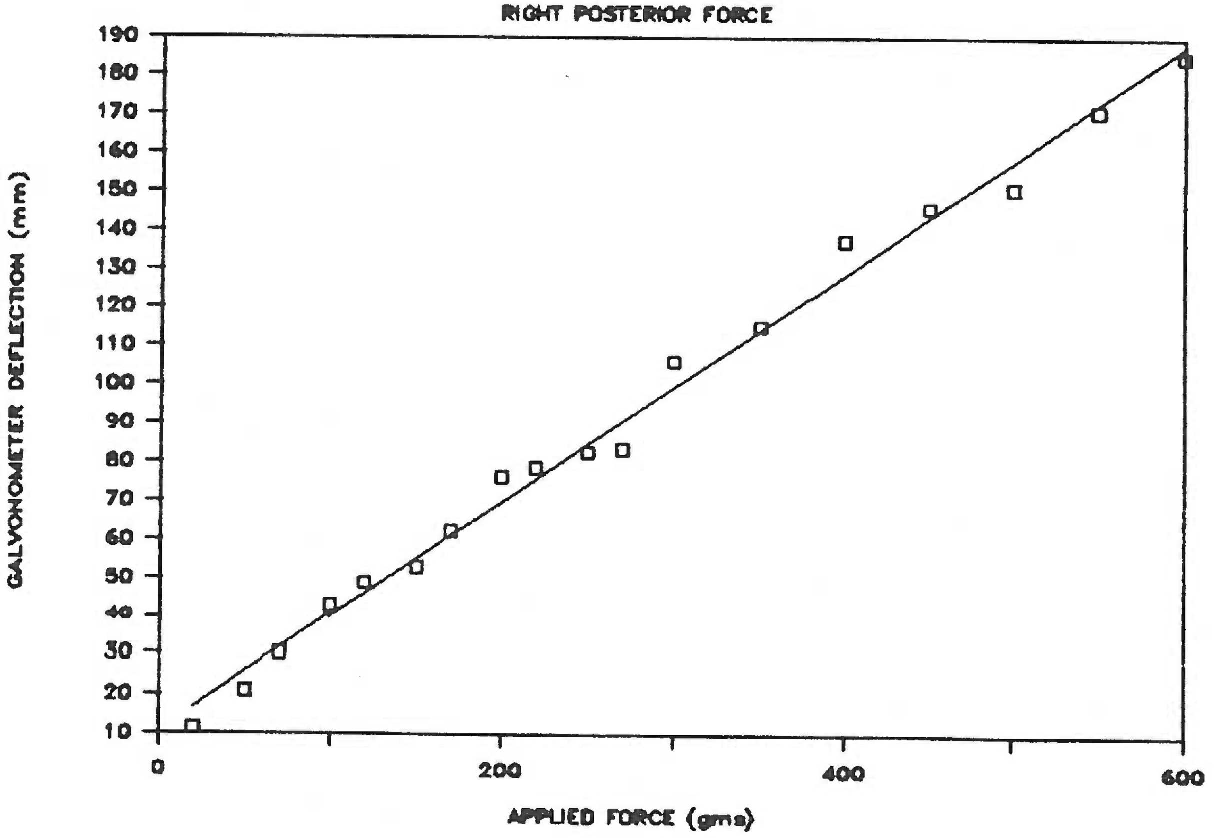


WHEATSTONE BRIDGE #7 CALIBRATION

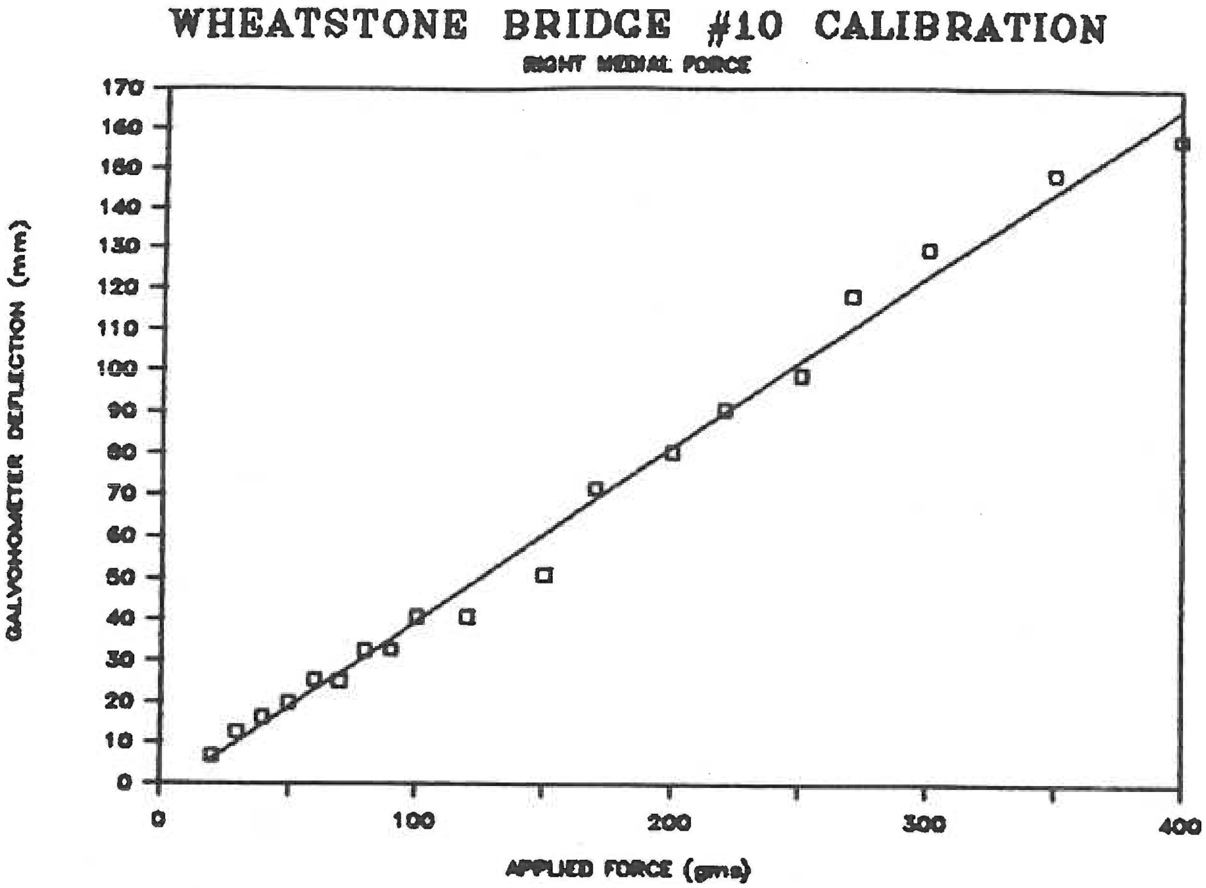
RIGHT MESIAL CROWN TIP

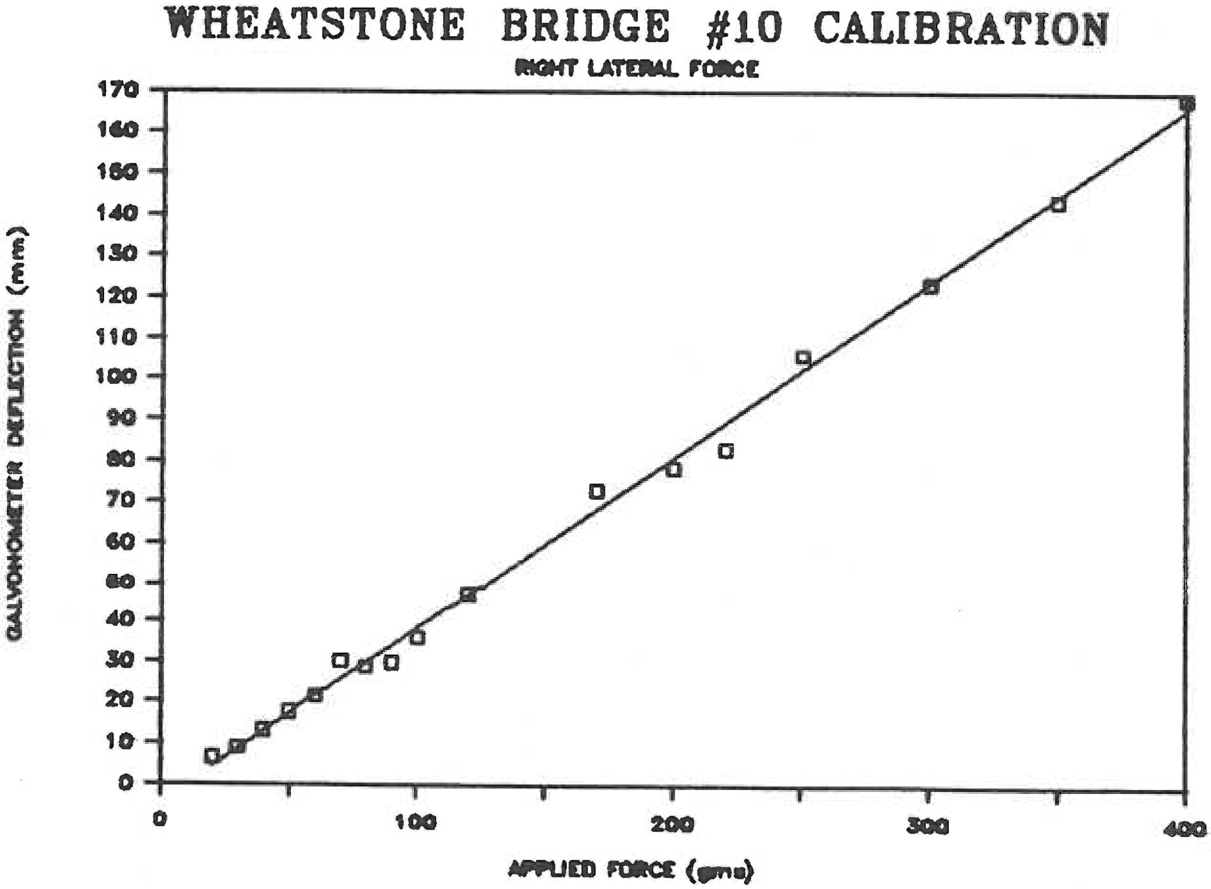


WHEATSTONE BRIDGE #9 CALIBRATION



WHEATSTONE BRIDGE #9 CALIBRATION


WHEATSTONE BRIDGE #10 CALIBRATION
RIGHT MEDIAL FORCE
GALVONOMETER DEFLECTION (mm)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
0
100
200
300
400
APPLIED FORCE (gms)


WHEATSTONE BRIDGE #10 CALIBRATION
RIGHT LATERAL FORCE
GALVONOMETER DEFLECTION (mm)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
0
100
200
300
400
APPLIED FORCE (gms)

# FINDINGS

The data obtained was evaluated using the previously described linear equations and data from the regression analysis. Table 2 presents data describing the resultant forces and moments derived by placing a 400 gm. tractional force on each side of a bilaterally symmetric facebow. Table 3 presents the same results for the asymmetric hinged facebow also having a 400 gm. tractional force applied to each side. Tables 4 and 5 present data describing the power arm facebow with and without a "stress breaking" swivel on the left side of the inner bow. These two facebows were only analyzed as to their distal and mediolateral components of force. To describe the unilateral effectiveness of the four designs the data was calculated to show the percentage of distal force delivered to the right simulated molar. This was calculated by dividing the right side distal force by the total distal force from both sides and multiplying by 100%. The bilaterally symmetric facebow delivered 51.4% of the distal force to the right side, the asymmetric hinged facebow 77.3%, the power arm facebow without a swivel 73.8%, and with a swivel 78.5%. (see histogram #1).

The net lateral forces delivered by the facebow designs were also calculated. The bilaterally symmetric facebow delivered a net lateral force to the right of 15 gm., while all of the unilateral designs delivered net lateral forces to the left. The asymmetric hinged facebow delivered 100.6 gm. of lateral force to the left side, the power arm facebow without a swivel 143.6 gm., and with a swivel 128.1 gm. (see histogram #2).

