STRAIN ANALYSIS OF VASOCONSTRICTION

AT

ARTERIAL BRANCH SITES

by

WILLIAM G.R. GIBSON

A THESIS
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ABSTRACT

Strain in the arterial wall as caused by vasoconstriction is theorized to be a factor in the genesis of arterial pathology at branch sites. An "in vitro" contractile tissue model was designed to test this theory by measuring the arterial strain in a branch during constriction.

Four canine renal arteries were studied. The arteries were chemically stimulated to contract and the resulting surface strain was measured using a stereoscopic, photographic technique. Strain measurements were confined to the apex of the acute angle of the arterial branch.

Both elongation (positive strain) and contraction (negative strain) were measured, in magnitudes of 1 to 3 times the fractional diametric contraction. The results showed uniform strain throughout the apex of the branch. The most significant result was elongation (positive strain) in a contracting artery which implies that vasoconstriction can cause tearing in the arterial wall.

Elongation in a contracting arterial branch is supportive of the theory that vasoconstriction is an important factor in the pathology of arteries at branch sites.

ACKNOWLEDGMENTS

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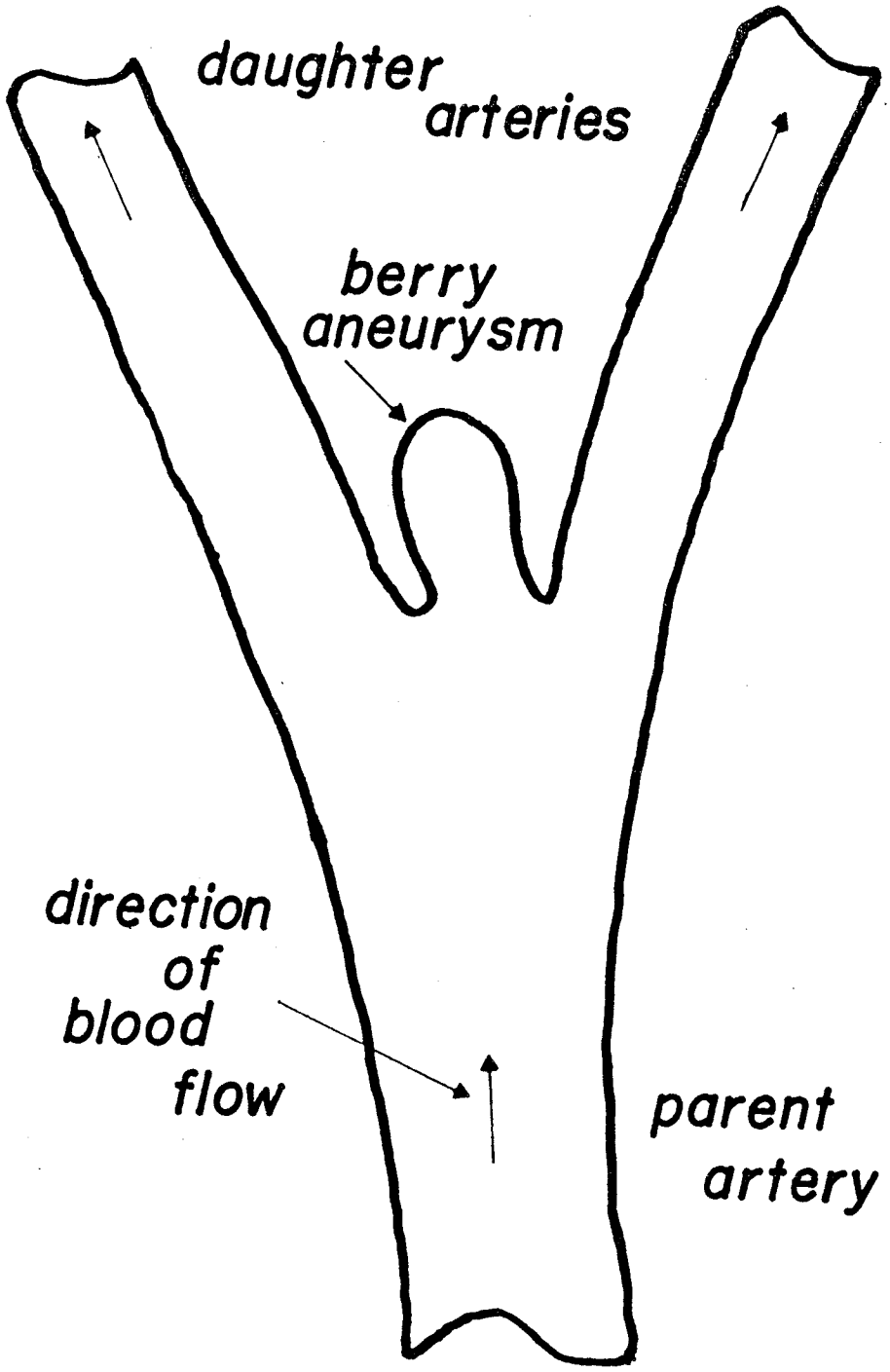

Figure 1.1 Arterial branch with a Berry Aneurysm.

1.1 ARTERIAL STRAIN

Branches in the arterial system are sites of discontinuites in both blood flow and arterial wall structure. Branch sites are also the location where significant problems occur with the arterial wall. For example, the formation of berry aneurysms which are berry like dialations in the arterial wall. The aneurysm is typically located at or close to the apex of the acute angle of a branch. Figure 1.1 depicts a typical branch with a berry aneurysm.

Another arterial branch problem has been recently noted by Taylor [1984] concerning the major coronary and renal arteries of asphyxiated neonates. The arteries had premortem tearing in the arterial wall at the acute angle of the branch which resulted in hemorrhage.

Two questions are: does the effect of vasospasm at a branch cause high strain in the arterial wall, and is vasospasm (or vasoconstriction) a factor in the pathogenesis of problems in the arterial wall at the branch? In the case of the development of aneurysms, the repeated strain as caused by the spasm may be a factor in the pathology of the arterial wall. With the case of rupture in infant arteries, severe vasospasm maybe the cause of significant strains which exceed the strain limits of the tissue resulting in lesions.

The objective of this thesis is to develop a

contractile "in vitro" tissue model of an arterial branch and to measure arterial wall strain. Strain measurements can then be made at several locations of the arterial branch to determine if vasoconstriction causes sites of high strain in the branch.

1.2 THESIS FORMAT

Chapter two, LITERATURE REVIEW, reviews the literature on the anatomy of arteries at branches as well as vasoconstriction. The chapter ends with a review of current methods of arterial strain measurement.

The third chapter, METHODS, covers the methods and techniques used in measuring arterial strain in the tissue model.

Chapter four, ANALYSIS, covers the procedure of strain analysis resulting in arterial strain data.

Chapters five and six, RESULTS and DISCUSSION, present the results of the experimental arterial strain measurements and discusses the relevance of this information to the possible pathological effects of vasoconstriction at arterial branches.

The final chapters, CONCLUSIONA and RECOMMENDATION, present a number of the conclusions that were made as a result of the study, and suggests possible procedures that can be taken in continuing the study of arterial strain measurement.

Several appendices have been included at the end of the text. These appendices contain detailed information and data as required for the continuation of the work in the study of arterial strain measurement. As well, reviews of arterial anatomy, method of strain measurement, and the equipment used in the study are found in the appendices.

Chapter 2 LITERATURE REVIEW

SUMMARY

Berry aneurysms commonly occur in the cerebral vascular circulation and may be fatal when ruptured. The cause of aneurysms is unknown, however, gaps in the media of the arterial wall, as well as hemodynamic factors are believed to play a part in the genesis of aneurysms.

Vasoconstriction is also thought to be a significant factor in the pathology of the arterial wall. Electrical and chemical techniques are used to stimulate vasoconstriction in an "in vitro" tissue model.

To understand the behavior of arteries under such conditions as blood flow and vasoconstriction, the material and structural properties of arteries were reviewed. Arteries are a heterogeneous structure with viscoelastic and anisotropic properties. The tissue characteristics of arteries were also found to be different depending upon the geometry of the testing specimen.

Current techniques used to measure changes in arterial diameter and length were reviewed. These techniques are adequate for strain calculation of straight sections of artery, but will not yield sufficient strain information for constriction of an arterial branch.

2.1 ARTERIAL ANATOMY

This section deals with the anatomy of an arterial branch, concentrating on aneurysms and medial gaps, and the mechanical aspects of the arterial structure. The basic anatomical structure of arteries is reviewed in Appendix A, Arterial Anatomy and Physiology.

2.1.1 Aneurysms and Medial Gaps

An aneurysms is defined as a localized and persistent dilatation that results from the yielding of components of the wall of the heart or blood vessels [Stehbens, 1972]. Rupture of a cerebral aneurysm has serious consequences, with a mortality ranging from 33 to 64 percent upon the rupture [Stehbens, 1981].

Berry aneurysms are the most common variety of saccular aneurysms in the cerebral circulation, with berry like formations in the branches of the arteries [Stehbens, 1972]. Stehbens [1981] stated that there are two basic views to the etiology of these aneurysms; the congenital theory and the degenerative theory. However, Stehbens stated that there is no scientific evidence supporting the congenital theory, and that aneurysms form as a result of a degenerative process. The role of medial gaps in this degenerative process has been controversial.

Medial gaps are defined as areas in the arterial wall at a branch site where thinning of the media occurs.

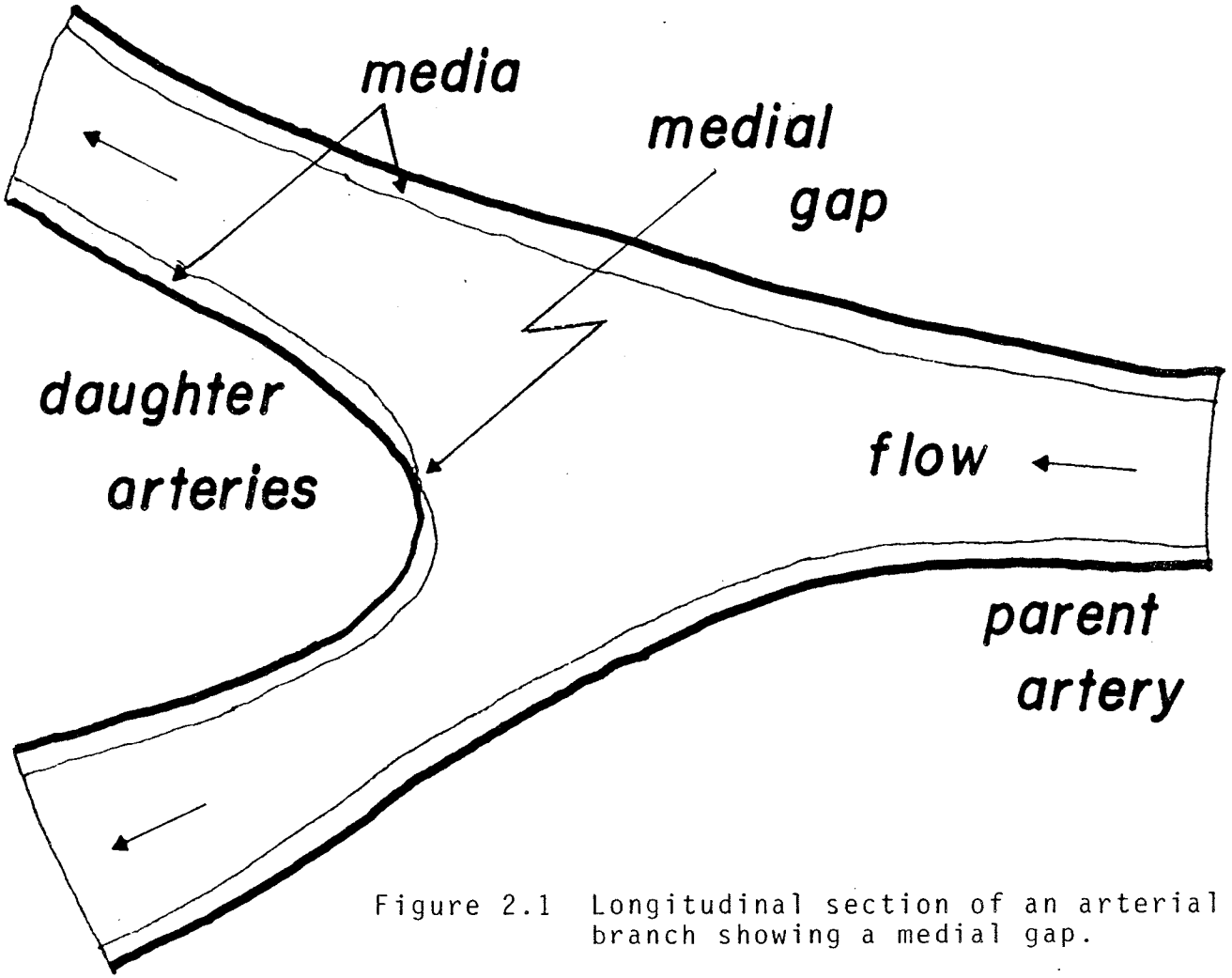

Figure 2.1 Longitudinal section of an arterial branch showing a medial gap.

These gaps in the media of the arterial wall are located close to the apex of either the acute or obtuse angle of the branch. Figure 2.1 is a sketch of a longitudinal histological section of an artery with a medial gap. A gap in the media may vary from a slight thinning of the media to a total absence of the media. The amount of adventitia and density of collagen in the arterial wall at the gap also varies [Stehbens, 1972].

Medial gaps occur predominately in muscular arteries, and in a wide variety of anatomical sites. The gaps are more frequently found in the acute angle of the branch than the lateral or obtuse angle [Hassler, 1961; Stehbens, 1972]. They are more easily found in older people as the gap is generally wider than that of a young person or child. Gaps commonly occur in human cerebral arteries and have also been found in human renal arteries [Stehbens, 1959]. Medial gaps have been located in cerebral arteries of dogs, horses, rabbits and cows [Hassler, 1961]. Stehbens [1963] located medial gaps in the forks of the major renal arteries of rabbits. Stehbens [1972] concludes that medial gaps are probably universal in the mammal, and are certainly universal in man.

The origin or cause of medial gaps, and their relationship to the formation of aneurysms is unknown. Glynn [1940] stated that medial gaps do not cause weakness in the arterial wall and do not play a part in the developement of aneurysms. Stehbens [1972] stated that there is no evidence

to suggest that medial gaps in themselves are areas of undue weakness in the arterial wall and their involvement with aneurysms is only fortuitous. Hassler [1961] linked medial gaps and aneurysms, and suggests that they are due to the effect of the streaming blood. Tuthill [1933] put forward the hypothesis that the gaps are artifacts caused by the twisting of the arteries. In a review of literature on aneurysms, Sekhar et al [1981] concluded that aneurysms result from a combination of hemodynamic factors, such as axial stream impingement and water hammer effect, and structural weakness of medial gaps at the arterial branch.

Whether the gaps provide any function in the artery at a branch site is unknown. Stehbens [1981] suggested that the gap may act as a raphe or seam between the muscle of adjacent arterial walls at branch sites where the effect of vasoconstriction is in opposing directions.

The review of the literature clearly reveals that the function of medial gaps and the relationship between the gaps and the formation of aneurysms are unknown.

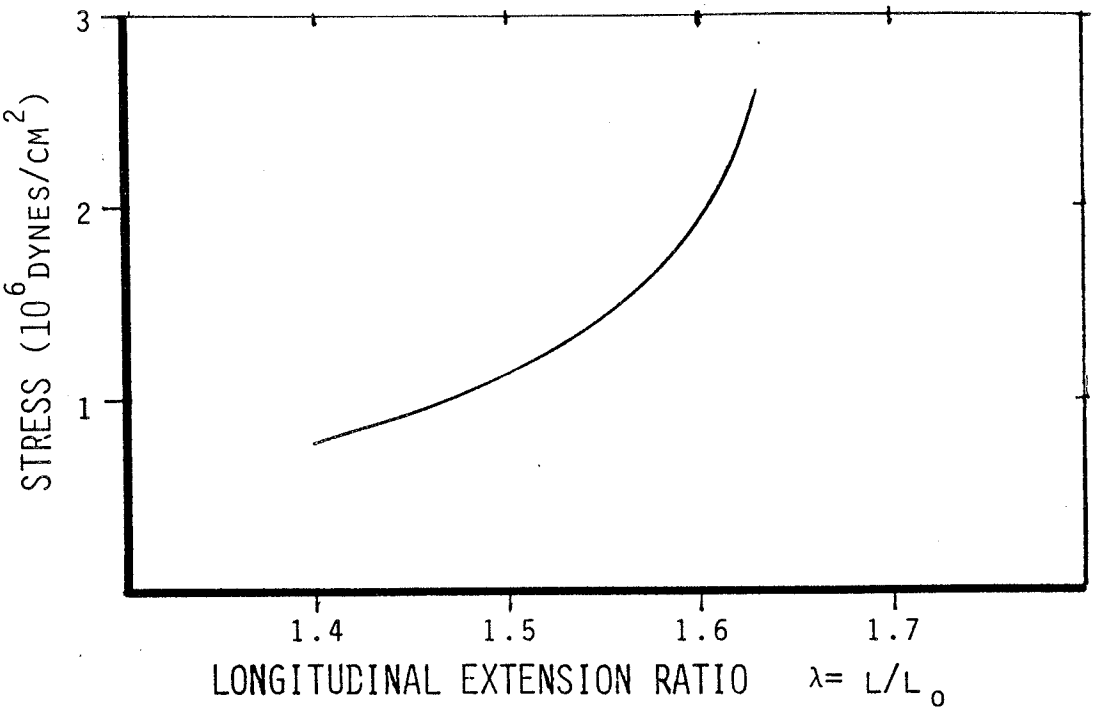

Figure 2.2 Stress-Strain Relationship, Dog Aorta, from Fung, 1981. L_o - initial length of specimen, L- strained length.

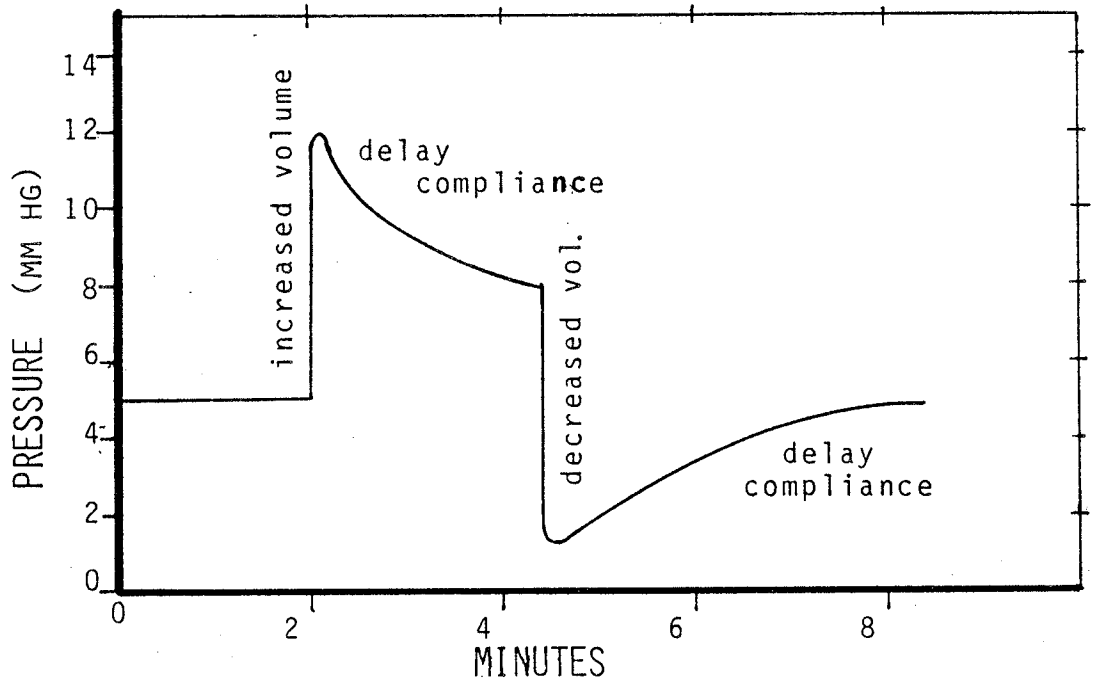

Figure 2.3 Visco Elastic properties of Vascular Tissue, from Guyton, 1967.

2.1.2 Mechanical Aspects

Arterial mechanics may be reviewed by studying two aspects of the artery: the material properties of tissue, and the structural aspects or behavior of an artery as a whole.

Material Properties:

The arterial wall is a heterogenous material predominately composed of three different types of materials; smooth muscle cells, elastin, and collagen [Wolf and Werthessen, 1979; Fung, 1981]. The effect of this varied composition is seen when examining the relationship between stress and strain of the arterial wall. The stress-strain curve of the arterial wall is very non-linear as seen in figure 2.2.

Arteries have been modelled as a viscoelastic material [Fung, 1981]. Two properties of a viscoelastic material are stress relaxation and creep. The effect of time with these arterial properties is demonstrated in the curve of figure 2.3.