TABLE 2: SYMMETRIC FACEBOW (400 gm/side)

| WHEATSTONE BRIDGE # | FORCE OR MOMENT MEASURED | RESULTANT FORCE | RESULTANT MOMENT | DIRECTION OF FORCE |
|---|---|---|---|---|
| 1 | L. bucco-ling. torq. | 2.4 | 28.8 | ling. crn. |
| 2 | L. mesio-dist. tip | 290.2 | 3482.4 | dist. crn. |
| 3 | L. intrusive-extrus. | 100.4 | | extrusive |
| 4 | L. antero-posterior | 380.6 | | posterior |
| 5 | L. medio-lateral | 36.1 | | lateral |
| 6 | R. bucco-ling. torq. | 10.0 | 120.0 | ling. crn. |
| 7 | R. mesio-dist. tip. | 306.3 | 3675.6 | dist. crn. |
| 8 | R. intrusive-extrus. | 385.1 | | extrusive |
| 9 | R. antero-posterior | 402.7 | | posterior |
| 10 | R. medio-lateral | 51.1 | | lateral |

## TABLE 3: ASYMMETRIC HINGED FACEBOW (400 gm/side)

| WHEATSTONE BRIDGE # | FORCE OR MOMENT MEASURED | RESULTANT FORCE | RESULTANT MOMENT | DIRECTION OF FORCE |
|---|---|---|---|---|
| 1 | L. bucco-ling. torq. | 110.1 | 1321.2 | bucc. crn. |
| 2 | L. mesio-dist. tip | 150.9 | 1810.8 | dist. crn. |
| 3 | L. intrusive-extrus. | 22.7 | | extrusive |
| 4 | L. antero-posterior | 170.1 | | posterior |
| 5 | L. medio-lateral | 63.5 | | lateral |
| 6 | R. bucco-ling. torq. | 99.4 | 1192.8 | ling. crn. |
| 7 | R. mesio-dist. tip. | 343.4 | 4120.8 | dist. crn. |
| 8 | R. intrusive-extrus. | 396.3 | | extrusive |
| 9 | R. antero-posterior | 580.2 | | posterior |
| 10 | R. medio-lateral | 37.1 | | medial |

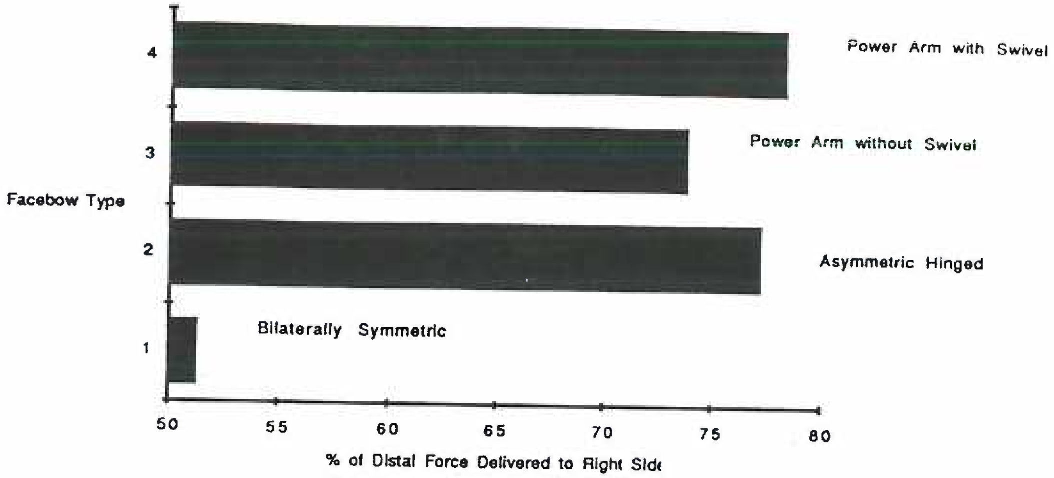
TABLE 4: POWER ARM FACEBOW WITH SWIVEL (400 gm/side)

| WHEATSTONE BRIDGE # | FORCE OR MOMENT MEASURED | RESULTANT FORCE | RESULTANT MOMENT | DIRECTION OF FORCE |
|---|---|---|---|---|
| 4 | L. antero-posterior | 166.4 | | posterior |
| 5 | L. medio-lateral | 96.8 | | lateral |
| 9 | R. antero-posterior | 608.0 | | posterior |
| 10 | R. medio-lateral | 31.3 | | medial |

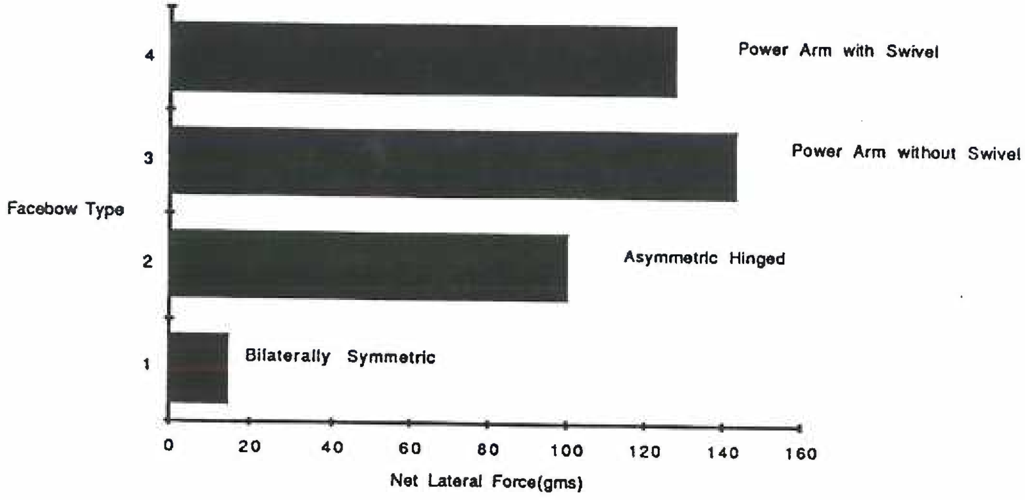
TABLE 5: POWER ARM FACEBOW WITHOUT SWIVEL (400 gm/side)

| WHEATSTONE BRIDGE # | FORCE OR MOMENT MEASURED | RESULTANT FORCE | RESULTANT MOMENT | DIRECTION OF FORCE |
|---|---|---|---|---|
| 4 | L. antero-posterior | 211.5 | | posterior |
| 5 | L. medio-lateral | 88.3 | | lateral |
| 9 | R. antero-posterior | 595.4 | | posterior |
| 10 | R. medio-lateral | 53.5 | | medial |

Histogram 1



Histogram 2



# DISCUSSION

At the start of this project the intent was to calibrate the Headgear Force Analyzer as accurately as possible and to test it with various headgear designs to see if meaningful data could be obtained. The findings that were obtained in this project are consistent with the forces one would expect from the facebow designs tested, except for those in the intrusive-extrusive directions. Right and left side forces were quite different in the extrusive direction for both the symmetric and asymmetric facebows. This was noted early in the testing procedures and several attempts were made to correct the discrepancy. First, the Wheatstone bridges involved (#3,8) were re-calibrated with similar results. The symmetric facebow was flipped over so that what was on the right was on the left and vice versa, however right side readings were still much higher. Finally, the eight strain gauges involved in the right side Wheatstone bridge configuration were wired to bridge #7 on the switching mechanism, instead of #8, once again with no significant change in the data.

These failed attempts at correction of the problem lead me to believe that analyzing these forces is a basic design problem of the machine. The design was supposed to separate out the extrusive-intrusive forces from the other forces involved on each simulated molar. These two Wheatstone bridge configurations used eight strain gauges each, whereas the other bridges only used four strain gauges. The eight gauges were configured so that two gauges were hooked in series on each of the four sides of the Wheatstone bridge. It is beyond the scope of this study and knowledge of this resident to change the design of the machine to allow accurate measurement of the forces involved in the extrusive and intrusive directions. The other forces and moments that were tested delivered data that was more consistent with what would be expected for the facebows tested.

The results from the bilaterally symmetric facebow that was tested show similar resultant forces and moments for both right and left sides. They are not exactly the same and this could be due to the fact that the symmetric facebow, may not have been entirely symmetric upon activation. An attempt was made to construct it to be as symmetric as possible, but this could change upon activation, which could result in the magnitude of the difference seen between the right and left side force values.

The distal and lateral forces are consistent with the results of a similar study, utilizing strain gauge transducers to evaluate headgear forces by Hershey, Houghton, and Burstone.[19] They reported the percentage of total distal force delivered to the heavy force side of the asymmetric swivel facebow as 72.2%, the power arm facebow was 71.9%, and the bilaterally symmetric facebow 49.5%. This study yielded similar results with the bilaterally symmetric facebow delivering 51.4% of the total distal force to the heavy force side, the power arm facebow delivering 73.8% and the asymmetric hinged facebow 77.3%.