Another characteristic of the arterial tissue is anisotropy. Figure 2.4 illustrates the difference between circumferential strain of an artery and the axial strain by examining the circumferential, longitudinal, and radial viscoelastic moduli for the canine aorta. The different frequencies correspond to the cycling rates used to test the

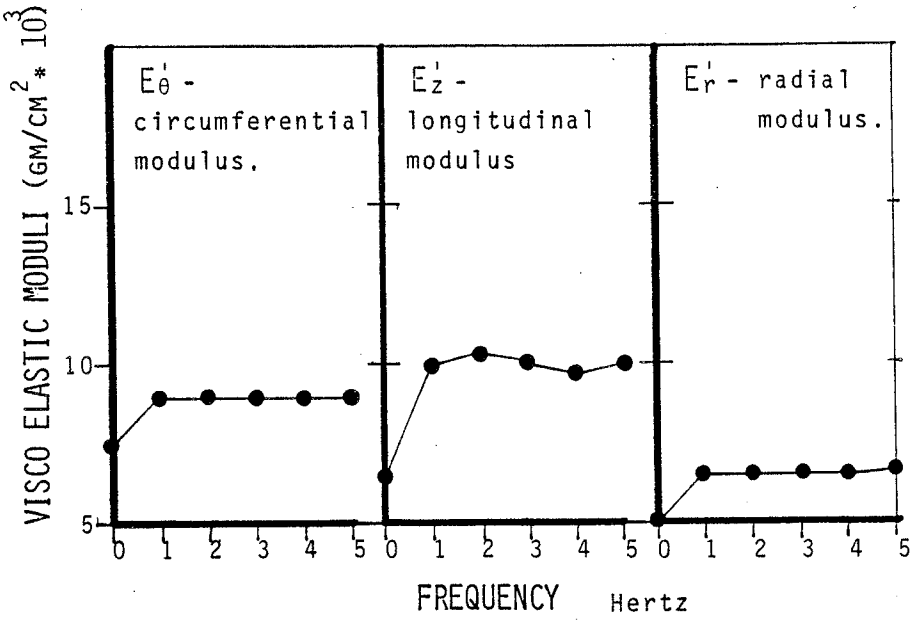

Figure 2.4 Anisotropy of Canine Aorta "in vitro". From Wolf and Werthessen, 1976. Tested with different load frequencies.

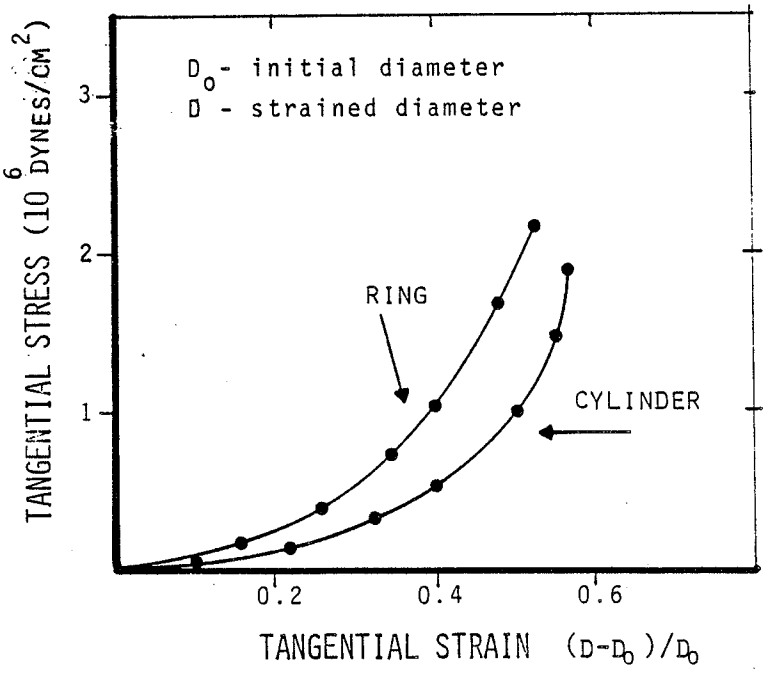

Figure 2.5 Difference in Stress-Strain due to Geometry of Testing Specimen. From Cox, 1983.

specimen [Wolf and Werhessen, 1976].

Structural Aspects:

The stress-strain characteristics of the arterial wall depend upon the test specimen geometry. Figure 2.5 shows this dependence when testing cylindrical arterial segments as opposed to testing arterial ring segments [Cox, 1983].

All 'in situ' arteries are in a pre-stressed state [Wolf and Werthessen, 1976]. This is demonstrated by the contraction of the artery when the artery is cut. The original 'in situ', pre-stressed condition should be established before testing tissue [Fung, 1981]. The effect of initial length can be illustrated when studying the tension-length curves of arterial smooth muscle (see figure 2.6). As the length of the muscle is altered, more or less tension can be developed by the muscle.

The angle that the branching artery makes with the parent artery is also important when studying the strain at a branch. Through a simple theoretical study by Kenyon [Wolf and Werthessen, 1976], the strain due to pressure in a 'Y' branch is less than that in a 'T' branch. Fenton et al [1984] showed in a numerical model of an arterial branch that the stress due to contraction of the artery is dependent on the angle of the branch. They also showed that a gap in the media reduces the stress in the arterial wall as caused by vasoconstriction in that location of the

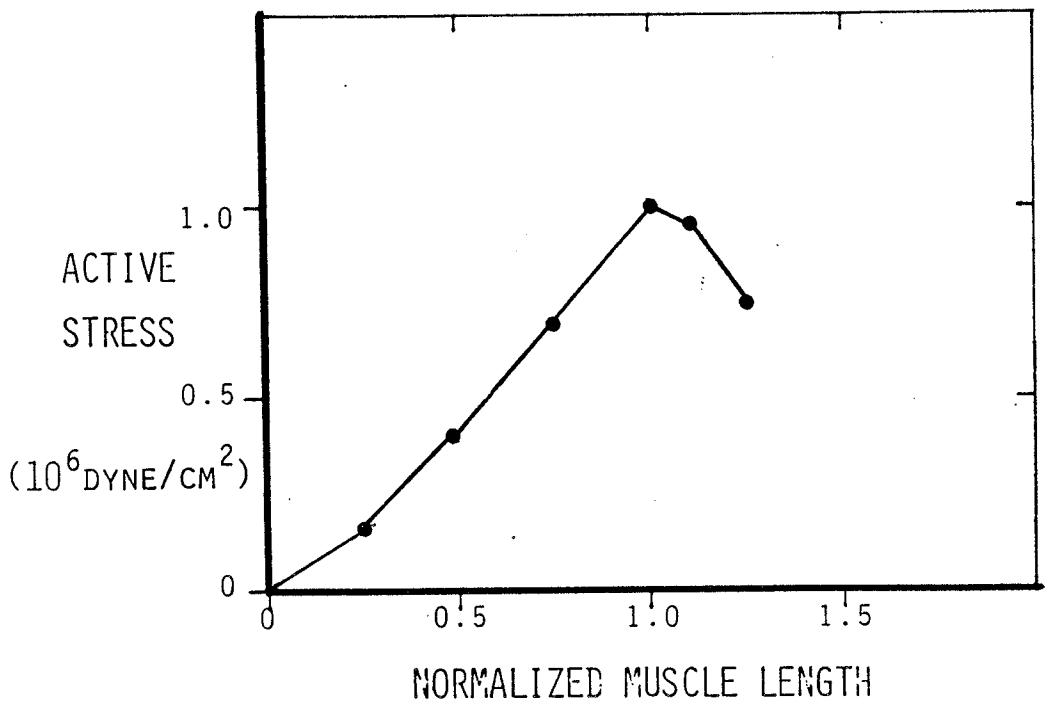

Figure 2.6 Length-Tension Relationship for smooth muscle. Canine carotid artery, from Cox, 1983.

branch.

This review of the literature indicates that the geometric and structural characteristics of arteries are complex. Consequently, theoretical models of the artery only approximate arterial physiology. These arterial characteristics must also be considered when designing an "in vitro" tissue model.

2.2 VASOCONSTRICTION

The reduction of an arterial diameter by stimulation of vascular smooth muscle is referred to as vasoconstriction. This section will deal with two aspects of vasoconstriction; the causes and effects of vasoconstriction, and "in vitro" stimulation of vascular smooth muscle. A review of vascular smooth muscle mechanics is found in Appendix A, Arterial Anatomy and Physiology.

2.2.1 Causes and Effects

The "in vivo" control of constriction of the arterial smooth muscle in arteries may be through nervous or non-nervous stimulation [McClintic, 1980; Jacob, 1978]. Nervous control of constriction is part of the sympathetic nervous system with the vasoconstrictor nerves originating from the vasoconstrictor centre of the medulla of the brain stem. Non-nervous control of arterial contraction may be through chemical, thermal or mechanical stimulation (eg. trauma).

Epinephrine, a hormone of the suprarenal medulla, is a chemical which dilates vessels in the heart, skeletal muscle and lung with constriction in all other vessels. Norepinephrine, also a hormone of the suprarenal medulla, is similar to epinephrine except that it does not affect the heart. Both chemicals affect the neuromuscular junctions causing muscle contraction. High levels of oxygen in the

blood vessels can cause local vasoconstriction. The mechanism of this function is unknown, however, one theory is that the concentration of oxygen in the arterial smooth muscle regulates the amount of muscle contraction [Guyton, 1971].

The major effect of vasoconstriction is the reduction in interluminal area causing an increase in vascular resistance. This increase in resistance may then cause either a reduction in blood flow or an increase in blood pressure. Long and strong periods of vasoconstriction, referred to as spasm, may have more pathological effects on the artery. For example, in Raynaud's disease, a total occlusion of the artery is caused by arterial spasm which causes ischemia of the local tissue [Spittel, 1984]. Severe spasm is also noted to cause damage to arterial endothelium [Jorris, 1980]. Taylor [1984] has noted severe premortum hemorrhage due to lesions in the medial gaps of branches in the major renal and coronary arteries of asphyxiated neonates. Taylor hypothesizes that the spasm as induced by the hypoxic state of the infant could be severe enough to be the cause of the lesions.

Strain in an arterial wall as a result of vasoconstriction or spasm is thought to be a factor in the existence of medial gaps in the arterial wall at a branch [Stehbens, 1981]. Stehbens states that medial gaps may act as a raphe or seam between the muscle of adjoining arterial walls at sites in a branch where the effect of vasoconstric-

tion is in two diverging directions.

This review of vasoconstriction indicates that vasoconstriction may be an important factor in the pathogenesis of arteries. As well, the anatomy of the arterial branch may be a consequence of vasoconstriction.

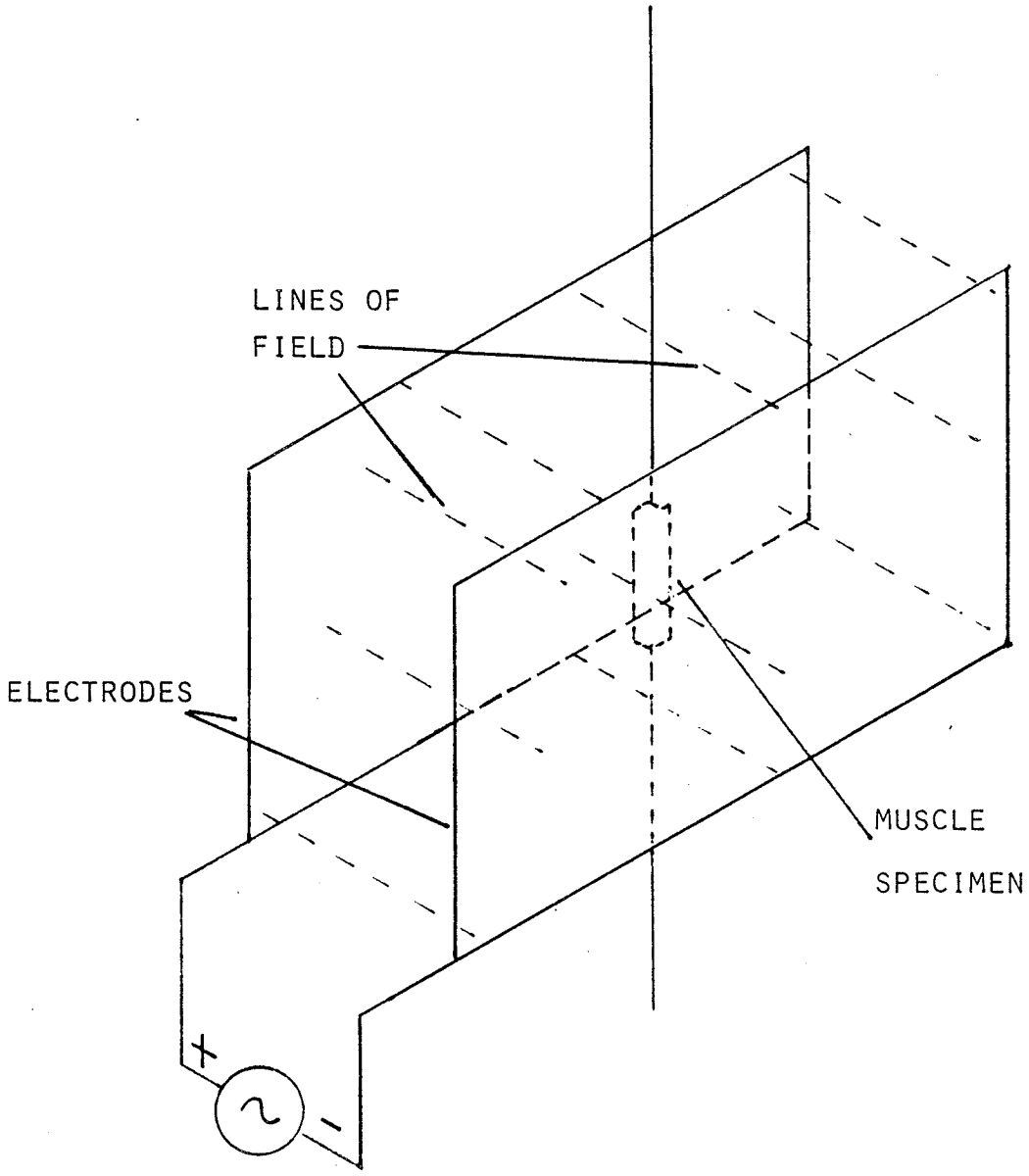

Figure 2.7 A schematic representation of Electrical Field Stimulation.

2.2.2 In Vitro Stimulation

Two principle methods of stimulation of "in vitro" vascular smooth muscle are electrical field stimulation [Danniel and Paton, 1975; Conde et al, 1978] and chemical stimulation [Estrada et al, 1981; Cox, 1978; Dobrin, 1973; Speden, 1972].

Field Stimulation:

The procedure of electrical stimulation is to subject the tissue to an electric field. The field is distributed such that all of the tissue is subjected equally to the field (see figure 2.7). This procedure results in a continuous contraction throughout the tissue.

Electrical stimulation of "in vitro" smooth muscle can occur through two different effects depending on the intensity, frequency and type of electric field. The first effect is stimulation through excitation of the nervous system of the tissue. The electric field may cause a release of neuro transmitters from nerve synapses which then causes contraction of the smooth muscle. The second method affects the smooth muscle directly by depolarizing the potential of each muscle cell causing a contraction [Danniel and Paton, 1975].

Generation of heat in the tissue is a problem encountered when using electrical field stimulation [Danniel and Paton, 1975]. The flow of current through the resistive

tissue results in power that the tissue must dissipate. This generation of heat may be destructive to the tissue.

Chemical Stimulation:

Norepinephrine is a popular chemical used for constricting arteries [Cox, 1978; Dobrin, 1973; Speden, 1972]. The chemical may be administered directly into the tissue bath or perfusion fluid. The chemical stimulant must be washed from the tissue and the tissue allowed to stablize after each stimulation period. The use of chemicals as a muscle stimulant is a simple procedure, however, the response time of each stimulation trial is longer than that when using electrical stimulation.

2.3 ARTERIAL STRAIN MEASUREMENT

'When the size or shape of a body is altered, the change in any dimension is termed a deformation, ... and the normal strain ... is defined as the deformation per unit length.' [Hisdon et al, 1967, p 48]. Current techniques of measuring deformation and strain in the arterial wall are reviewed in this section.

Strain measurement of the arterial wall to determine arterial wall mechanics has been well documented and can be found in texts such as Fung [1981]. The early studies of arterial strain used arterial strips. These studies investigated one and two dimensional stress-strain relationships of the arterial tissue. However, the structural properties of the artery as a whole were not determined.

Strain measurements of the structural behavior of arteries have been confined to measuring change in either the length or diameter of the artery [Busse and Kellner, 1982; Conde et al, 1978; Cox, 1983; Cox, 1978; Dobrin, 1973; Estrada et al, 1981; Speden, 1972]. A common procedure for measuring arterial length changes in a segment of artery is to fix one end of the artery and allow the other end to move under a load while measuring the change. Measurement of changes in arterial diameter have been made using a cantilever system. One end of the lever rests against the artery and any change in the artery's diameter will cause the lever to swing. The amount of swing is then proportional

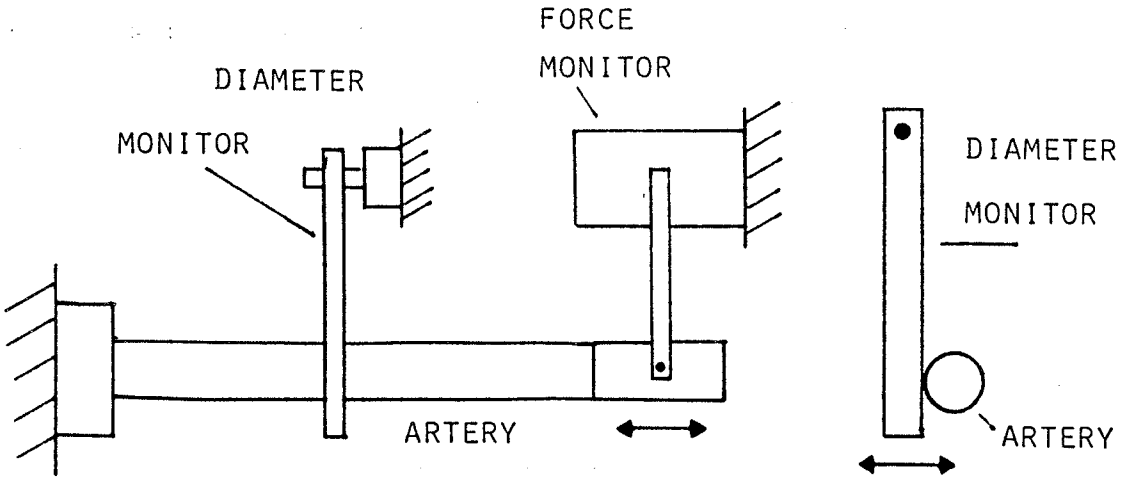

Figure 2.8 A technique for measuring length and diameter changes in an artery.

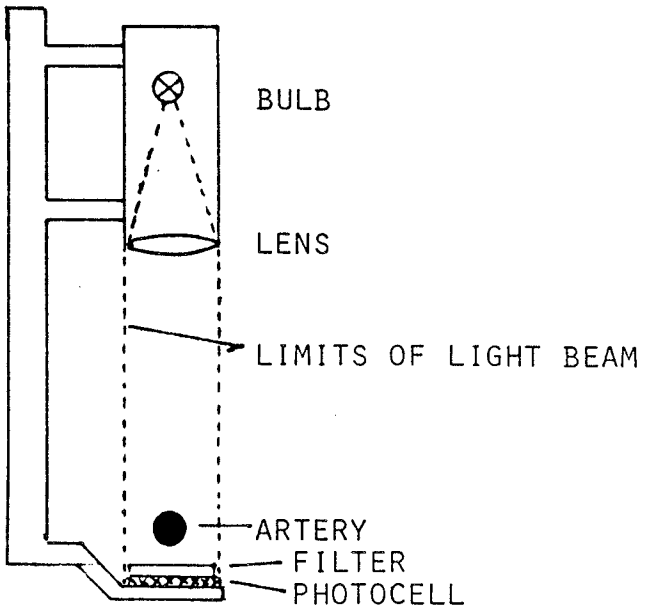

Figure 2.9 Photoelectric method of measuring arterial diameter changes.

to the amount of change. Figure 2.8 illustrates the procedures used in measuring length and diameter changes in an artery.

A more sophisticated arterial diameter monitoring system uses a photo-optical principle [Wetterer et al, 1977]. A light source illuminates the artery to be measured, creating a shadow on solar cells. As the arterial diameter increases or decreases, the voltage output from the solar cells decrease or increase respectively. Figure 2.9 illustrates this technique of monitoring the arterial diameter.

The information given by diametric and longitudinal changes may be sufficient for calculating arterial mechanics of a cylindrical artery. However, these methods are not sufficient for non-symmetrical sections of artery such as branches. Consequently, the strain in the arterial wall tissue of the branch is poorly approximated with the actual characteristics of the constricted artery at the branch remaining unknown. No method of strain measurement has been found that will yield strain information for any shaped arterial segment, especially arterial surface strain at the apex of a branch.

Chapter 3 METHODS

SUMMARY

The objective of the "in vitro" tissue model was to simulate the active physiology of an arterial branch "in vivo" prior to and during vasoconstriction. Ideally, an "in vivo" tissue model would be used, however, the complications of such a model were too extensive for this preliminary study. The "in vitro" model was used to measure arterial strain as caused by vasoconstriction. The artery was kept under a hydrostatic pressure of approximately 120 mm Hg during the experiment.

Strain measurement was made in the area of the apex of the acute angle of the arterial branch. This was acomplished by multiplane photographs taken of the arterial branch. The three dimensional coordinates of specific points or marks on the artery are calculated using the information from the multiplane views.

The artery was stimulated chemically into an isobaric contraction for active constriction. As well, a passive contraction (reduction in interluminal pressure) was studied.

The arterial structure may be important in qualifying the strain results. The arteries used in the study were 'fixed' using formalin, and stored for histological sectioning to determine arterial wall structure and to check for medial gaps within the branch.