Hershey also performed a theoretical mathematical analysis of the facebows involved in his study and that analysis was applied in this study to the asymmetric eccentrically hinged facebow. The theoretical distal force computed (using a 400 gm. tractional force applied to each side) for the left side was 177.3 gm. and the right side 597.5 gm. The net lateral force computed was 81.2 gm. This study found a left side distal force of 170.1 gm. and a right side distal force of 580.2 gm. from the asymmetric hinged facebow design tested. The experimental net lateral force was 100.6 gm. These results are very similar and add validity to the accuracy of this analyzer for measuring forces in the antero-posterior and medio-lateral directions.

The symmetric facebow tested delivered a lateral force to the simulated molars on both sides. This agrees with conclusions made in other studies,[1,19] namely that a tractional force applied to the outer bow of a facebow causes an expansion of the inner bow. Hershey called this the archial expansion effect of a load placed on the inner bow.

The moments applied to the simulated molar teeth have not been reported on by any other investigators, therefore I have no other results to compare them too. They seem to be consistent with the other data obtained for example, the symmetric facebow provided distal crown tip to the molars that was nearly equal in magnitude on both sides. The asymmetric hinged facebow delivered a much greater distal crown tip to the right side than the left as would be expected as the right side had a much greater distal force than the left. The left side had a resultant moment for bucco-lingual torque in the buccal crown direction as would be expected for that side because of the lateral force on the left molar. The right side showed just the opposite torque moment because it received a medial force from the asymmetric facebow.

The findings from the Headgear Force Analyzer are consistent with other studies of this type for forces measured in the antero-posterior, and medio-lateral directions. It is the first study of its kind to report on the moments applied to molars in the bucco-lingual and mesio-distal directions. The findings obtained indicate that it is not an accurate indicator of forces in the intrusive-extrusive direction. The analyzer can now serve as a valuable tool in evaluating orthodontic forces produced by cervical traction. New facebow designs can be tested and analyzed to study whether they do what they indeed claim to do.

The Headgear Force Analyzer has not as yet been shown to produce repeatable consistent results. During data collection it was noted that the galvanometer deflection was not constant for several trials of the same design and force. This may be due to the age and condition of the Sanborn Strain Gauge Amplifier. It was also very hard to keep the system in balance through the use of the internal capacitor and resistor. Another possible reason for inconsistency in the results is friction in the machine itself, as the swivel pulleys would not always center themselves to the line of the applied force. To deal with the friction problem the applied force was made greater by pulling down on the buckets and then released to allow friction to dissipate and the pulleys were tapped so they would center along the line of traction.

The consistency and repeatability of test data could therefore be improved by; 1) replacing the current swivel pulleys with more freely moveable pulleys with less friction and 2) replacing the Sanborn Strain Gauge Amplifier with a more current and sophisticated machine. Houghton in 1977 performed a similar study using strain gauges and he had the strain gauge signals amplified, filtered and then had them converted from analog to digital signals which were then fed into the computer for data reduction and analysis.[17] This allowed on-line calibration and analysis of data and this type of set-up would be useful here. The alternative choice would be to make multiple measurements and then calculate the mean and use that as the resultant force in order to minimize the variations in the set-up. Multiple measurements were performed in this study however, I think a more consistent amplifier and set-up would yield more beneficial results.

The results from the four facebow designs tested showed that significant unilateral effectiveness can be obtained through the use of either a power arm facebow or an asymmetric eccentrically hinged facebow. The "stress breaking" swivel suggested by Kaprelian[18] to minimize the detrimental lateral effect on the side that receives the lesser distal force was also evaluated. The results obtained in comparing two power arm facebows made as identical as possible did not prove that the swivel was effective. Although the distal forces obtained were not identical the unilateral effectiveness, measured by the percentage of distal force delivered to the right inner bow, was similar. The facebow with the swivel had a percentage of 78.5% and the one without the swivel 73.8%. Therefore, if the swivel was effective in reducing the lateral force on the left side the resultant force measured would be less than the "control" facebow without the swivel. This was not the case as the force on the left side of the swivel facebow was 96.8 gm. and that of the non-swivel facebow was 88.3 gm. The use of the swivel to reduce lateral forces during unilateral headgear use is therefore not recommended by the results of this study.