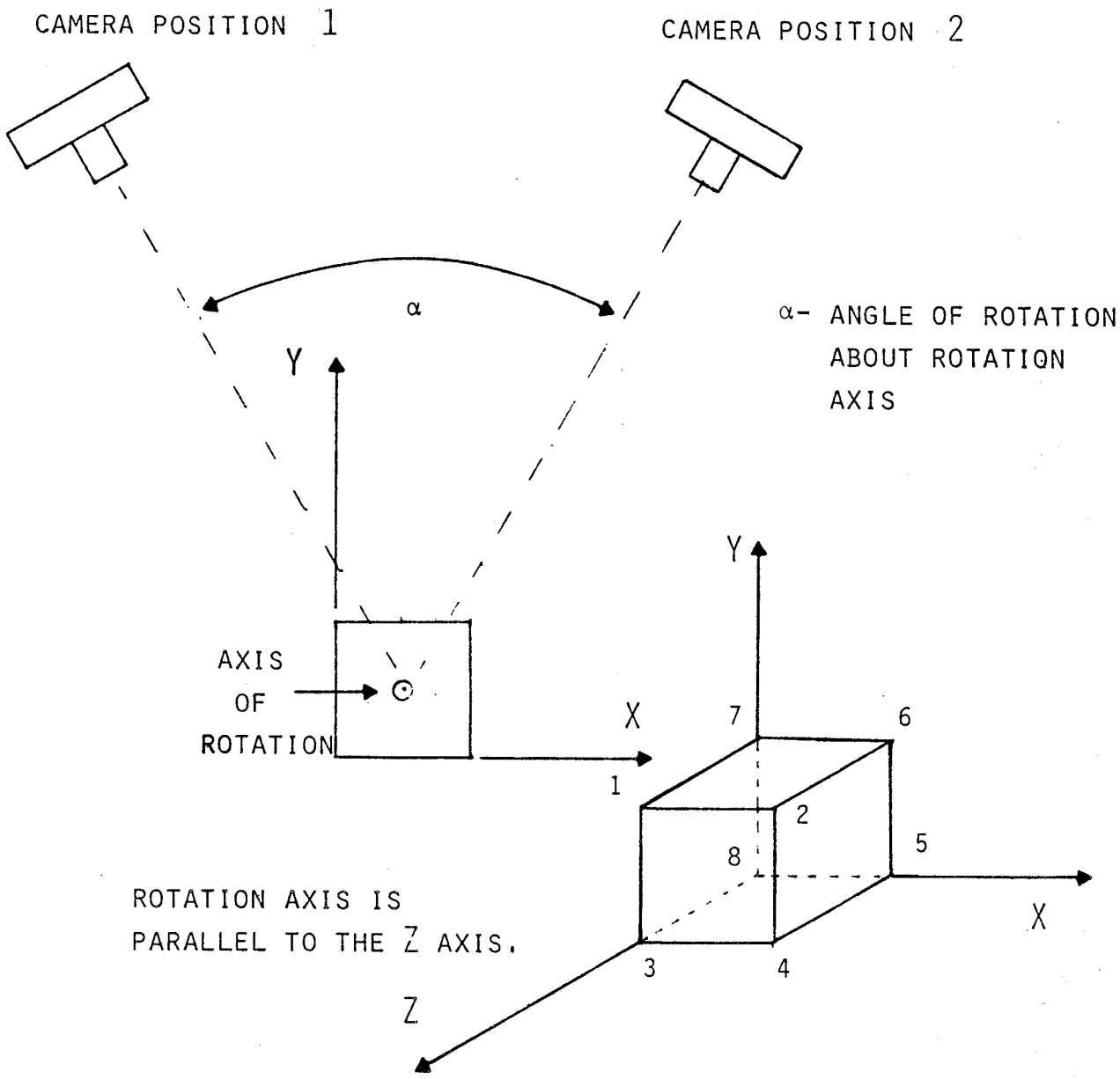

Figure 3.1 Multiplane photography of a cube.

3.1 MULTIPLANE PHOTOGRAPHY

A brief study of different strain measurement techniques was conducted to determine a suitable method for measuring arterial strain (see Appendix B, Design Study). Multiplane photography was chosen as the most effective method of arterial strain measurement. This section will describe, in greater depth, multiplane photography, as well as establishing how multiplane photography was applied in measuring arterial strain. The section then ends with a discussion of the limitations of this method of strain measurement.

3.2.1 Description

Multiplane photography is a procedure where two dimensional photographs (plane views) are taken at different, but known, rotational angles about an object. The photographs from the different plane views are used to reconstruct the original object in three dimensions.

To illustrate the method of multiplane photography, a cube, with each of the eight corners numbered, is photographed as seen in 3.1, position 1. The view is rotated about the cube to a new position at a known angle from the first position and photographed again, figure 3.1, position 2. The plane views of both positions of figure 3.1 yield information about the cube as seen in figure 3.2. Points coordinates which are in an axis which is parallel to

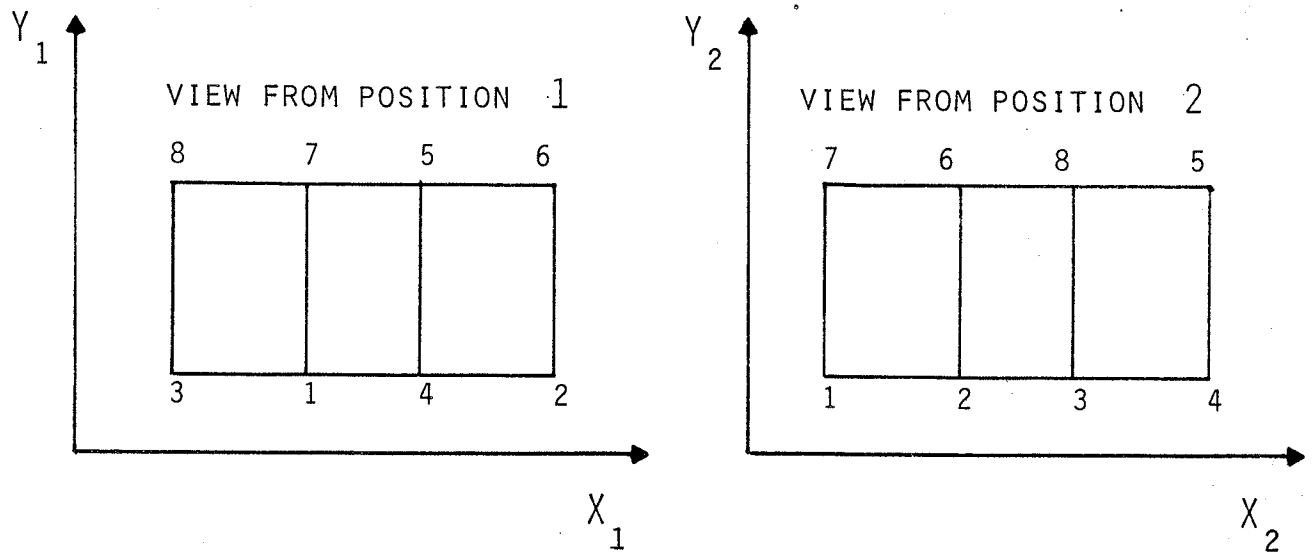

Figure 3.2 Plane views of multiplane photography. The corners of the cube are numbered corresponding to the three dimensional representation. The plane views are not to scale.

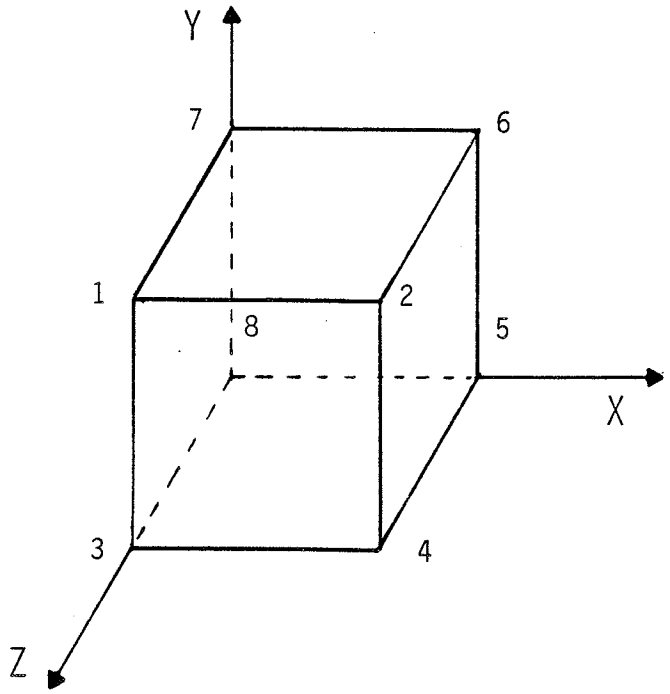

Figure 3.3 The cube reconstructed from the multiplane views

the axis of rotation do not change in dimension from the original cube, but all other distances are changed. The basic concept is to use the relationship between each view which results in the expressions (3.1), (3.2) and (3.3);

$$X = X_1 \tag{3.1}$$

$$Y = -X_2/\cos(90-\alpha) + X_1 \tan(90-\alpha) \tag{3.2}$$

$$Z = Y_1 = Y_2 \tag{3.3}$$

The X-coordinate and Y-coordinate of each point is used in these expressions to calculate the three dimensional cube as seen in figure 3.3.

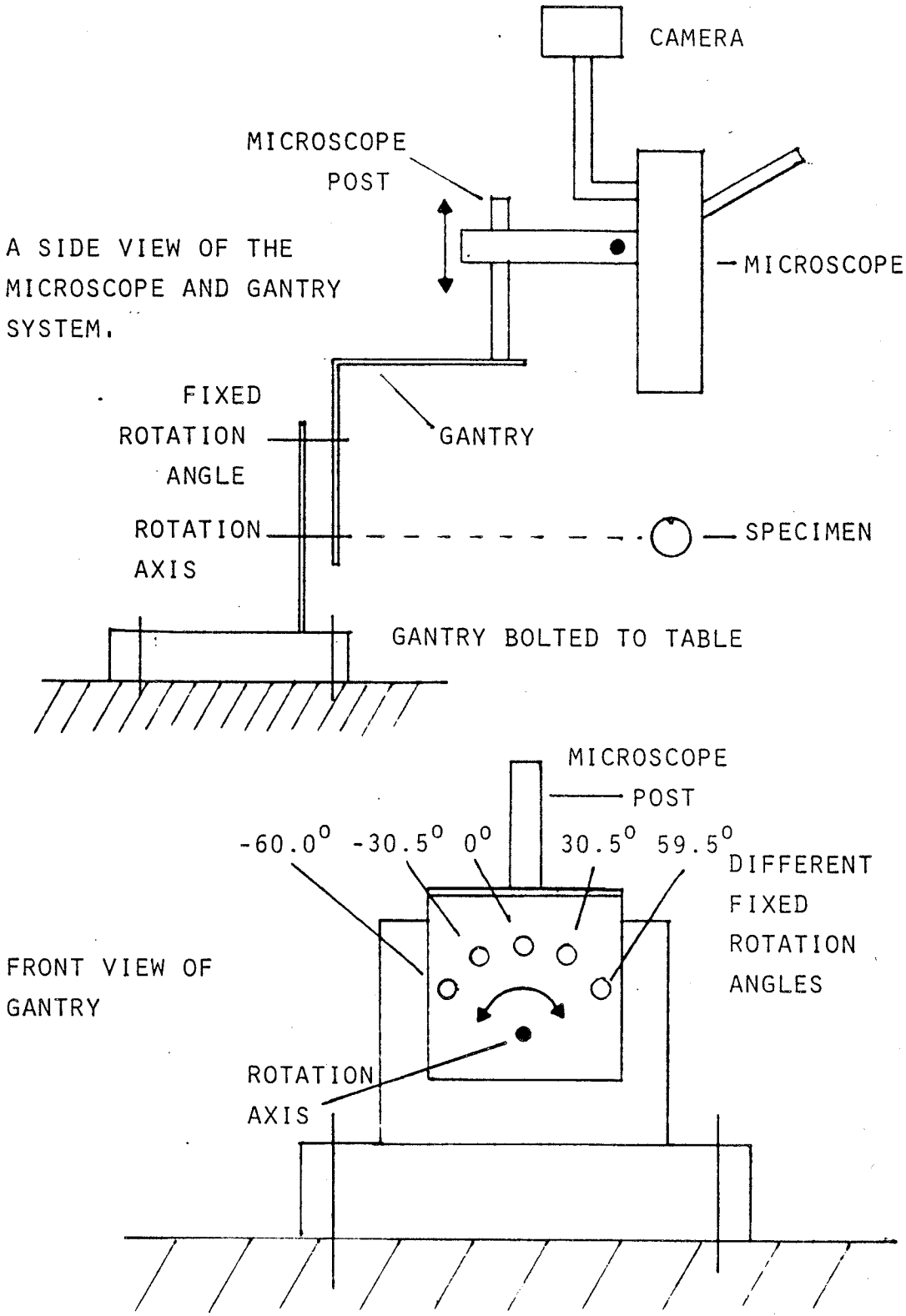

Figure 3.4 Microscope and gantry system.

3.1.2 Application

This section describes the general method of multiplane photography as applied to arterial strain measurement. The procedure of marking the artery and photographing the artery from several views using a rotating microscope and camera are described. Section 3.2, Experimental Model, gives a more detailed description of this process used for each experiment.

A Wild M8 dissecting microscope with a 35 mm. camera attachment was mounted on a rotating gantry (see Appendix I, Equipment). Figure 3.4 shows a block representation of the microscope, camera and gantry system. The specimen is placed within a distance Y from the centre of rotation of the gantry as determined from Table 3.1. If the object is outside of this distance and the microscope is rotated from the initial view, the object will move out of the field of view of the camera and also become out of focus. The gantry can then be rotated throughout -60 to +60 degrees in 30 degree increments from the top position with the specimen in focus. The need for this confined distance for viewing the object is illustrated in figure 3.5. At angles 1 and 2, the field of view, X, does not contain the object of width W.

To measure the strain in the arterial wall of a branch, the artery was placed in the radius of view and several two dimensional photographs of the branch were taken at different angles. The artery was elevated out of the bath

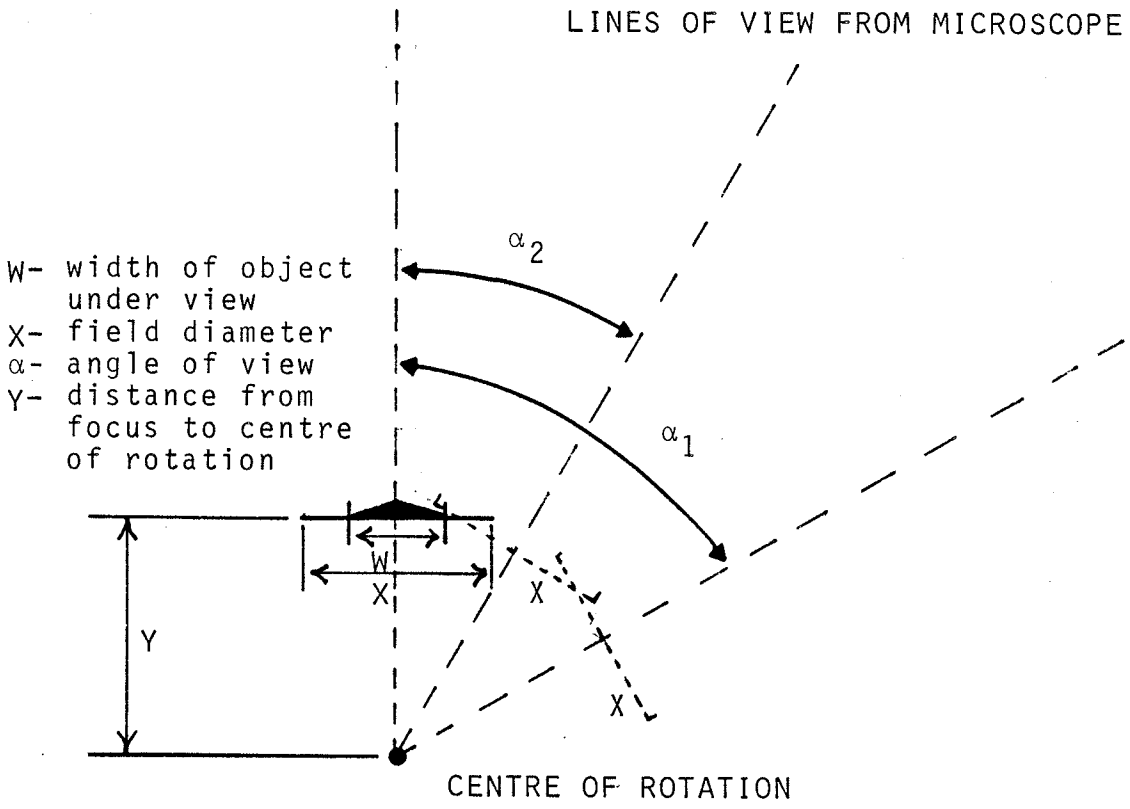

Figure 3.5 Field of view for rotation of microscope.

Magnification	6	12	25	50	angle of view
X	33.8	17.5	8.4	4.2	30^{o}
	32.1	15.8	6.7	2.5	60^{o}
$Y_{max.}$	18.9	9.5	4.3	1.9	

$X/2 = Y\sin\alpha + W/2\cos\alpha$

Table 3.1 Dissecting microscope radius of view. X-width of view, Y- distance from focus to centre of rotation, α- angle of view. For a given magnification, the maximum distance from the centre of rotation to the focus point Y (max.) can be calculated for different angles of view. Calculations were made using W=2. W-width of object. All values in millimetres.

so that the diffraction effect of water was not a factor between the different views. The same procedure was used when photographing the constricted artery. The artery was then lowered back in the bath after the series of photographs were completed.

Reconstruction of the points on the artery in three dimensions requires that each point is present in each two dimensional view. As the arterial wall had no consistent markings that would allow for common points or areas on the artery to be recognized in different plane views, marks on the artery were required. Graphite powder was chosen as the best method of marking the artery (see Appendix C, Marking Arteries). The coordinates of different marks in each plane view were determined so that the three dimensional coordinates of each mark could be calculated. Using this procedure, the points on the artery were used to measure changes in the arterial wall as caused by vasoconstriction, and arterial strain was then calculated (see Chapter 4. Analysis).

3.1.3 Limitations

Two limitations that are inherent in the optics of the measuring system are resolution and distortion. The resolution was measured by photographing a stage micrometer with the microscope and camera system. The microscope and camera system resolved 20 microns at a magnification of 12X which was the magnification used in the study. Points used for strain calculation were approximately 0.5 mm apart (see Chapter 4. Analysis) which implies a noise level of 4% for 10% strain (ie. 10 +/- 4%). However, this is only an approximation to the resolution of the strain analysis, with the deviations of the averaged results indicating the system resolution (see Chapter 5, Results). A more descriptive discussion of determining the system resolution is found in Appendix B, Design Study.

The distortion of the optics was defined as the change in image length of a fixed object length in different locations of the field as viewed through the optic system. The distortion was measured by photographing a 1 mm grid. The negative of the photograph was enlarged to the same magnitude as used when sketching the arterial negatives using a slide projector. The maximum distortion was at the outer edges of the negative, with 2.8% distortion in the vertical direction and 0.13% in the horizontal direction. The distortion was less than 0.13% in both the horizontal and vertical directions in the inner area of the negative.

The inner area of the enlarged negatives were used for strain analysis, so that the effects of distortion on the analysis was insignificant.

Two other limitations of this strain measuring technique are associated directly with the artery. The first is tissue marking. A study of different marking techniques was initiated to determine the most effective means of marking the arteries (see Appendix C, Marking Arteries). The technique that was accepted for use, graphite powder, will not cause any damage to the tissue. As well, this technique resulted in good adhesion to the tissue. Therefore, the procedure of marking the artery was not considered to be a significant limitation in the study.

The second problem with using photography is with removing the artery from the bath for each series of pictures. The tissue is kept alive and responsive by both perfusion and the bath. Removal of the tissue from the bath reduces the reaction of the tissue to stimulation and shortens the time that the tissue can be kept alive. Supramaximal contractions of the artery were not required for this study, for any amount of contraction was sufficient for measuring the strain that was caused by that contraction. The process of measuring arterial strain was not long, only a few hours. The reduction of life time of the tissue was not expected to be of considerable consequence, only limiting the amount of information obtained from each experiment.

Removal of the tissue from the bath might also cause the tissue to dry out, especially when under the light required for photography. To help with this respect, the artery was not completly removed from the bath for photographing. With the bottom of the artery still in water, the effect of water surface tension kept the artery moist. This thin layer of water does not cause significant refraction affects and consequently did not distort the photographs of the artery.

Simultaneous multiple two dimensional photographs from different angles is not possible when using a single microscope and camera attachment. A problem with time lag and possible changes between two dimensional views therefore exists. The microscope was rotated with the gantry throughout the angles desired for each two dimensional photograph. Rotating the system like this between plane views causes a time lag between each view. The time required for rotating and photographing each plane view was calculated in the design study of Appendix B, and was approximately forty-five seconds.

The effect of a time lag between views would not be a factor with photographs of the artery in the resting state, as the artery was not in motion. However, when the artery had been stimulated to contract, the artery's geometry may change between each two dimensional photograph. This required that the artery be stimulated for long periods

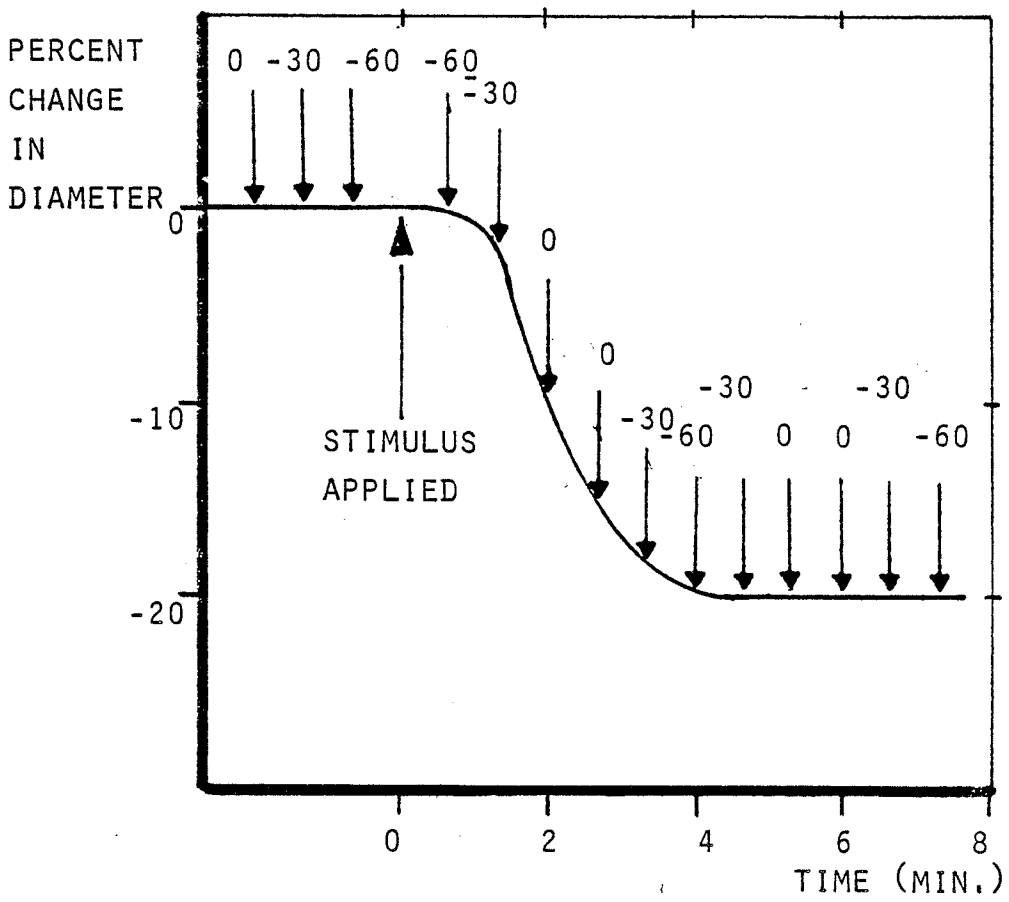

Figure 3.6 Simulated data, arterial diameter as a function of time. The arrows indicate the time of a photograph. Only the photographs taken when the diameter is constant are used for reconstruction and strain analysis

of time so that the artery would be in a stable constricted state for each series of two dimensional photographs. As well, a continuous series of different angle plane photographs was made to ensure that at least one series of different plane views of a stably constricted artery would be obtained. Figure 3.6 illustrates this concept of photographing the artery during the process of contraction.

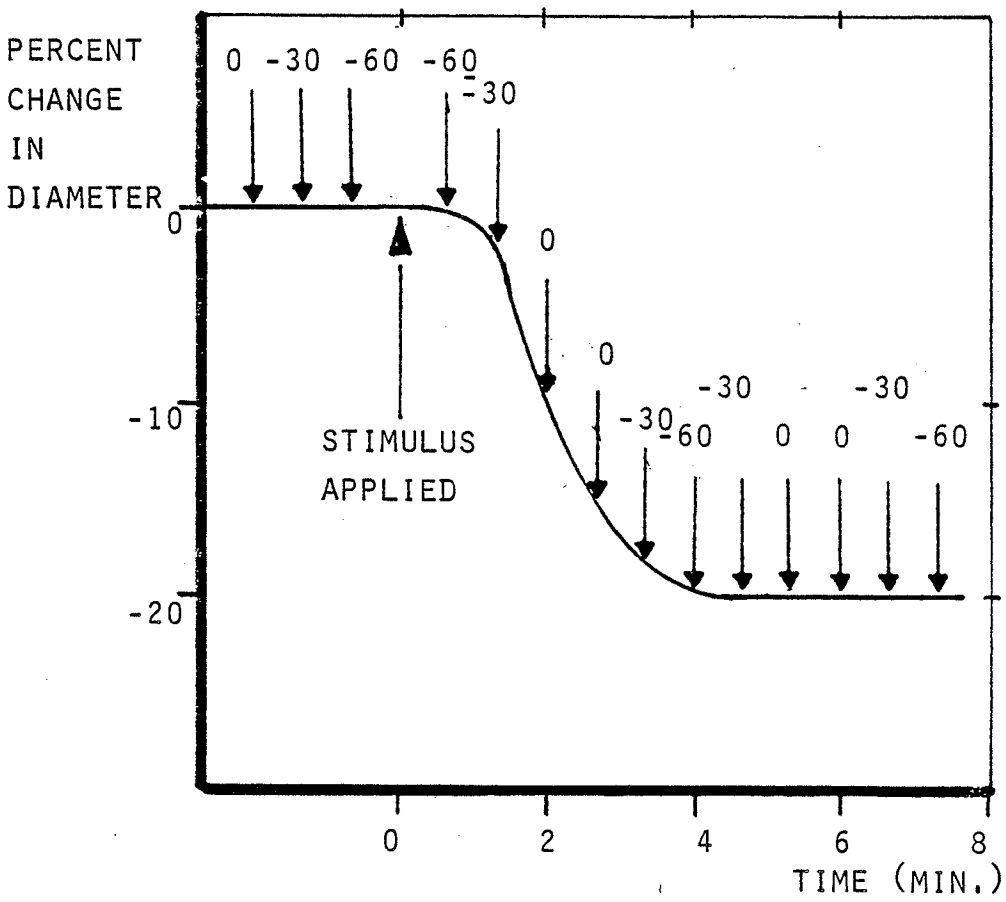

Figure 3.6 Simulated data, arterial diameter as a function of time. The arrows indicate the time of a photograph. Only the photographs taken when the diameter is constant are used for reconstruction and strain analysis

3.2 EXPERIMENTAL MODEL

This section explains the experimental procedures used in measuring strain as caused by vasoconstriction in the "in vitro" tissue model. Prior to these experiments, a tissue study was completed which determined the tissue that was to be used, and to perfect the tech- niques required for the final study (see Appendix D, Tissue Preparation Study).

The first section, Tissue Preparation and Incubation, describes the techniques used in obtaining and handling the tissue preparations. The second section, Photography, covers the procedure of photographing the arteries during the experiment. The third section, Vaso- constriction, describes the method of stimulating the artery.

The experimental procedure was long and complex. To reduce the possiblity of error occurring and to ensure consistency between each experiment, an experimental protocol was established which outlined the working format of each experiment (see Appendix E, Experimental Protocol).

3.2.1 Tissue Preparation and Incubation

Small dogs ranging in weight from 6-9 kg were anesthetized intravenously with 30 mg/kg of sodium pentobarbital and sacrificed with an intracoronary injection of potassium chloride. The left kidney of the animal was removed, with the renal artery cut at the branch of the renal artery from the abdominal aorta. The kidney, with attached renal artery, was placed into 250 ml. of cooled physiologic saline solution (approximately 5 degrees celsius) which had been bubbled with 95% oxygen and 5% carbon dioxide for 5 minutes. The physiologic saline solution consisted of NaCl, 115 mM.; NaHCO3, 25mM.; NaH2PO4, 1.38mM.; KCl, 2.51mM.; MgSO4, 2.46mM.; CaCl2, 191mM.; Dextrose, 5.55mM [Lockwood, 1960].

The tissue was transported to the experimental laboratory and the renal artery with the first few major branches into the kidney were dissected from within the renal pelvis. The artery was flushed with the transport solution to remove any blood from within the arterial lumen and placed in the artery bath. The bath solution consisted of a physiologic saline solution with the same constituents as used for the tissue transport. The bath solution was maintained at 37 degrees celsius and was continually bubbled with 95% oxygen and 5% carbon dioxide.

After the tissue was placed in the bath, the artery was cannulated at the parent artery of the renal artery and

at an arbitrary daughter artery after the first major branch. The first cannula was connected to a perfusate system which contained similar physiologic saline solution as with the bath. The perfusate was warmed to 37 degrees celsius and bubbled continuously with 95% oxygen and 5% carbon dioxide. The second cannula was connected to a discharge line. The artery was perfused at a pressure of approximately 160 cm. of water and a small flow through the artery of approximately 4 ml/min. was established. This procedure of obtaining the tissue and perfusing the artery took approximately one hour. The tissue was kept in solution, either the transport solution or bath solution, during the entire process.

Upon the successful completion of perfusing the artery, the artery was allowed to incubate in the bath for approximately one hour. During the incubation time, small branches of the arterial segment were tied off so that there would be as few leaks as possible in the artery. As well, extraneous perivascular tissue and loose adventitia were dissected from the artery.

3.2.2 Photography

The camera attached to the microscope was loaded with Kodak, Tri-Pan-X, black and white film with thirty-six exposures. The film was advanced to the first picture and the shutter speed of the camera was set to one quarter of a second, aperture set fully open (see Appendix J, Equipment).

The microscope gantry was set in the vertical position (zero degrees). The microscope focus was set so that the specimen would be in focus at the point of rotation of the gantry. This was so that the specimen would be in view and focus throughout the rotation of the gantry.

After the incubation time, the artery was removed from the bath and graphite powder was sprayed lightly onto the arterial branch. A procedure of washing the graphite and respraying was completed to ensure that the graphite was securely fixed to the artery (see Appendix C, Marking Arteries). A qualitative examination of the arterial branch using the microscope determined if the marks were suitable for the study. If the marks did not seem suitable, the marking process was repeated.

Two final procedures were completed prior to the first series of plane photographs of the artery in the resting state. In the first, the microscope was rotated through the angles that were to be used for the different plane views. This procedure was a final check to ensure that the specimen was in view and in focus for the different

angles that were to be used. The second procedure stopped the flow of perfusate through the artery by closing the discharge line of the perfusion system. This was to maintain constant pressure in the artery during the photographing procedures.

The first photograph of the arterial branch in the resting state was taken with the microscope in the vertical position (0 degrees) and then photographed from -30 degrees and -60 degrees. After the resting state photographs were completed, the artery was stimulated to contract and the process of photographing the artery from consecutive angles was initiated. Photographs were taken approximately every 30 to 45 seconds for 8 minutes.

The complete procedure of photographing the artery from the resting state to the completion of constricted state took approximately 10 minutes. The artery was out of the bath for this period of time and then placed into the bath after completion of the photographs. A flow of approximately 4 ml/min of perfusate through the artery was re-established. The artery was allowed to rest for approximately 30 minutes after each experiment trial.

After the experiment had been completed, each roll of film was double exposed to lines which were parallel to the axis of rotation of the gantry. This procedure ensured the proper orientation of the sides when digitizing the marks of the artery.

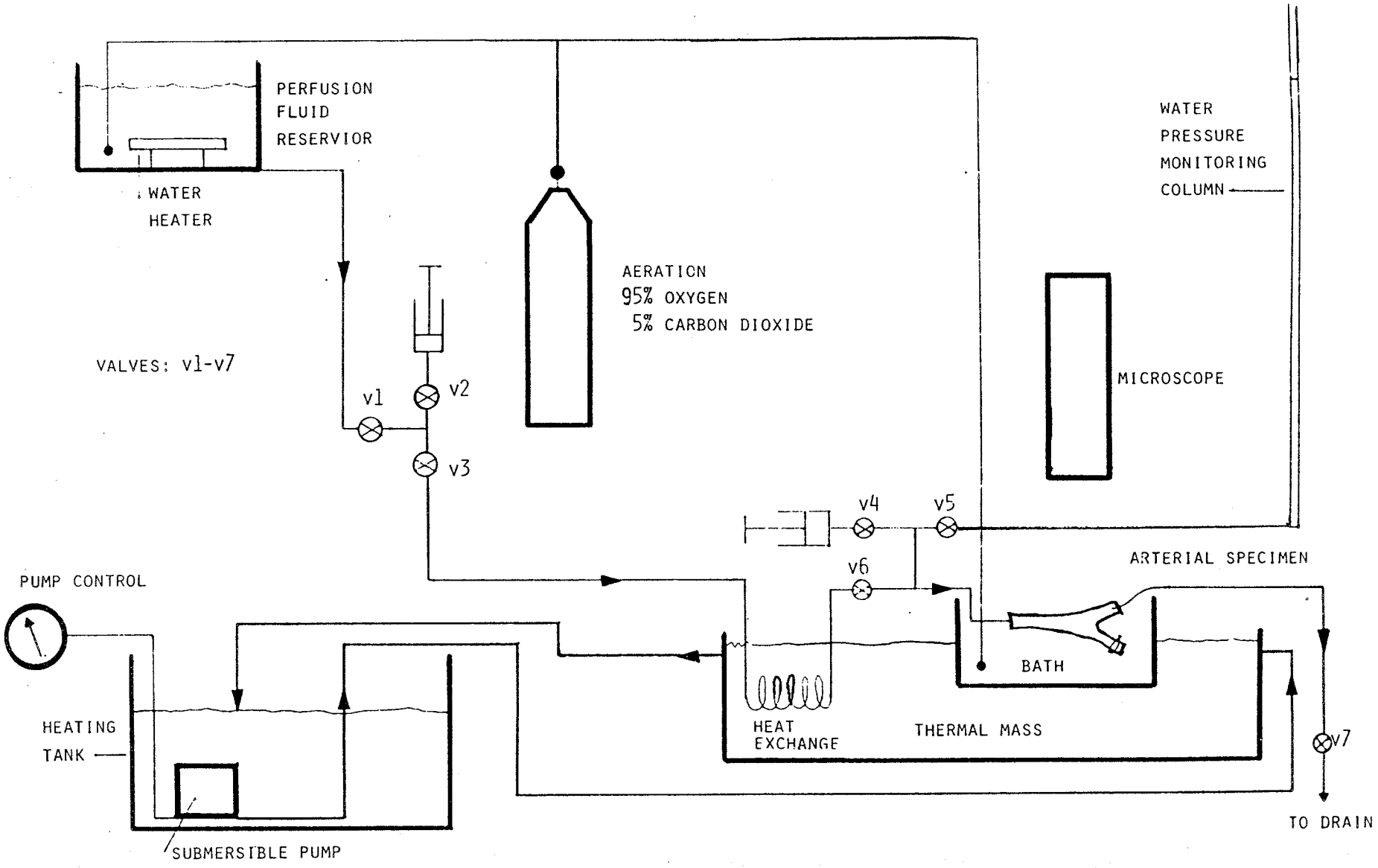

FIGURE 3.7 ARTERIAL PERFUSION AND BATH SYSTEM

3.2.3 Vasoconstriction

The arteries used in this study were stimulated using norepinephrine and dopamine hydrochloride (see Appendix D, Tissue Preparation Study). The appropriate concentrations of the chemical was mixed using deionized water. The chemical mixture was injected slowly into the perfusion system at the location seen in figure 3.7. The discharge line of the perfusion system was opened slightly and the chemical flowed into the arterial segment. Food colouring had been added to the stimulant solution so that the location of the chemical could be monitored. The chemical was then positioned within the artery. The discharge line was closed and the artery was monitored photographically.

After each series of photographs of the artery with the chemical stimulant, the chemical was flushed from the artery using the perfusion fluid, and the final series of photographs were taken of the artery relaxing. A timing diagram of the stimulation and photographing procedure is seen in figure 3.8.

After each stimulation period, the artery was replaced into the bath with a flow through the artery of approximately 4 ml/min. A rest period of approximately 30 minutes was used before another stimulation trial was executed.

To ensure that a diametric change in the artery

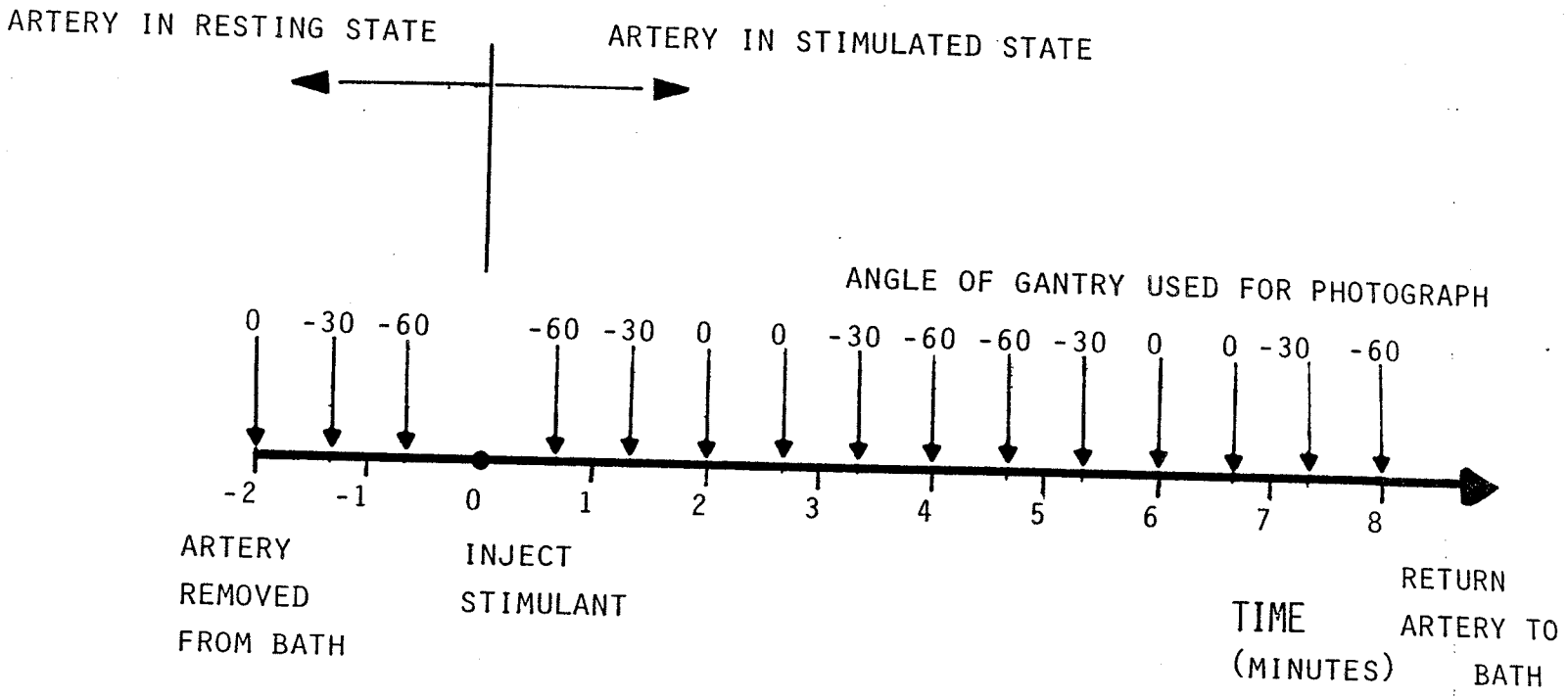

Figure 3.8 Approximate timing diagram of the experimental procedure. Each arrow indicates the approximate time for each photograph taken during the experiment. The exact time for each photograph and time between photographs varies for each experiment.

would be obtained for each experiment, a pressure test was conducted. The pressure test simulated an arterial contraction by lowering the interluminal pressure of the artery 70 mm Hg which caused a reduction in arterial diameter. The procedure of photographing the artery during this test was similar to that used for stimulated vasoconstriction. Three plane views of the artery in the resting state were photographed, the interluminal pressure was reduced, and then the final three photographs of the artery in the reduced pressure state were taken.

3.3 HISTOLOGY

Upon the completion of each experiment, formalin was introduced into the bath and into the perfusate of the artery. The formalin was used to fix the tissue while in a physiolgic state. The arterial branch was prepared for histological sectionins. The cross section of the three arterial segments, parent, top and bottom branches were prepared for sectionins. Longitudinal serial sections of the branch were also made to determine the arterial wall structure and to find medial gaps if they existed. The cross sectional slides were used to determine arterial wall thickness.

The histological slides of the longitudinal sections of the arterial branches did not show medial gaps. The histological sections were badly distorted and contained artifacts such as folds and tears. The wall thickness of each branch of the arteries as well as each parent were calculated using the approximated diameters from the cross-sectional slides. This information is located in table 5.1, Initial geometric condition of the four renal arteries, of Chapter 5, Results.

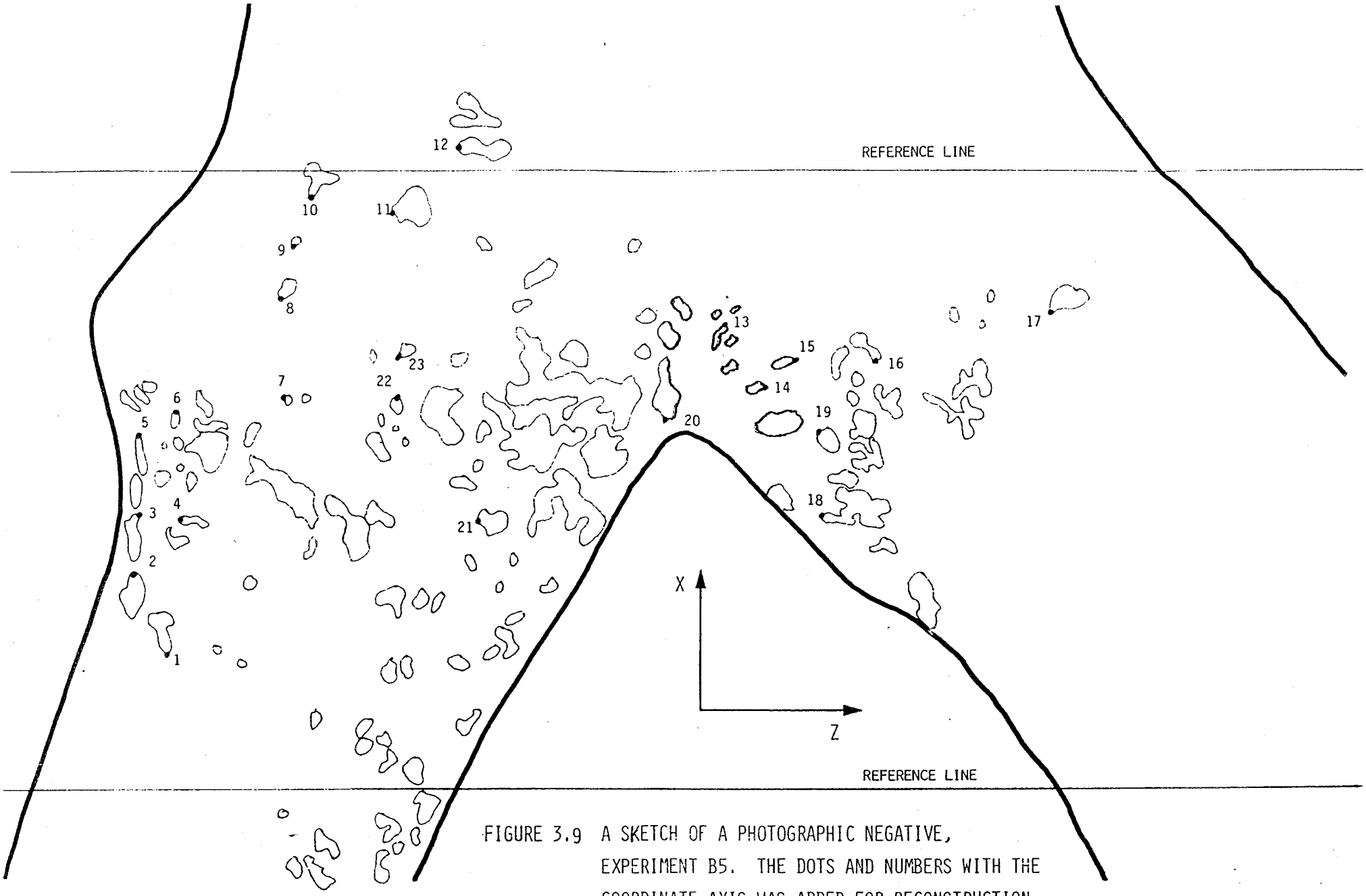

FIGURE 3.9 A SKETCH OF A PHOTOGRAPHIC NEGATIVE, EXPERIMENT B5. THE DOTS AND NUMBERS WITH THE COORDINATE AXIS WAS ADDED FOR RECONSTRUCTION.