## SUMMARY AND CONCLUSIONS

A research project was conducted to accurately calibrate and test a mechanical model (previously designed and constructed by Birdwell) capable of evaluating forces and moments applied to simulated molar teeth by headgear. The four facebow designs evaluated were a bilaterally symmetric facebow, an asymmetric eccentrically hinged facebow, a power arm facebow with an inner bow swivel, and a power arm facebow without a swivel. All of the facebows were tested in the same manner and under a tractional force of 400 gm. delivered to each side of the outer bow tips. The forces evaluated were those acting in the antero-posterior, medio-lateral, and intrusive-extrusive directions. The moments evaluated were those acting in a mesio-distal and bucco-lingual direction commonly referred to as tip and torque.

The results of this research project yielded the following conclusions:

1) An accurate and valid mechanical model has been constructed for evaluation of forces and moments produced by headgear traction.

2) The mechanical model produced accurate results in all forces and moment directions except for the intrusive-extrusive forces, which are not valid with the model as it exists today.

3) The Headgear Force Analyzer has not yet been proven to deliver consistent and repeatable results with the current machinery used to amplify and filter the strain gauge signals.

4) The asymmetric eccentrically hinged facebow and the power arm facebows delivered an effective unilateral distal force.

5) All of the facebows tested that delivered an effective unilateral distal force also produced a significant net lateral force to the inner bow receiving the lesser distal force. The clinician should keep this in mind when using these designs.

6) The "stress-breaking" swivel applied to the inner bow of the side receiving the lesser distal force did not decrease the lateral force on that side. It also did not decrease the net lateral force to any clinical significance.

7) Considering expense, ease of construction, and inventory control, the power arm facebow seems to the most advantageous unilateral design to use in practice.

## REFERENCES

1. Marenda, R.E.: Eccentric traction with the Kloehn headgear, Unpublished thesis Univ. of Oregon, 1965.

2. Birdwell, D.J.: A mechanical model for the resolution of forces produced by symmetric and asymmetric headgear, Unpublished thesis Oregon Health Sciences Univ., 1987.

3. Dental Cosmos, 8:91, 1867.

4. Angle, E.H.: New sytems of regulation and retention, Dent. Register 41:597-603.

5. Case, C, <u>Dental Orthopedia</u>, ed.2, Chicago, C.S. Case Co. 132-135, 1921.

6. Oppenhein, A.: A possibility of physiologic orthodontic movement, Am. J. Orthod. and Oral Surg. 30:345-368, 1944.

7. Kloehn, S.J.: Guiding alveolar growth and eruption of teeth to reduce treatment time and produce a more balanced denture and face, Angle Orthod. 17:10-37, 1947.

8. Kloehn, S.J.: Orthodontics - force or persuasion, Angle Orthod. 23:56-65, 1953.

9. Baldridge, J.P.: Construction and use of unilateral headcap with report of cases, unpublished report presented to Midwestern Component, Angle Society, 1953.

10. Block, A.J.: An analysis of midline and offcenter extraoral force, Angle Orthod. 24:1-7, 1954.

11. Haack, D.C., and Weinstein, S.: The mechanics of centric and eccentric cervical traction, Am. J. Orthod. 44:346-357, 1968.

12. Drenker, E.W.: Unilateral cervical traction with a Kloehn extraoral mechanism, Angle Orthod. 29:201-205, 1959.

13. Baldridge, J.P.: Unilateral action with a headcap, Angle Orthod. 31:63-68, 1961.

14. Zwemer, T.J., and Chase, A.B.: An electronic method for measuring cervical traction forces, J. Dent. Res. 39:669, 1960.

15. Burstone, C.J., Koenig, H., and Solonche, D.J.: Force systems for two bracket segments, J. Dent. Res. No. 76, 1973.

16. Burstone, C.J., Solanche, D.J., Anderson, N.D., and Papir, D.J.: A strain gauge transducer model for evaluation of clinical appliances in a two-tooth segment, Am. J. Orthod. 69:591, 1976.

17. Houghton, C.W.: A theoretical and laboratory evaluation of unilateral face-bows, Masters thesis, University of North Carolina School of Dentistry, 1977.

18. Kaprelian, G.: An effective unilateral facebow, J. Clin. Orthod. 76:60-61, 1982.

19. Hershey, H.G., Houghton, C.W., and Burstone, C.J.: Unilateral facebows: A theoretical and laboratory analysis, Am. J. Orthod. 79:229-249, 1981.