3.4 DATA AQUISITION

The negatives of the arterial photographs were mounted into glass slide frames. A contact sheet of the negatives was used to determine the appropriate series of slides to use for data acqusition. The chosen slides were projected onto a flat wall using a kodak slide projector. The slides were enlarged to approximately 35 cm by 25 cm., a magnification of approximately 10. The total magnification of each artery of the slides was approximately 100.

The artery and marks of the artery of the projected slides were traced onto paper. As well, the reference lines and reference wire used for orientation of the slide and magnification calculations respectively were also traced onto the sketched artery. A separate trace was made of each series of slides that were to be used for analysis. The corresponding angle of photography of each slide was noted on each trace.

The traced slides were taken to a computerized, digitizing tablet. The digitizing system communicated serially with the main computer used for the study (see Appendix F, Serial Communication Link, Data Transmission). The marks on the artery of each plane view of the experiment were digitized, producing two dimensional coordinates of each mark of the artery. Figure 3.9 illustrates a sketch of a negative slide of the artery of experiment B5. The points that were digitized are numbered in the sketch. Information

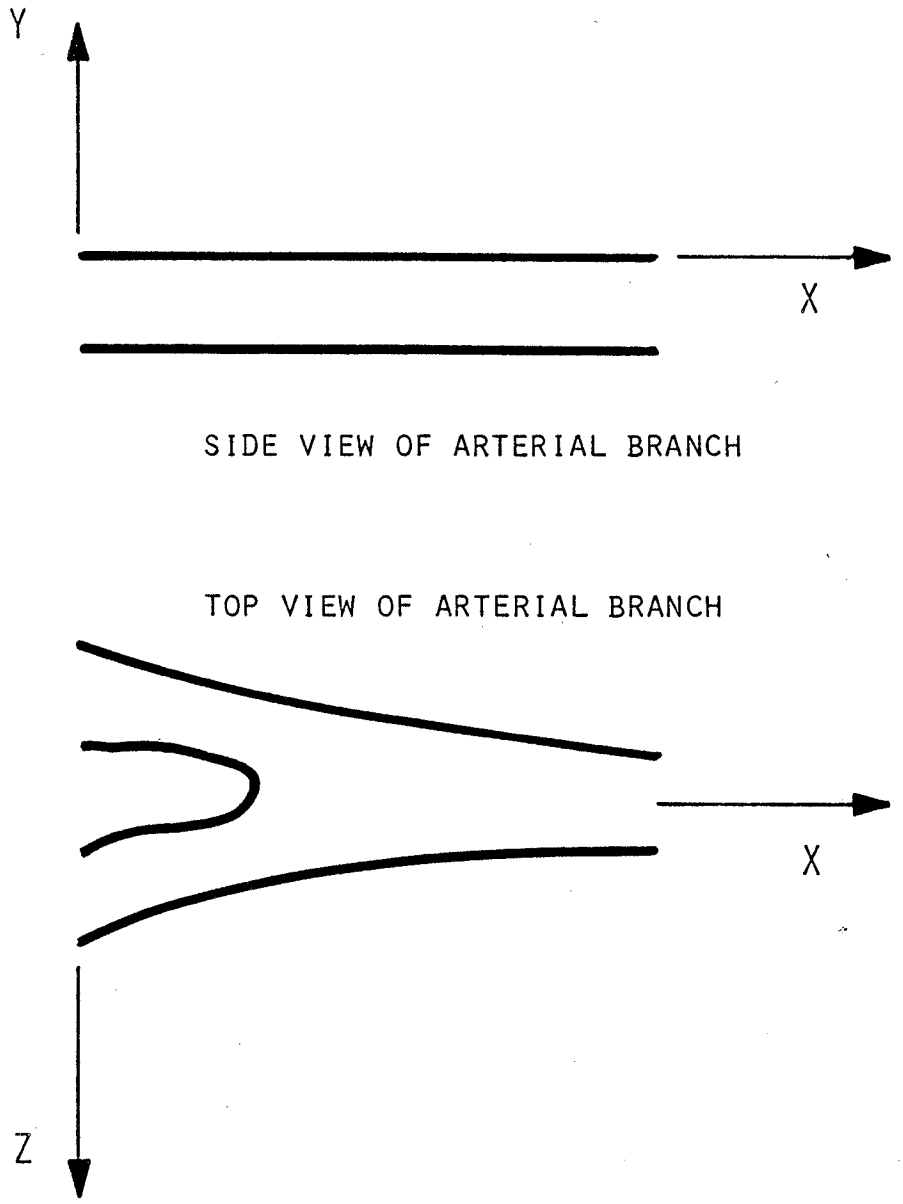

Figure 3.10 Orientation of coordinate system used for the reconstruction of the renal arteries. This is the initial orientation used, and may be translated and rotated. Rotation is in the X-Y plane only.

describing each digitized slide, such as view angle, number of views, number of points (marks) to be digitized, the digitized reference wire size, and the digitized orientation, as well as the digitized points of the artery were recorded on 8.5 inch floppy magnetic disk for permanent storage. Files of the slides were organized such that each series of plane views to be used for three dimensional reconstruction were stored in one file of a specific name.

Reconstruction of the three dimensional coordinates of each series of plane views was completed using the main computer system. An algorithm was written to use the plane views of each file and construct the three dimensional view of that file and store the information in a new file with a corresponding name (see Appendix G, Reconstruction Technique). The resting state series of the artery as well as the constricted state series were reconstructed in this manner. The reconstruction program would also orient the marks of the artery to any coordinate system orientation desired by the user. This cartesian coordinated system was initially referenced as seen in figure 3.10. The resting and constricted views of the artery were oriented similarly. The information of the artery was then ready for strain analysis.

Several testing techniques were conducted to check for errors in the reconstruction and strain analysis programs to ensure correct results (see Appendix I, Error Check for Reconstruction and Strain Calculations).

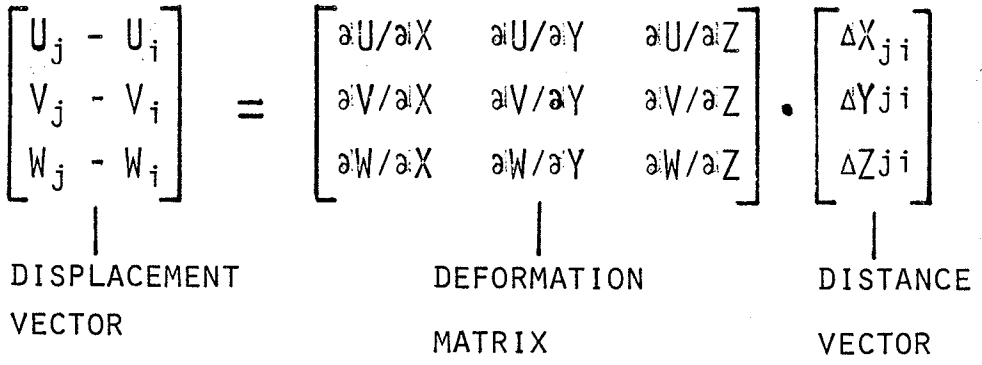

Figure 4.1 Matrix calculation of the deformation matrix. The calculation requires three different displacements, each with components in the x,y, and z directions.

Chapter 4 ANALYSIS

This chapter describes the method of strain analysis. A first order series expansion of deformation is used with the deformation information of the digitized arterial photographs to calculate strain. The average principle strains of each three dimensional plane were computed using different combinations of points for strain analysis within a given area of the artery. This procedure improved the confidence of the results by determining the deviation of each principle strain result within the area of analysis.

Strain analysis was made using a first order approximation to the Taylor series expansion of deformation [Fenton et al, 1978]. A vector Ui in the X axis direction deforms to vector UJ as expressed in equation 4.1. Similar equations for vectors Vi in the Y axis direction and Wi in the Z axis direction are seen in equations 4.2 and 4.3.

$$U_j = U_i + \partial U/\partial X * \Delta X_{ji} + \partial U/\partial Y * \Delta Y_{ji} + \partial U/\partial Z * \Delta Z_{ji} \quad (4.1)$$

$$V_j = V_i \quad \partial V/\partial X * \Delta X_{ji} + \partial V/\partial Y * \Delta Y_{ji} + \partial V/\partial Z * \Delta Z_{ji} \quad (4.2)$$

$$W_j = W_i \quad \partial W/\partial X * \Delta X_{ji} + \partial W/\partial Y * \Delta Y_{ji} + \partial W/\partial Z * \Delta Z_{ji} \quad (4.3)$$

The above equations may be represented in matrix form as seen in figure 4.1. A detailed review of the strain calculation is found in Appendix H, Strain Calculation.

To calculate the three dimensional strain matrix, 3

pairs of points are required. The points are chosen from within a small area on the artery. The deformation matrix is assumed to be constant within this area, and so the area is kept small to reduce the error of this assumption. An arbitrary distance between each pair of points of approximately 0.5 mm was chosen. The distance between points was calculated as approximately one-fifth the parent artery diameter.

As well as calculating the three dimensional strain matrix, two dimensional strain calculations were made in the X-Y plane, the X-Z plane and the Y-Z plane. The principle strains and angle of rotation was calculated for each two dimensional analysis.

Strain calculations were performed for different areas of the arterial branch depending upon the number of points available for analysis from the arterial sketches. As well, different combinations of points were used in each given area so that an average strain in that area could be calculated. This procedure of averaging the principle strain calculations in a given area was used to decrease the significance of an error due to possible random motion of a point or error in reconstruction. The deviation of the averaged results would indicate the significance of the results in a given area. The number of different points used for the average calculation depended upon the number of available points in that area.

A test procedure was conducted to determine if the

```
                                WORKING IN X-Z PLANE
USING POINTS
27-26
27- 8
STRAIN MATRIX
dU/dX  dU/dZ      0.67217E-01 -0.10480E+01
dW/dX  dW/dZ  =   0.22386E-01 -0.32683E-01

PRINCIPLE STRAINS AND ANGLE

EPI =  0.5325E+00     EPII = -0.4980E+00

       THATA P = -0.4222E+02    degrees

STRAIN ANALYSIS USING INITIAL COORDINATE ORIENTATION


                                WORKING IN X-Z PLANE
USING POINTS
27-26
27- 8
STRAIN MATRIX
dU/dX  dU/dZ      0.53264E+00 -0.53558E+00
dW/dX  dW/dZ  =   0.53500E+00 -0.49771E+00

PRINCIPLE STRAINS AND ANGLE

EPI =  0.5326E+00     EPII = -0.4977E+00

       THATA P = -0.1604E-01    degrees


STRAIN ANALYSIS USING DATA ROTATED TO ORIENTATION
OF PRINCIPLE STRAINS OF INITIAL ANALYSIS.
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Figure 4.2 Results of principle strain calculation check. The analysis is from experiment B5, using point numbers 27, 26, and 8. The strain matrix of the second analysis contains the principle strains of the first analysis.

principle strains that were calculated at a principle angle to the original coordinate system were the true principle strains. The initial coordinate orientation used for the strain analysis was rotated throush the angle calculated for the principle strains for one particular combination of points. The principle strains were then calculated using the new rotated files for analysis. The results showed that the new principle strains calculated were orientated with the rotated coordinate system, and were the same as the initially calculated principle strains. Figure 4.2 shows the results of one rotation and check procedure.

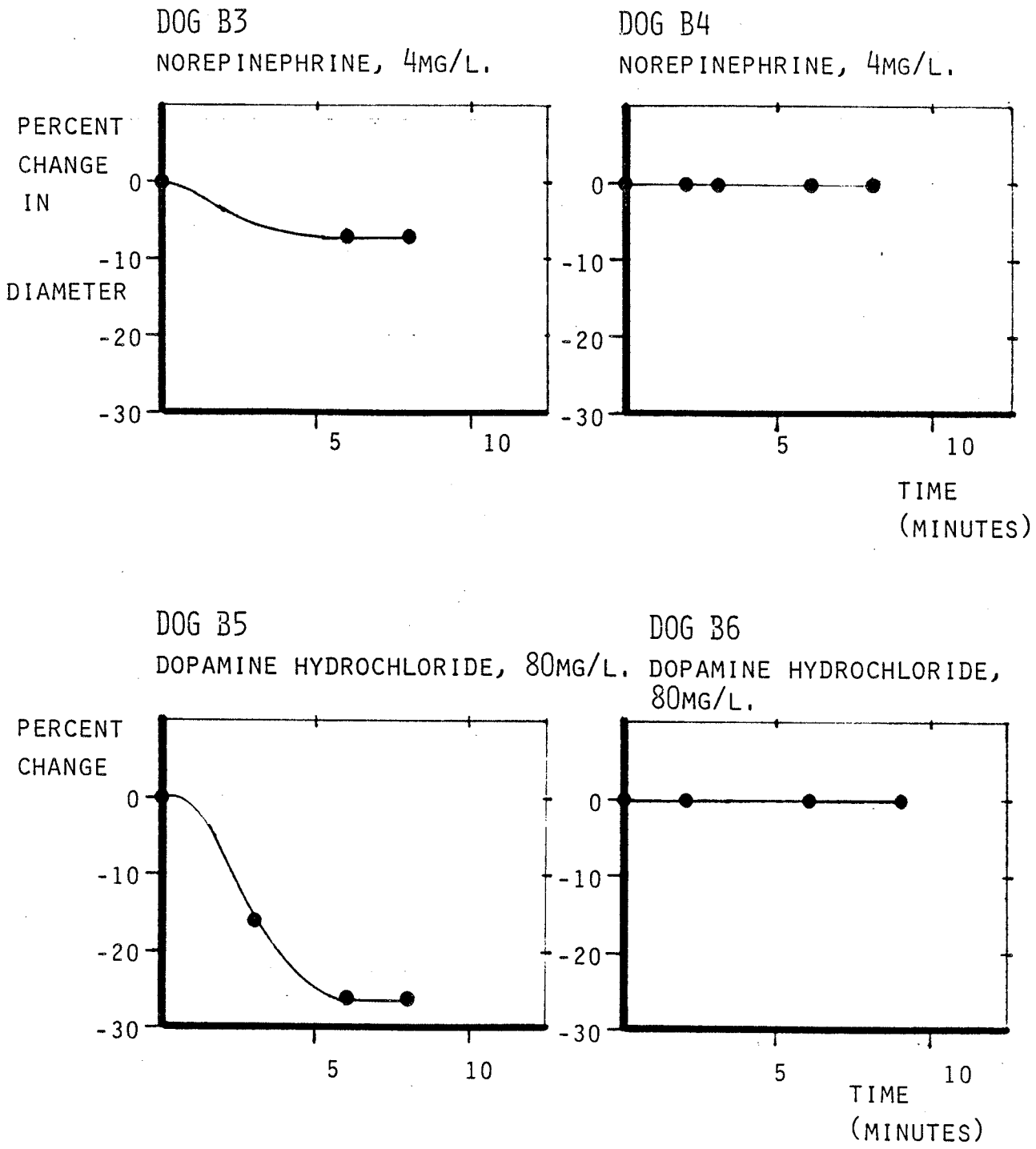


Figure 5.1 Arterial diameter versus time for the four canine renal arteries. The type and concentration of the stimulant used for each artery is noted.

Chapter 5 RESULTS

This chapter presents the results of the strain measurement experiments. Four experiments were conducted; B3, B4, B5, and B6. The initial geometric conditions of each artery used in the study are listed in table 5.1. Two of the four experiments using active constriction had diametric contractions. Figure 5.1 shows the arterial diameter as a function of time for each of the four experiments. The stimulus used in each experiment is noted in the figure. The arteries that did not contract had also been stimulated with twice and three times the stimulant dose as listed with still no diametric contraction. Table 5.2 contains information pertaining to geometric changes in each of the four arteries. The diametric changes given are the maximum change measured within the branch.

Table 5.3 lists the principle strains that were averaged for each different area of the arteries with the standard deviations of these averages. The strain as calculated for given areas within the apex of the arterial branch of experiment B3 was approximatly three times as great in both contraction and elongation as that of the diametric contraction. Biaxial elongation was also measured in one area of this contracting artery. This artery was stimulated with norepinephrine, 4 mg/l. Experiment B4 did not have a diametric contraction and was not analyzed due to unsatisfactory technical quality. This artery was also

stimulated with norepinephrine, 4 mg/l. Experiment B5, the second experiment with a diametric contraction, had strain in both contraction and elongation approximately equal to the diametric contraction. This artery was stimulated with dopamine hydrochloride, 80 mg/l. The final experiment, B6, did not have a diametric contraction when stimulated with dopamine, 80 mg/l. The artery was analyzed and strains in contraction and elongation of approximately 10 percent were calculated.

The reconstructed points of each artery were within a small arc along the surface of the artery in the X-Z plane. Strain results were obtained from analysis in this region only. These plane views of the principle strains were plotted on a sketch of each artery are seen in figures 5.2, 5.3 and 5.4. The principle strains as calculated for the passive constrictions are seen in figures 5.5 to 5.8. Experiments B3 and B6 both had areas in the apex of the branch with biaxial contraction.Table 5.3 lists the averaged principle strains with variance for passive constriction of all four arteries.

Experiment	Parent artery	Daughter Arteries		Branch Angle
		Top	Bottom	
B3				
D	2.3	1.5	1.4	70
t	0.27	0.22	0.22	
B4				
D	2.7	2.0	2.3	26
t	0.32	0.15	0.16	
B5				
D	3.1	2.0	2.1	50
t	0.49	0.16	0.34	
B6				
D	2.0	1.5	1.5	110
t	0.19	0.19	0.16	
Average				
D	2.5 +/- 0.5	1.8 +/- 0.3		
t	0.32 +/- 0.13	0.20 +/- 0.06		

Table 5.1

Initial geometric conditions of the four canine renal arteries used in the study. D - diameter in mm, t - wall thickness in mm. The branch angle is the acute angle between the two daughter arteries, given in degrees.

experiment	stimulant	D	A
B3	norepinephrine, 4 mg/l.	-7	-14
	pressure	-14	-20
B4	norepinephrine, 4 mg/l.	0	0
	pressure	-15	-120
B5	dopamine, 80 mg/l.	-26	8
	pressure	-13	37
B6	dopamine, 80 mg/l.	0	0
	pressure	-25	-9

Table 5.2

Geometric changes in canine renal arteries using different stimulants. D- percent change in diameter referenced to the initial diameter. A - percent change in the angle of the branch referenced to the initial angle. Pressure - a decrease in interluminal pressure of approximately 70 mm Hg. (passive constriction). Dopamine - dopamine hydrochloride.

Experiment	Ep1 +/- S.D.	Ep2 +/- S.D.	Op +/- S.D.
B3			
area 1 n = 4	22 +/- 3	-21 +/- 2	36 +/- 2
area 2 n = 2	22 +/- 1	6 +/- 1	61 +/- 1
area 3 n = 5	11 +/- 1	1 +/- 2	63 +/- 3
B5			
area 1 n = 5	13 +/- 2	-15 +/- 3	-27 +/- 3
area 2 n = 10	18 +/- 4	-27 +/- 4	-46 +/- 3
B6			
area 1 n = 4	7 +/- 1	-9 +/- 1	-48 +/- 1
area 2 n = 4	11 +/- 1	-11 +/- 1	-47 +/- 1
area 3 n = 5	12 +/- 1	-15 +/- 1	-40 +/- 1

Table 5.3 Principle strains caused by vasoconstriction. The strains are averaged from a number of calculations using different combinations of points (n) on the artery within a similar area. Ep1 - First principle strain, Ep2 - Second principle strain, and Op - angle of principle strains in degrees. S.D.- Standard deviation. Principle strains given in percent.

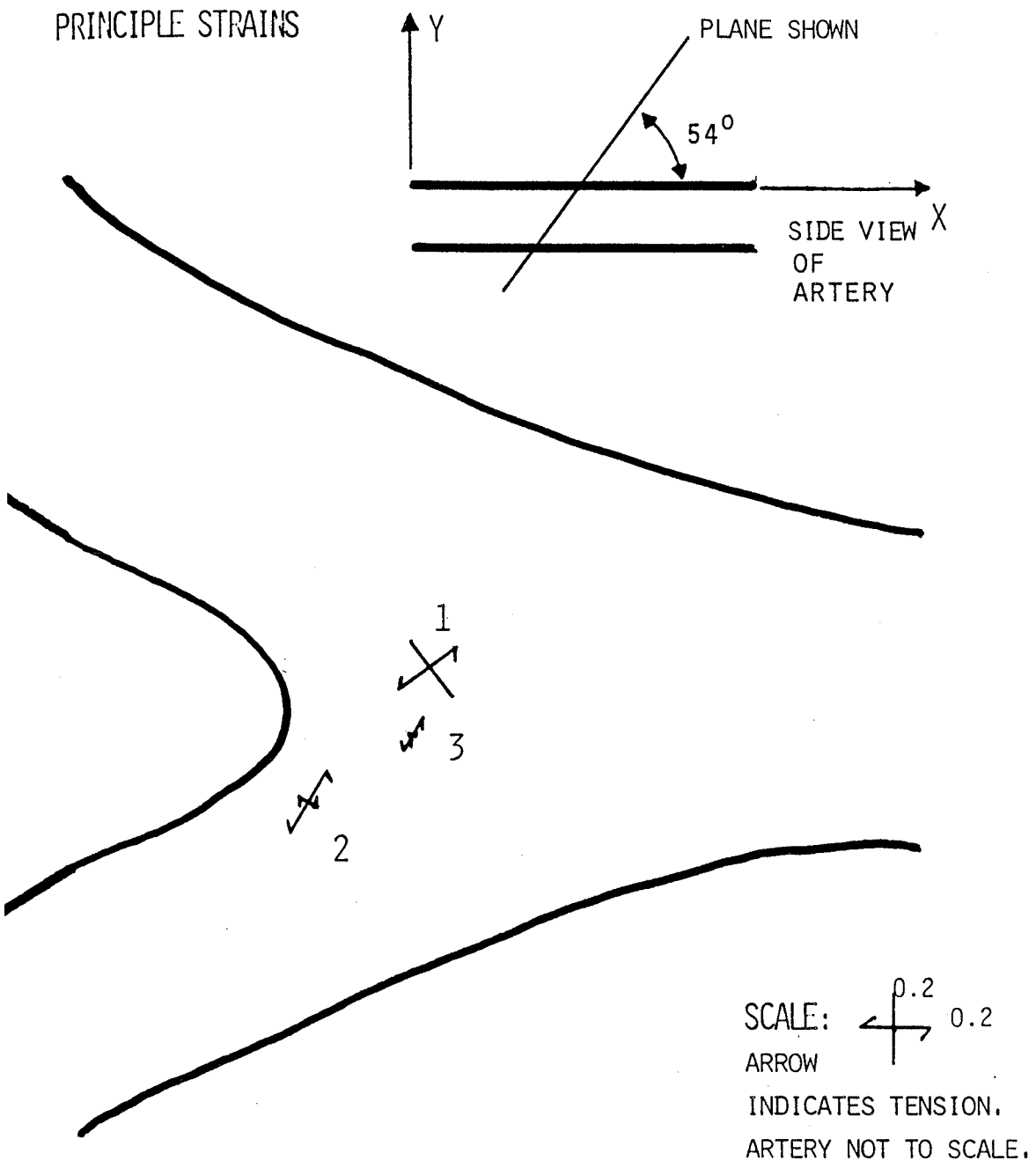


Figure 5.2 Canine renal artery, dog B3. Showing principle strains as caused by vaso-constriction using norepinephrine, 4mg/litre.

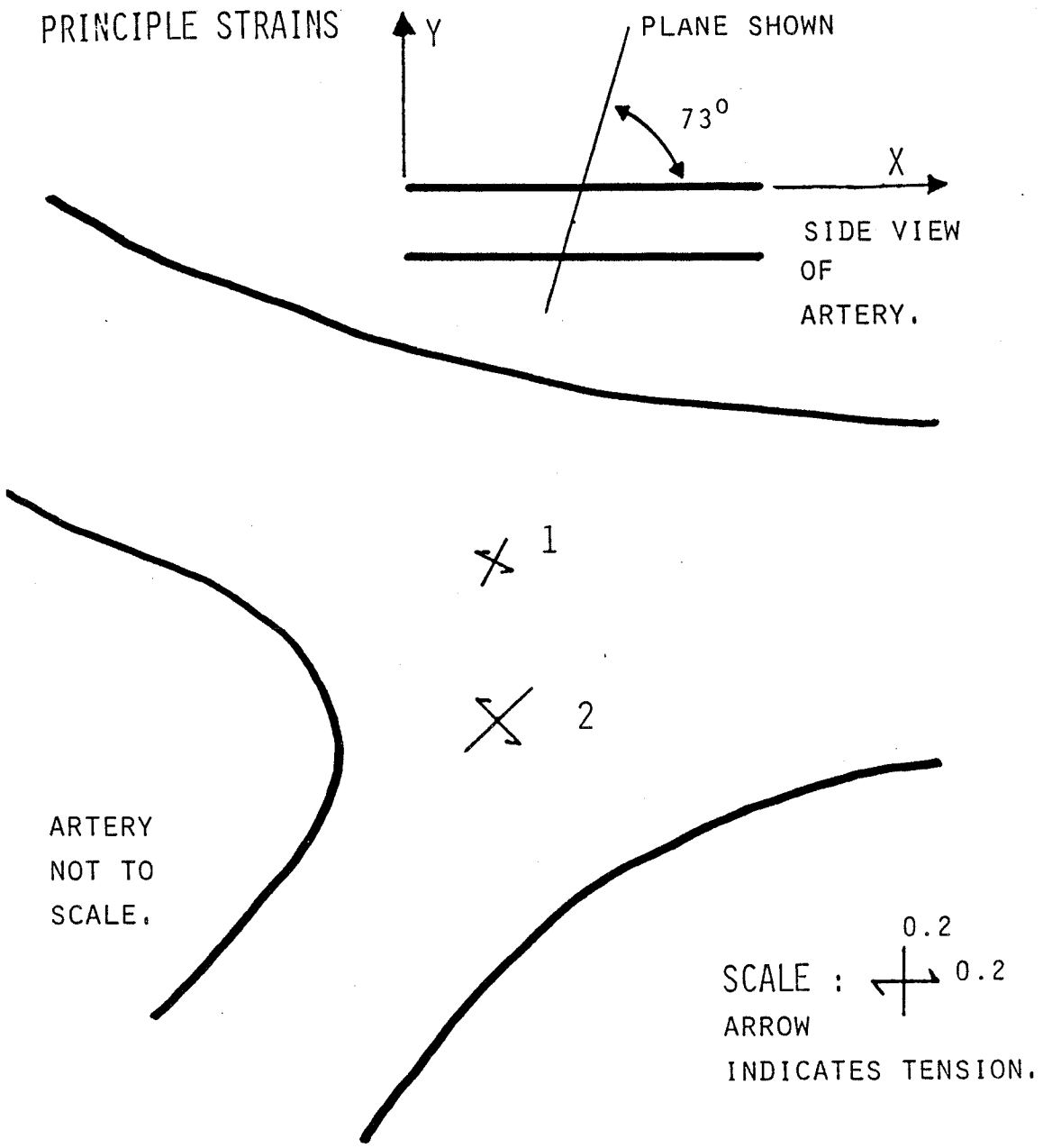


Figure 5.3 Canine renal artery, dog B5. Showing average principle strains as caused by vaso-constriction using dopamine 80mg/litre.

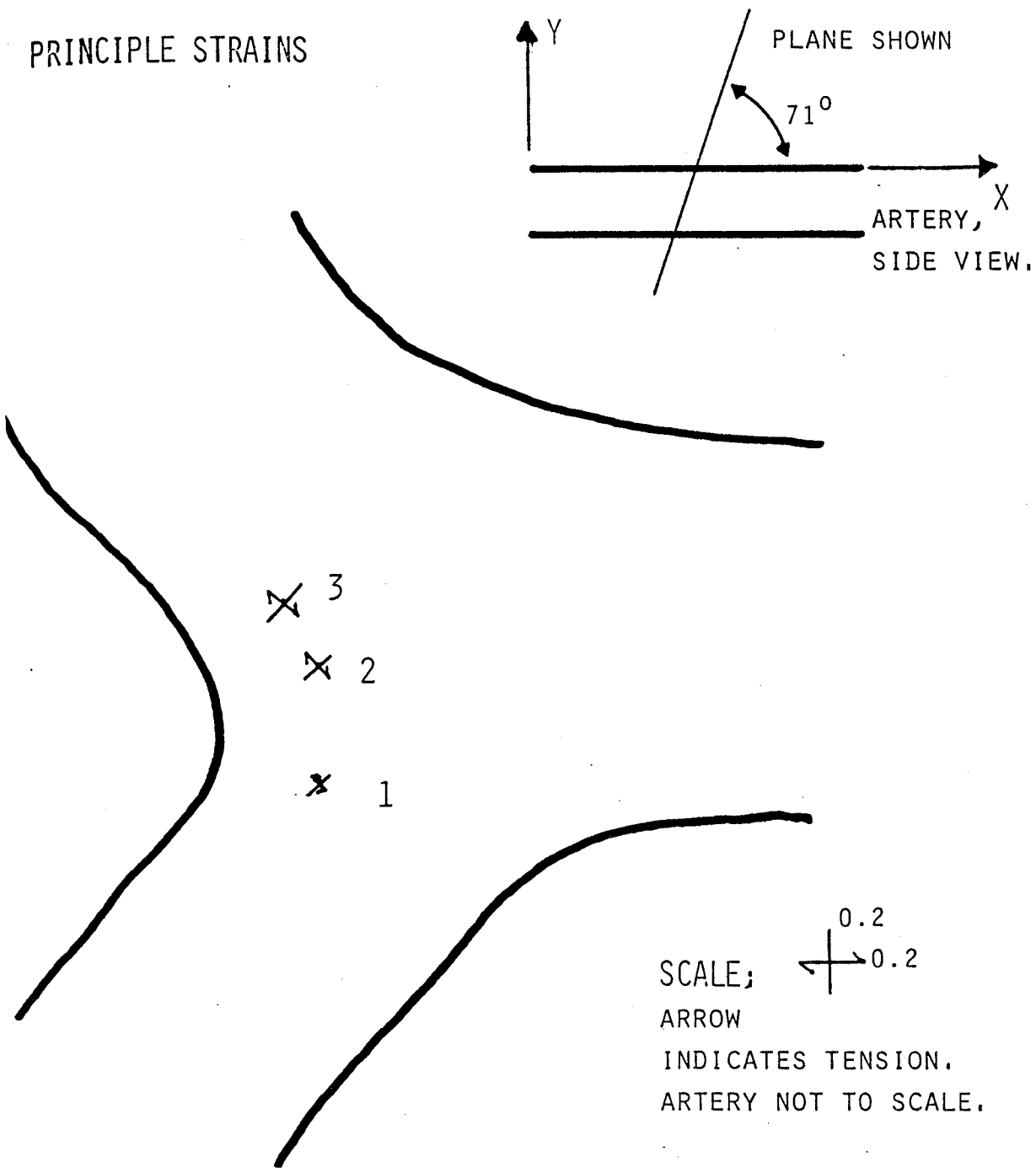


Figure 5.4 Canine renal artery, dog B6. Showing average principle strains. Using dopamine, 80 mg/l., no diametric contraction.

Experiment	Ep1 +/- S.D.	Ep2 +/- S.D.	Op +/- S.D.
B3			
area 1 n = 4	4 +/- 2	-34 +/- 3	85 +/- 4
area 2 n = 2	-2 +/- 1	-33 +/- 1	-22 +/- 1
area 3 n = 3	-1 +/- 2	-43 +/- 1	-36 +/- 2
area 4 n = 2	10 +/- 2	-33 +/- 2	-52 +/- 2
B4			
area 1 n = 2	29 +/- 1	-51 +/- 1	-43 +/- 1
area 2 n = 3	39 +/- 1	-50 +/- 1	-45 +/- 1
area 3 n = 3	37 +/- 1	-57 +/- 3	-45 +/- 1
area 4 n = 5	38 +/- 1	-54 +/- 4	-44 +/- 2
B5			
area 1 n = 4	73 +/- 5	-66 +/- 4	-47 +/- 2
area 2 n = 5	16 +/- 3	-39 +/- 3	-46 +/- 2
B6			
area 1 n = 2	3 +/- 1	-29 +/- 1	60 +/- 1
area 2 n = 2	-5 +/- 1	-23 +/- 1	78 +/- 1
area 3 n = 2	-12 +/- 1	-21 +/- 1	79 +/- 2

Table 5.4 Principle strains caused by passive constriction. The strains are averaged from a number of calculations using different combinations of points (n) on the artery within a similar area. Ep1 - First principle strain, Ep2 - Second principle strain, and Op - angle of principle strains in degrees. S.D.- Standard deviation. The hydrostatic interluminal pressure reduction for the four cases was approximately 70 mm Hg. Principle strains are given in percent.

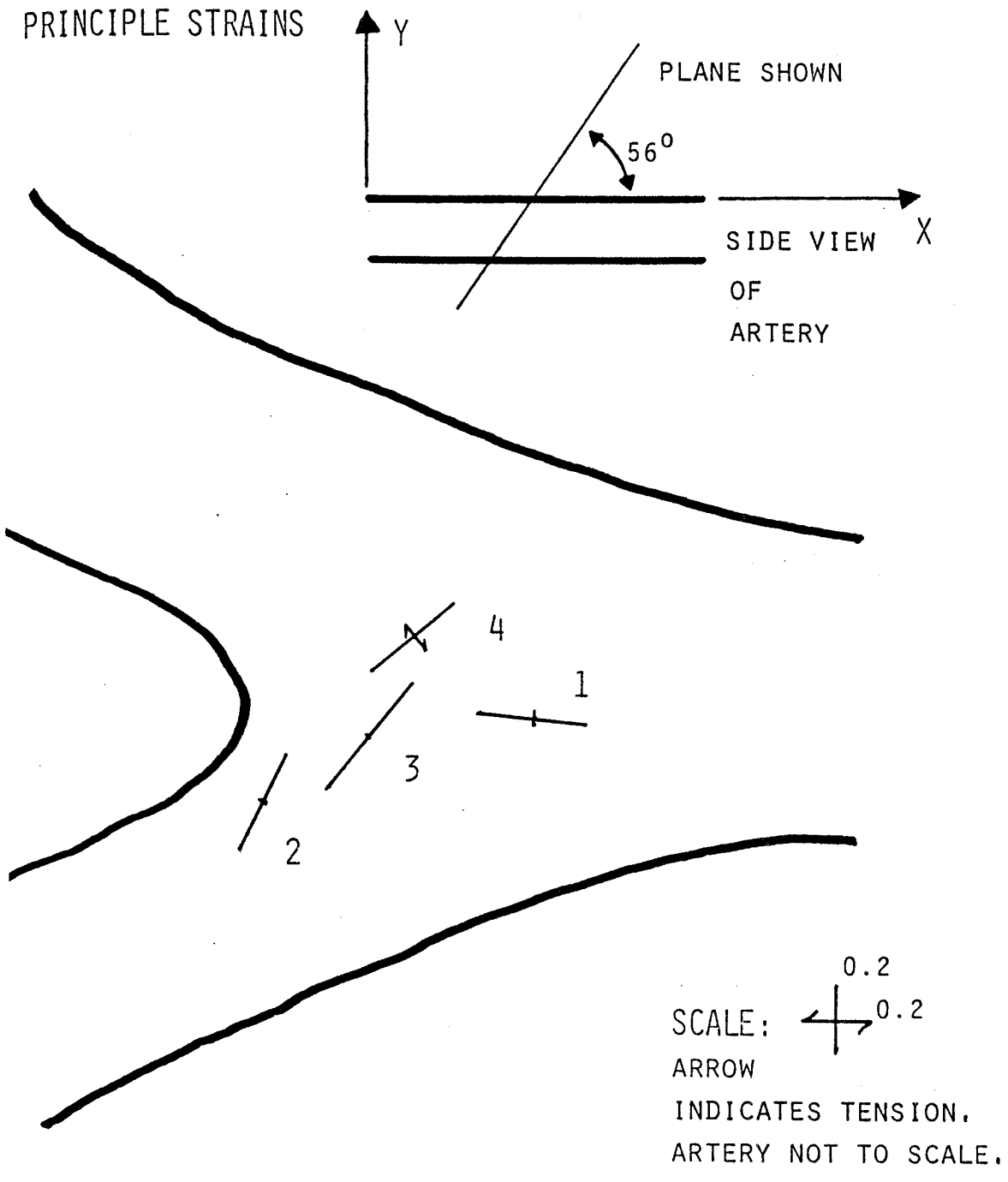


Figure 5.5 Canine renal artery, dog B3, showing average principle strains of passive constriction.

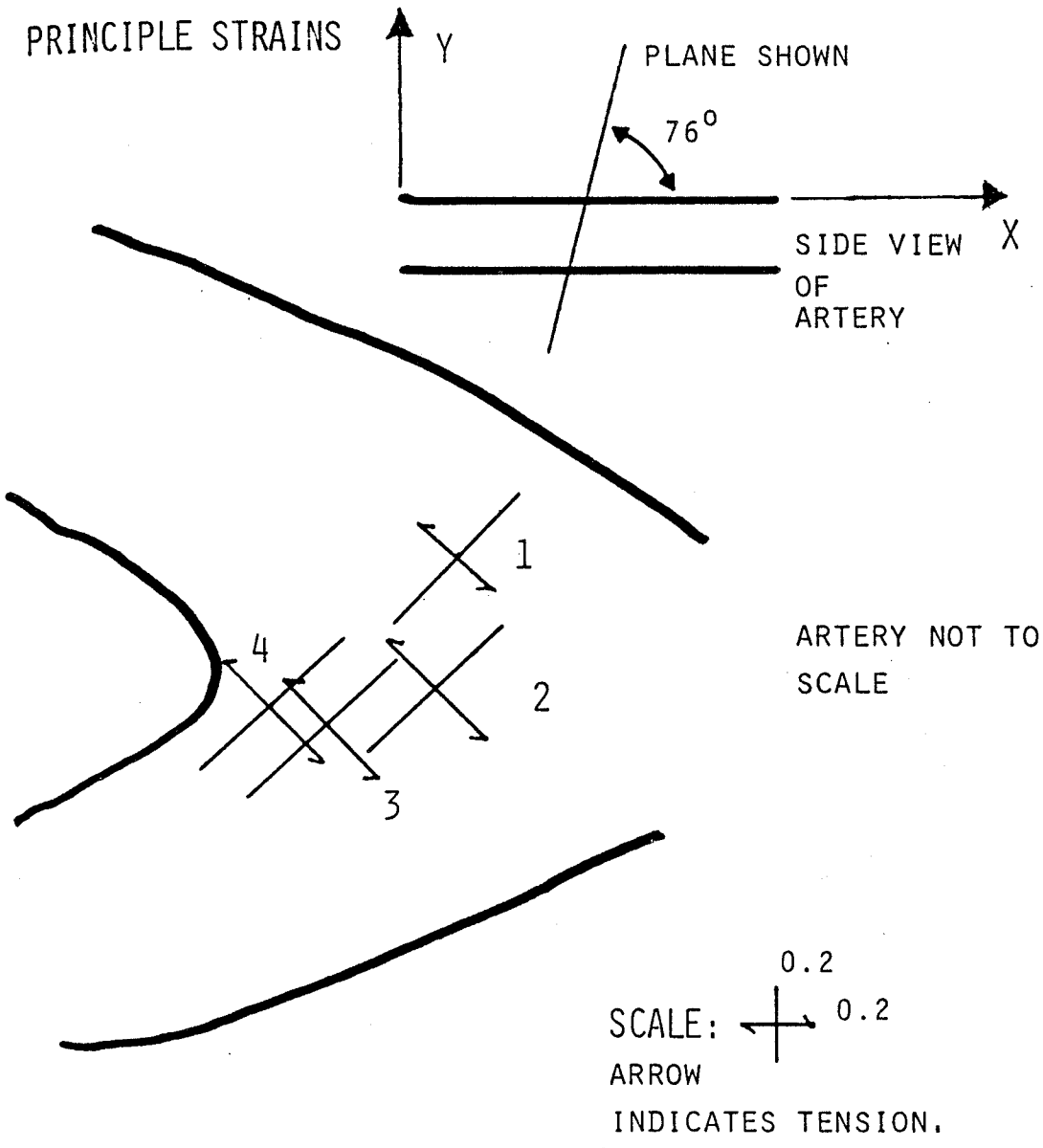


Figure 5.6 Canine renal artery, dog B4, showing average principle strains of passive constriction.

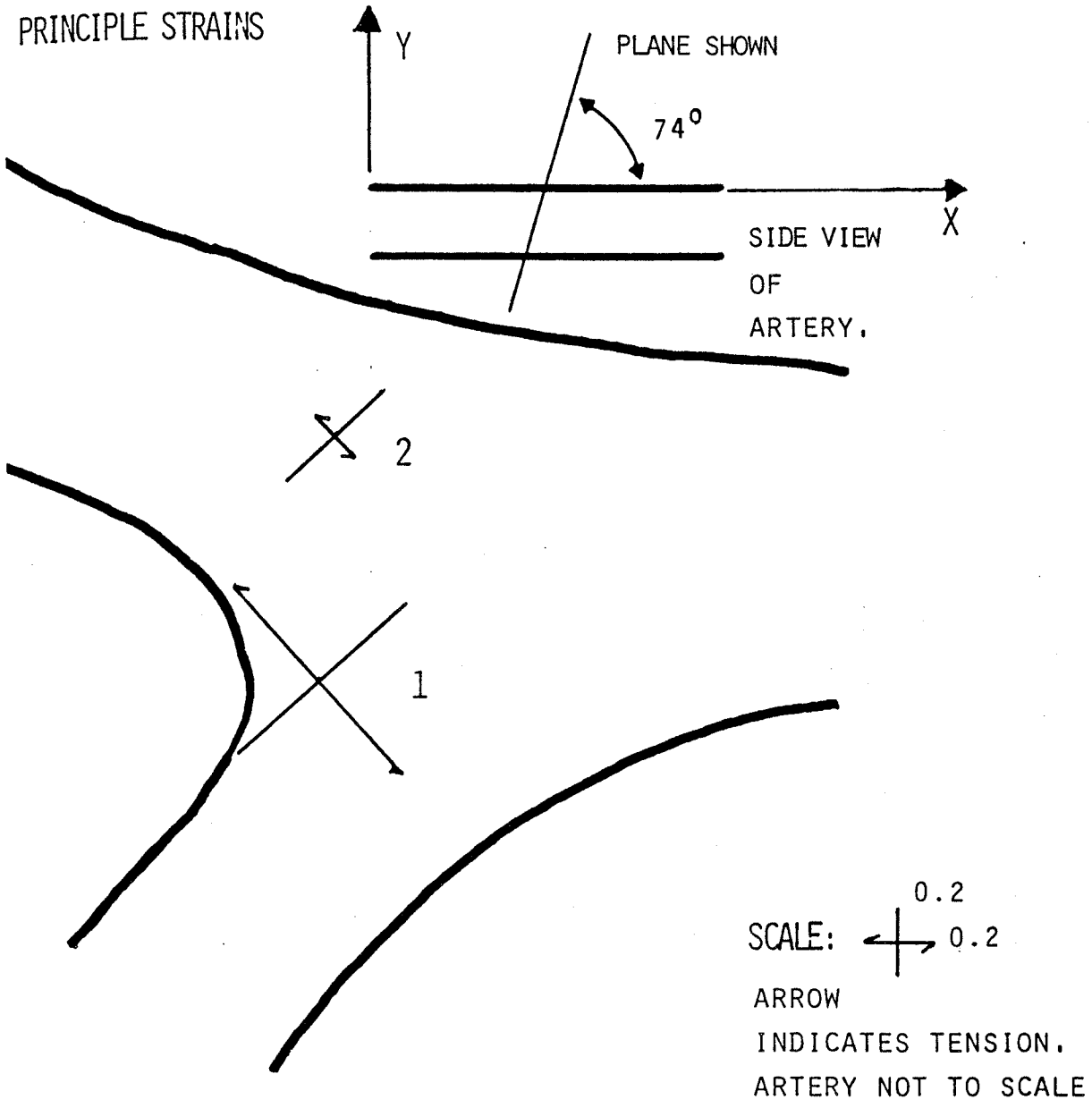


Figure 5.7 Canine renal artery, dog B5. Showing average principle strains of passive contraction.

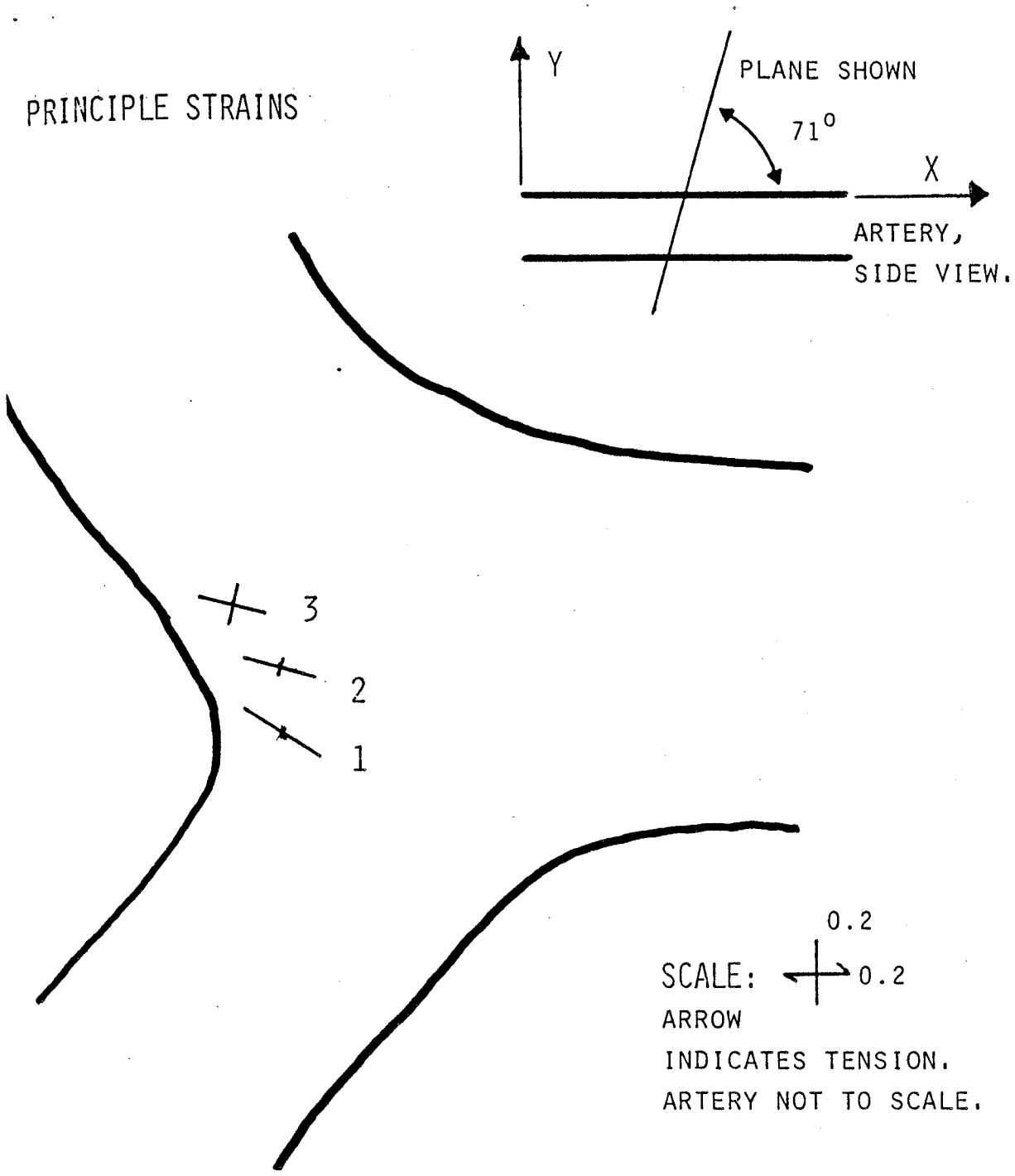


Figure 5.8 Canine renal artery, dog B6. Showing average principle strains of passive constriction.

Chapter 6 DISCUSSION

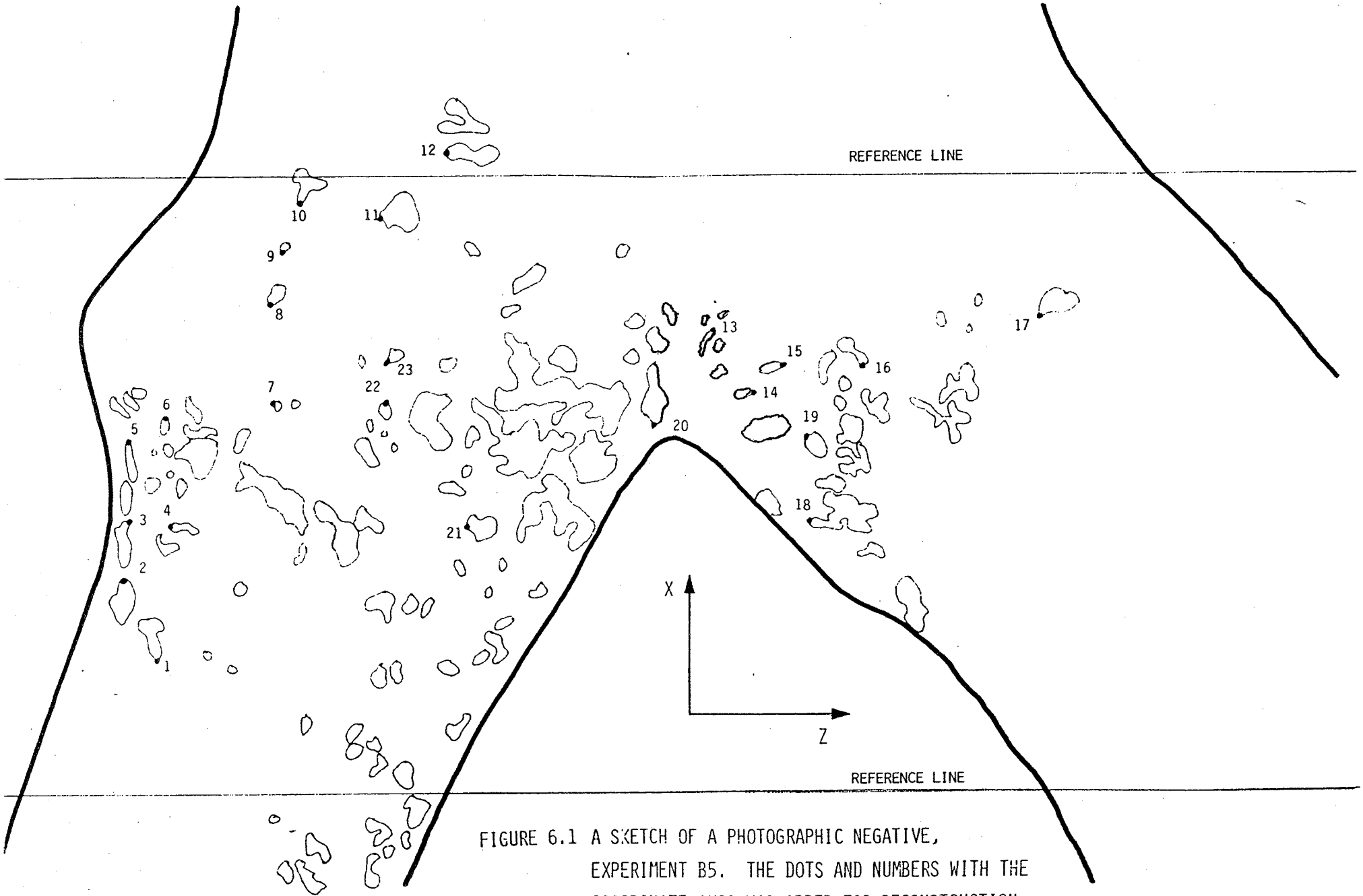


FIGURE 6.1 A SKETCH OF A PHOTOGRAPHIC NEGATIVE, EXPERIMENT B5. THE DOTS AND NUMBERS WITH THE COORDINATE AXIS WAS ADDED FOR RECONSTRUCTION.

INTRODUCTION

This chapter discusses the results of the strain measurement experiments. The first section reviews the error in the strain measurement regarding precision and accuracy as well as suggesting the cause for such errors. The second section investigates the procedures used in the experiments to determine their effect on the results. The final section is a discussion of the implications of the strain results.

6.1 MEASUREMENT ERROR

Error due to limited precision and accuracy is investigated. The accuracy of the strain measurement technique was calculated by testing the resolution of the microscope and photography system. As noted in the discussion of methods, this system could resolve 20 microns. This resolution implies that 10 percent strain as calculated using points a distance of 0.5 mm apart is precise within 4 percent. However, the deviation of the averaged strain results gives a better indication of the error in the results.

The deviation in the strains as calculated for the for the different combinations of points used in an area of the artery can be attributed to several factors. The two major factors are the size and shape of the point that was used for strain analysis, as well as recognizing the points from the different angle views (see figure 6.1). The smaller

the point with very noticeable characteristics the more easily reproduceable is a precise location of the point. As well, a point that has a noticeable shape can easily be recognized in the different views. Not all points used in the study had these characteristics, however, the points with such characteristics were used when possible.

Errors in strain analysis due to the random motion of the points on the artery used for strain analysis was possible. However, averaging the strain results as calculated using a number of different points resulted with small calculated deviations. Random point motion would increase the deviation of the results, reducing the resolution. Consequently, any motion of the points used to mark the artery was within the resolution of the system (less than approximately 20 microns).

The second source of error is the possible addition of several small errors through the reconstruction process. Each view has to be properly oriented with respect to the reference lines, which depends on selected points of the photographed lines. As well, rotation and translation of the points after initial reconstruction to an orientation that is relative to the artery also is a source of error magnification. The standard deviations in the strain results was felt to be the most significant indication of the precision and accuracy of the strain results.

6.2 EFFECT OF EXPERIMENTAL PROCEDURE

The reason for the inconsistency in arterial contraction is unknown. The handling of the tissue from removal to cannulation was consistent for each experiment, as was the bath and perfusate temperature, ph and pressure. The tethering of each artery and the return to 'in situ' length was not precisely conducted for each experiment.

The procedure of tethering the artery may be the reason for the inconsistent response of the arteries to the same stimulus. After cannulation of the arteries, the artery was pressurized with perfusate which caused the artery to stretch in both length and diameter. The artery was then tethered securely to the base on which the artery lay. Returning the arteries to their initial 'in situ' length was not possible. The section of renal artery used was excised from within the renal pelvis and the 'in situ' length could not be measured. The tethered position of each artery was different for each experiment.

6.3 IMPLICATIONS OF RESULTS

Of the three major layers of the arterial wall, the effect of vasoconstriction on the endothelium is the most important to study. As mentioned previously, the endothelium is the critical interface between blood and arterial tissue. The strain as caused by constriction of the artery was measured on the adventitia. The adventitia is described as a loosely bound layer of the arterial wall. When the media contracts, the adventitia may not indicate the extent of the contraction due to the loose interface between the two layers. However, the interface between the endothelium and the media is more rigid than that of the adventitia and media. As a consequence, any strain in the endothelium could be greater than that measured on the adventitia. Consequently, the endothelium may be strained greater than that measured measured on the adventitia, possibly causing microlesions in the endothelium.

The strain results of the study indicate that both tension and compression three times that of diametric contraction may occur in the apical region. Extrapolation of these results would indicate that for much more substantial vasoconstriction or spasm, the apex of the branch may then experience very large strains. For example, an arterial spasm which occludes the artery implies close to 100 percent reduction in arterial diameter. Assuming a linear relationship between the diametric contraction and the strain in the

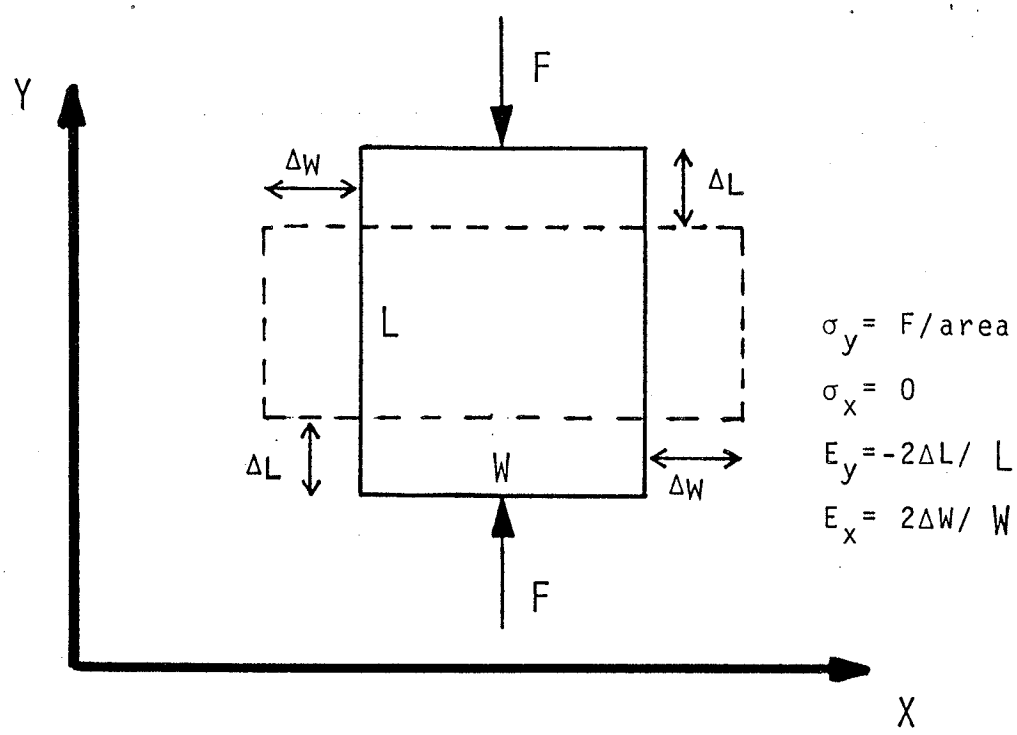


Figure 6.2 Poisson effect, strain without stress. The force in the Y-direction causes stress and strain in the Y-direction but only strain in the X-direction.

$$\begin{bmatrix} \sigma_{p1} \\ \sigma_{p2} \end{bmatrix} = \frac{E}{1 - \upsilon^2} \cdot \begin{bmatrix} 1 & \upsilon \\ \upsilon & 1 \end{bmatrix} \cdot \begin{bmatrix} E_{p1} \\ E_{p2} \end{bmatrix}$$

Figure 6.3 Elastic model, relationship between stress and strain. σ_{p1} and σ_{p2}- principle stresses, E_{p1} and E_{p2}- principle strains. E - elastic modulus, υ- Poisson's ratio. (Fung, 1981; Patel and Vaishnav, 1969)

apex of the branch, strains experienced in the apex may be in the range of 100 to 300 percent. These extrapolated values are intended only to illustrate that vasospasm may cause very large strain in the apex region of an arterial branch.

The angle of the principle strains of the X-Z plane of the two arteries with significant diametric contractions are at approximately forty-five degrees to the longitudinal axis of the parent artery. This orientation may be indicative of the orientation of the smooth muscle cell bundle in that area of the arterial branch. The same principle strain orientation is present in two of the four experiments using the passive constriction (change in interluminal pressure).

The presence of strain does not imply stress in the artery. This Poisson effect is illustrated in figure 6.2. Using the approximate relationship between stress and strain as seen in figure 6.3, the stress in the artery from the average strain of each artery was calculated (see table 6.1). These calculations indicate that a contracting artery may have tension (biaxial in B3) in the apex of the branch.

The branch angle between the daughter arteries changed when the arteries contracted. The effect of this change in angle of the branch on the strain in the apical region is unknown. The changes in angle that were measured were not similar for each experiment. This may be due to physiological factors such as muscle distribution and effect of stimulation. Other factors such as the effect of

tethering of the artery and initial arterial position might be significant in causing this inconsistiency.

The presence of elongation (positive strain) in the artery during passive constriction was not expected. In a passive or relaxed state, the artery would be expected to be in total contraction. Positive strain or elongation in these cases may be as a result of the effect of tethering the artery. The artery is tethered after the artery has been pressurized. The artery is stretched (prestressed) by this process of pressurization and tethering. The release of pressure may then reveal the tension in the artery, especially in the line between the two tethering points. This tension which is initially induced in the artery is then measured when the surrounding area is released of the strain due to pressurization.

Experiment	Sp1	Sp2
B3 area 1	.23	-.20
area 2	.49	.33
area 3	.23	.13
B5 area 1	.11	-.17
area 2	.9	-.36
B6 area 1	.5	-.11
area 2	.11	-.11
area 3	.9	-.18

Table 6.1
Principle stresses calculated from principle strain as caused by vasoconstriction. Sp1, Sp2 - First and second principle stresses, given in units 1000 gmf/cm^2. Calculated using elastic modulus of 1.5 * 10^3 gmf/cm^2 [Funs, 1981], and Poisson ratio of 0.49 [Patel and Vaishnav, 1969].

Chapter 7 CONCLUSION

Notwithstanding the limited number of experiments used in the study as well as the limitations in the data, the method presented in this study was the first to measure the strain in constricted arteries at branch sites. Both elongation and contraction of 1 to 3 times the magnitude of the diametric contraction was found in the constricted arteries. Elongation within a constricted artery may have significant consequences, and is suggestive that vasoconstriction might produce strain which may cause microlesions in the artery.

The comparison between passive constriction (a reduction in interluminal pressure) and active constriction (chemically stimulated vasoconstriction) indicates that passive constriction cannot be used to model vasoconstriction. The use of reactive, living tissue in a contractile "in vitro" model is required.

Chapter 8 RECOMENDATIONS

The general procedure used to measure arterial strain as described within the text should be used for any further study of arterial strain at a branch site. However, tethering the "in vitro" tissue is a significant problem that should be addressed in the tissue model that is to be used. The use of cerebral vessels "in vivo" on the "in vitro" brain would remove the problem of tethering the arteries.

If canine cerebral vessels are used, or any brain with small vessels, micro-manipulators should be used for cannulating and working with the tissue. These manipulators remove the distructive affects of large motion which will then aleviate the problems that were experienced during this study when using small vessels.

APPENDICES

APPENDIX A ARTERIAL ANATOMY AND PHYSIOLOGY

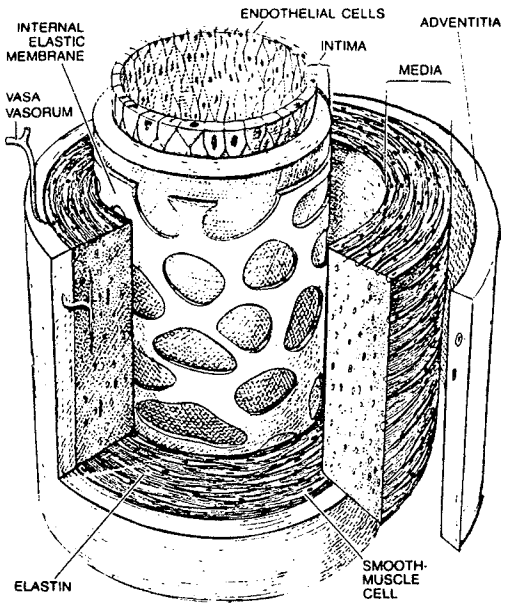


Figure A.1 Arterial Anatomy

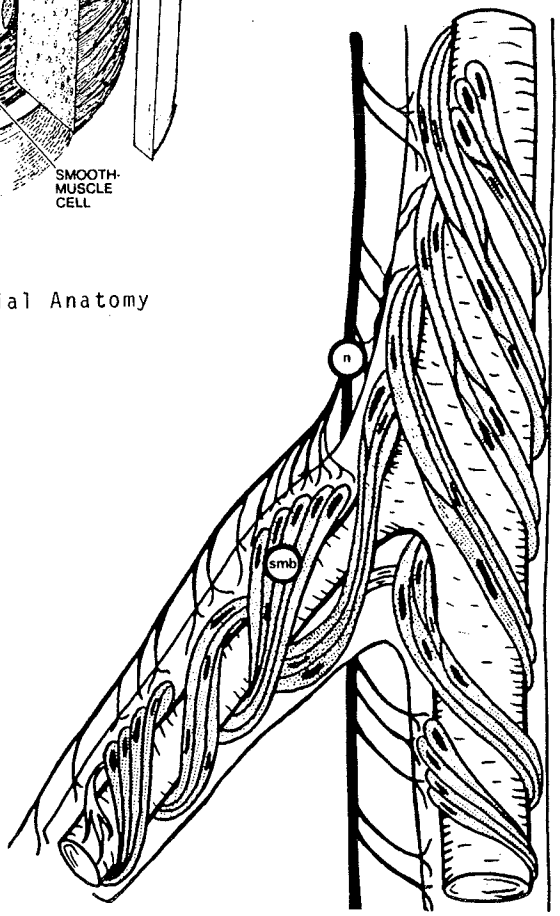


Figure A.2 A sketch of muscle distribution in an arterial branch. smb- smooth muscle bundle, n- nerve.

A.1 ANATOMY

The arterial wall consists of three identifiable layers; the intima, the media, and the adventitia (see figure A.1). The intima has a single cell layer of endothelial cells on an internal elastic lamina. The endothelium is a remarkable interface between the arterial tissue and the blood, with a permeablity that allows the exchange of nutrients and metabolites between the blood and tissue in the inner two-thirds of the arterial wall [Wolf and Wethesen, 1976]. Between the endothelium and the internal elastic lamina is a basement membrane, a thin layer of non-cellular material.

The media, or middle layer, is made of up to 25-40 circular layers of smooth muscle cells which are oriented in a helical fashion about the artery (see figure A.2) [McClintic, 1980]. The muscle cells are interminsled with elastic fibers and small amounts of non-cellular connective tissue.

The adventitia, the outer most layer of the arterial wall, is loosely bound to the artery and consists of elastic and collagen fibrils . Small nerve bundles run alons the outer portion of the adventitia. Vasovasorum, a network of small arteries that supply blood to the outer one-third portion of the artery, is also distributed throughout the adventitia. Smaller arteries do not contain vasa-vasorum and rely on the diffusion of nutrients through the endothelium.

The structure of arteries varies significantly with anatomical location. For example, cerebral arteries have more elastic tissue concentrated in the intima and a thinner media and adventitia with less support from perivascular tissue. The arrangement of the intima of cerebral arteries is believed to offer greater ability to dampen the systolic pulsations. As the cerebral arteries are protected by the skull, there is no need for a thick media and adventitia to protect the artery from external pressures or collapse [Stehbens, 1972].

A.2 PHYSIOLOGY

The function of the arterial system is to supply blood to the tissue of the body. Stimulation of the arterial smooth muscle cells through the autonomic nervous system results in changes in arterial diameter which regulates the flow of blood through the arteries and tissue which it supports.

A generalized model of the innervation of smooth muscle has two important features [Wolf, 1973]. The first is that the effector is not a single muscle cell but a bundle of cells in electrical continuity with each other. The second is that the autonomic nerves run very long distances along the smooth muscle and have varicosites which contain high levels of transmitter substances along the nerve.

There are three different types of smooth muscle cells in this model of vascular smooth muscle [Wolf, 1973]. The first are the directly innervated muscle cells which are directly affected by the transmitter released from the nerve cells. The second type of smooth muscle cell is the coupled cell, adjoining cells which are electrically coupled to the innervated cells through low resistance pathways or nexuses. Junction potentials can be recorded in these pathways and the potentials are slow so that a whole area of an effector bundle becomes depolarized simultaneously. The action potentials of this process then propagates to activate the third type of muscle cell, the indirectly coupled cells.

Vascular smooth muscle is a multi-unit structure made up of spindle shaped cells 50-100 microns long and 2-5 microns broad [McClintic, 1980]. The cells contain myofibrils in the sarcoplasm and a cylinder shaped nucleus in the centre of the cell. The contraction of the smooth muscle cell is similar in many ways to that of skeletal muscle.

The following description of the smooth muscle contraction process is found in Guyton [1971]. The process begins with the chemical stimulation between the nerve cell and the smooth muscle cell, ending with a discription of smooth muscle cell contraction.

Adjoining nerve cells create stimulation in smooth muscle cells by releasing norepinephrine from the sole foot of the nerve into the synaptic cleft of the muscle cell. The presence of the norepinephrine near the muscle cell causes a change in the muscle cell's permeablity to sodium and the influx of sodium into the muscle cell raises the cell potential and an action potential is elicited. The process of stimulation and contraction takes considerably more time in smooth muscle than in skeletal muscle. Approximately 50 milliseconds is needed for the permeability of the muscle cell wall to change and another 100 milliseconds is required for the development of an action potential.

After the release of norepinephrine from the sole foot, cholinesterase accumulates around the gutter of the synaptic cleft and destroys the norepinephrine. This process of stimulation of the vascular smooth muscle resulting in a

contraction may take up to 50 to 200 times as long as in skeletal muscle.

The contractile process of smooth muscle is also similar to that of skeletal muscle, as smooth muscle contains both actin and myosin filaments. However, the arrangement of the filaments in smooth muscle is at different angles and not neatly aligned, although most of the filaments are orientated in the longitudinal direction of the muscle fibers. The ratchet method of contraction is also theorized to be the process used in the contraction of the muscle cells. This contraction is activated by calcium ions, and ATP is converted to ADP. The contraction occurrs during depolarization of the muscle cell and stops following repolarizatrion.

The lack of a T tubule system in smooth muscle combined with an undeveloped sarcoplasmic reticulum system for rapid reabsorbtion of calcium ions may explain the slow contraction and relaxation of smooth muscle. A "drag" between the contractile elements is also believed to be the cause of slow contraction and relaxation. This drag also defines the ablity of smooth muscle to maintain long periods of contraction without utilizing much ATP.

APPENDIX B DESIGN STUDY

INTRODUCTION

The objective of the design study was to determine an effective simple method for measuring arterial strain during vasoconstriction. An effective method is defined by the characteristics listed below:

1) non invasive and non reactive,
2) can measure strain in complex shapes with whole body motion,
3) 1 percent resolution of arterial strain.

The final characteristic implies an overall system resolution of 20-100 microns for arteries varying in outside diameter of 2-10 mm.

The implications of a simple strain measuring method is that extensive and expensive equipment be avoided. This would be so that more time could be afforded to the study of arterial strain and not to the design and construction of a complex strain measuring system. As well, funding for the study was limited.

To determine the most appropriate measuring scheme, possible techniques are briefly reported in section B.1, Techniques Considered. Resulting from this brief review, Stereoscopic photography is reviewed further in section B.2, Measuring Statistics.

B.1 TECHNIQUES CONSIDERED

The classic technique of using strain gauges to measure arterial strain is not possible. Most mechanical methods of measuring deformation of the arterial wall would also be subject to motion artifact, as well as not being capable of handling free body motion. Methods such as ultrasound, ultraviolet illumination photography and holography were investigated.

Ultrasound would be used to measure any change in the wall thickness of the artery. If a section of the arterial wall elongated or contracted, the wall thickness would decrease or increase respectively. However, ultrasound was unable to meet the resolution criteria. The required frequency of operation would be approximately 300 megaHertz inorder to resolve changes in a typical arterial wall with a thickness of .1 mm. This frequency is out of the range of current ultra-sonic transducers. As well, a problem with distinguishing precise locations on the arterial wall would have to be overcome.

Ultraviolet illumination photography is a technique used to monitor arterial dimensions [Macfarlane et al, 1983]. The type of measurement would be the same as ultrasound, whereby the changes in the arterial wall thickness would be measured. However, the problem of distinguishing precise locations of measurement on the artery is present.

The limited strain information of arterial wall thickness changes was felt not be adequate information in determining the affect of vasoconstriction at an arterial branch site. As a consequence, both ultrasound and ultraviolet techniques were not investigated further.

Holography, another possible technique, has been used to measure strain in mechanical structures [Dhir and Sikora, 1972]. A brief review of the technique indicated that extracting deformation information from the free body motion might present a problem. Holography was also felt to be too complex and extensive a procedure for such a preliminary study.

Stereoscopic photography, a process of viewing an object in three dimensions to measure strain was investigated. A dissecting microscope, with an attached camera, would be required for photographing the artery. This system was presently available for use in the Pathology laboratory. A form of marking the arterial surface would be required so that before and after positions on the surface of the artery would be recognizable. The simplicity of this technique, linked with the low cost of implementing a test study, were grounds for conducting such a trial study.

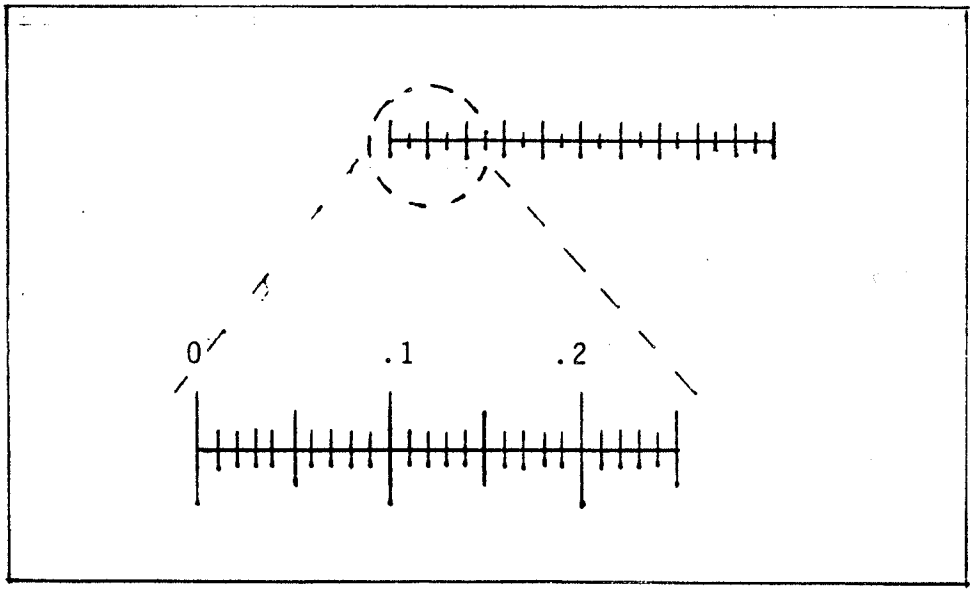


Figure B.1 Stage micrometer. The micrometer was photographed to determine system resolution.

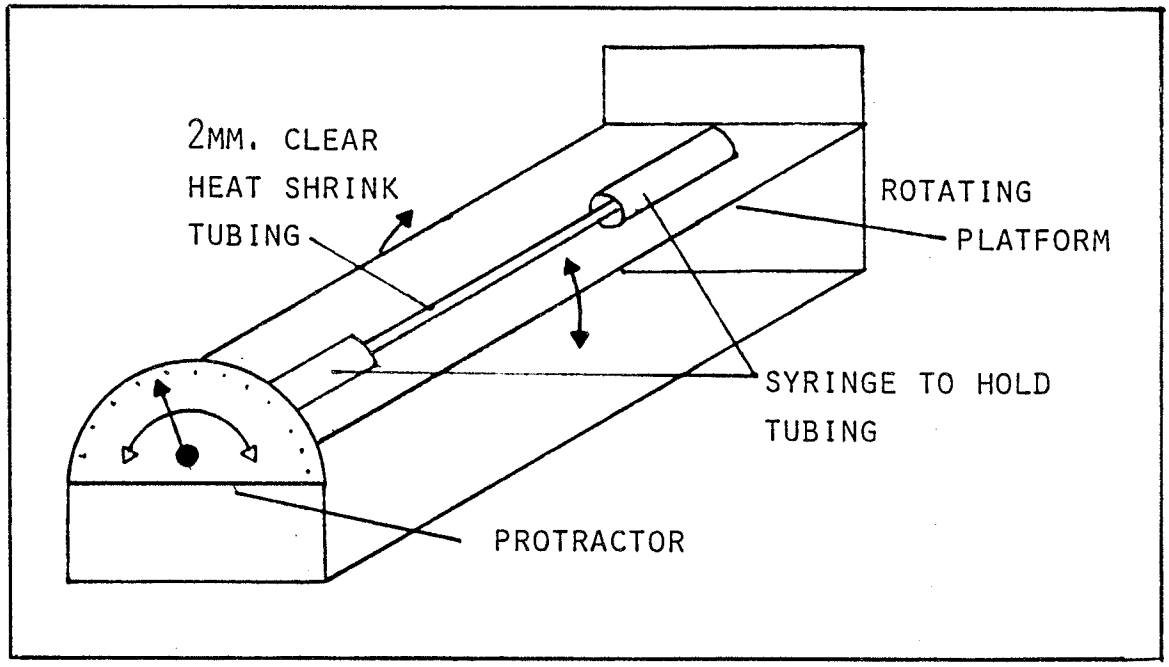


Figure B.2 Tubing and gantry used in the trial study. The rotating platform can be fixed at any known angle for photographing in multiplanes.

B.2 MEASURING STATISTICS

The process of photographing an object in different views to measure strain in the object is reviewed. The resolution of the optic system was measured and a simulated study was conducted to test the procedure of this strain measuring technique.

Resolution

Photographs of a stage micrometer were taken to yield a measurement of the overall system resolution. The stage micrometer has 2 mm divided into 10 micron intervals with highlighted lines on every 50 microns and 100 microns, see figure B.1. The micrometer was photographed using magnifications of; 6X, 9X, 12X, 18X and 50X.

The results from the resolution photographs indicated the following resolutions:

6X	can resolve	50 micrometers
9X	better than	50
12X	better than	50
18X		10
50X	better than	10

The approximation to the resolution is as a result of the use of the stage micrometer for the measurement. The micrometer was constructed with line pairs at 10 microns

apart, with every 50 microns highlighted. The photograph at 12X magnification could not definitely distinguish the 10 micron lines however, two 10 micron lines were very easily distinguished. Thererfore 20 microns was felt to be a reasonable approximation of the resolution when using a magnification of 12X.

The distortion of the optics was defined as the change in image length of a fixed object length in different locations of the field as viewed through the optic system. The distortion was measured by photographing a 1 mm. grid at a magnification of 12X. The negative of the photograph was enlarged using a slide projector to the same magnitude as was used when sketching the arterial negatives. The maximum distortion was at the outer edges of the negative, with 2.8% distortion in the vertical direction and 0.13% in the horizontal direction. Both the horizontal and vertical distortion in the inner area of the negative was less than 0.13%. The inner area of the enlarged negatives was used for strain analysis.

Simulated Study

A study was conducted which simulated the techniques used to measure arterial strain. A small gantry was constructed which allowed for the support and rotation of a small plastic tube. The plastic tube, a 2mm diameter clear piece of heat-shrink tubing, was used to simulate an artery for the study. The diametric size of the tube was felt to be

an approximate size of the arteries that were to be used in study. Figure B.2 illustrates schematically the gantry and tube. The gantry would allow for measured rotations about a fixed axis of the tube so that the dissecting microscope could remain stationary.

The tube was randomly marked with a fine mist of black spray paint which resulted in marks of varying size. The tube and gantry were photographed from several different rotational angles.

The results of the simulated study showed that as the angle between different views increased, recognition of points from one view to the next was difficult. Small angles, 30 to 60 from the vertical position, with sixty being the upper limit, were decided as best to use when photographing the tube. As well, when using larger magnifications of the tube, small disturbances with the tube during photography became a critical problem.

APPENDIX C MARKING ARTERIES

To be able to measure strain using the multiplane photography technique, the arterial wall must be marked. These marks will enable the measurement of strain in the arterial wall. As the strain in the constricted artery is of interest at several locations of the artery, a number of reference points are required. Listed below are the requirements that the marking scheme must meet:

a) adhesive (well fixed to the artery)
b) non-invasive
c) will not stimulate vascular muscle
d) water insoluble
e) less than 100 microns in size
f) high contrast with respect to the artery
g) easy placement of many marks

Numerous techniques were tested and the results of the tests are seen in table C.1. A brief overview of the techniques tested is given below.

Histological stains were used to highlight the elastic and collagen fibers of the adventitia so that different surface characteristics could be used to monitor arterial changes. The contrast of the stains was poor. As well, definite points on the artery could not be identified after changes in the artery's shape were introduced.

The objective of the ink procedure was to place small dots into the adventitia using a micro-pipette. The india ink was water soluble and diluted causing a staining effect upon the artery. The indelible printer's ink used for lables of clothing did not disperse under water but would

not lodge properly in the adventitia and the marks moved. The procedure of "placing" the ink dots on the artery was difficult and tedius.

Different pastes were used as a type of protein glue with the intention of securing small marks onto the adventitia. Both pastes used were not successful in this attempt, and placement of the marks was tedius and difficult.

Several miscellaneous techniques are referred to as "others". Breaking off the tip of micro-pipettes into the adventitia was tested as a possible marking technique. This procedure was difficult as the artery was very flexible, with the pipette breaking prior to placement or pulling out during the breaking procedure. This technique of breaking the pipette in the artery was very damaging to the artery. Electric sparks as generated from an electro-surgical unit were used to cauterize small marks into the adventitia. The process of cauterization could not be perfected, and either severe damage was caused to the artery, or no effect at all would occur.

The use of graphite or tantalum powder offered the most successful means of marking the artery. Initially, the powder was sprayed lightly on the artery, however, any movement of water on the surface of the artery would move the marks. A technique was then discovered whereby the graphite was sprayed on the artery and washed off. After

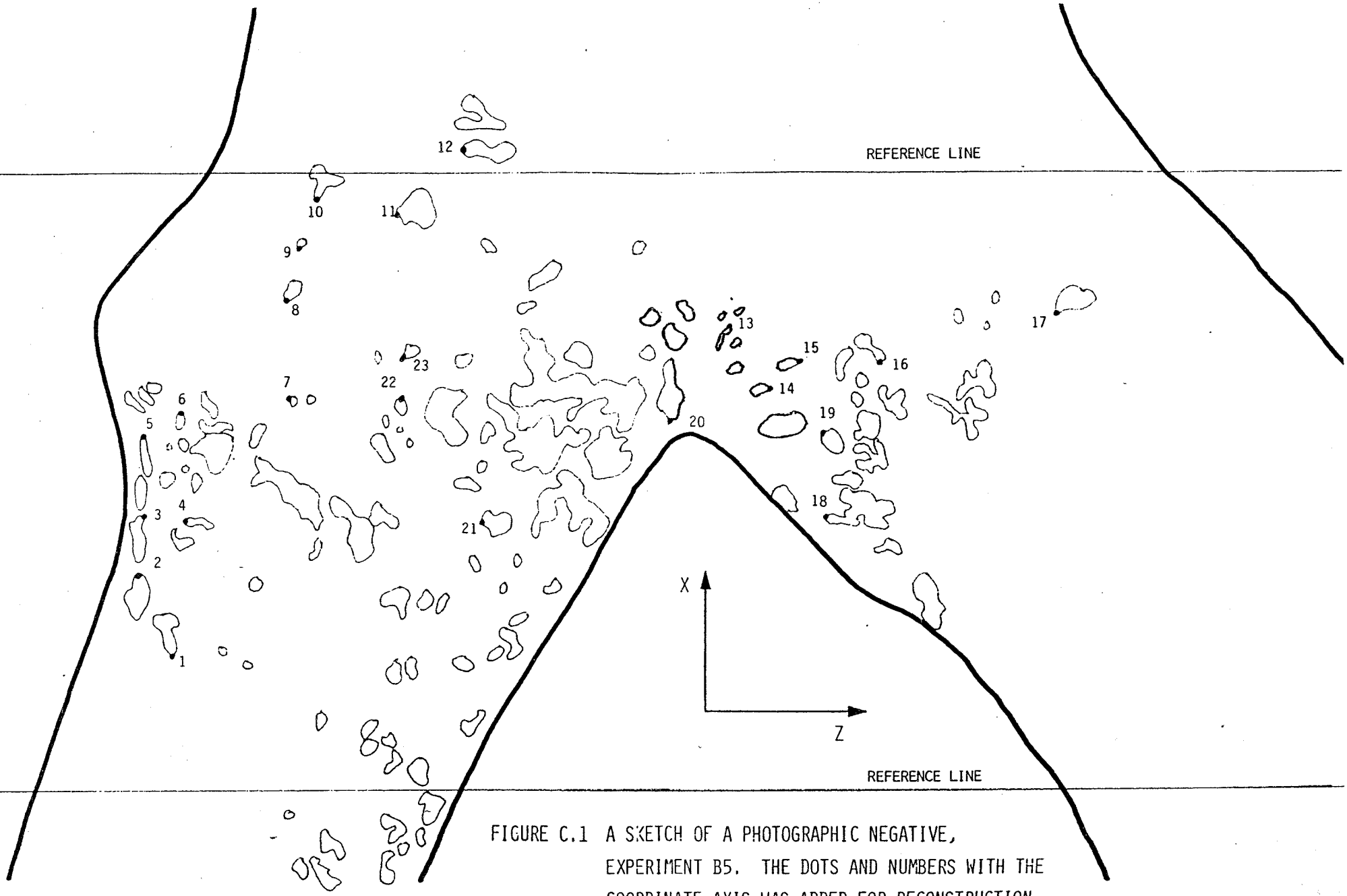


FIGURE C.1 A SKETCH OF A PHOTOGRAPHIC NEGATIVE, EXPERIMENT B5. THE DOTS AND NUMBERS WITH THE COORDINATE AXIS WAS ADDED FOR RECONSTRUCTION.

several washings and reapplications of the powder, particles would become lodged in the fibers of the adventitia. After the particles became lodged, repeated washing of the artery and changes in arterial size (as induced by changes in interlumimal pressure) would not dislodge the marks. A qualitative measurement of point motion (adhesivness) was made by super-imposing photographs of the artery. The photographs were taken before and after the artery was sprayed with water (a simulated disturbance). This test indicated insignificant motion of the points (less than system resolution, 20 microns) after they were properly lodged into the adventitia.

The graphite powder was considered superior to the tantalum in that the graphite particles were of random size and shapes, allowing for ease in recognition of each point or mark from another (see figure C.1).

TABLE C.1 ARTERIAL MARKING TECHNIQUES

Stains:	Requirements: (a)	(b)	(c)	(d)	(e)	(f)	(g)	comments
Humberstone	*	*	*		NA		*	Stains elastin of adventitia - highlights the surface details of the artery.
Iodine	*	*	*		NA		*	
Mercurchrome	*	*	*		NA		*	
Inks:								
India	*	*	*		NA			Applied by micro-pipette in small drops.
Fabric		*	*	*		*		Indelible ink used on cloth labels
Powders:								
Tantalum	*	*	*	*	*	*	*	10 microns particles, sprayed on lightly
Graphite	*	*	*	*	*	*	*	10-50 microns particles, sprayed on
Pastes:								
Dye			*		*			Protein adhering dye paste for clothing
Gelatin & Formalin			*	*				Small gelatin particals mixed with formalin and touched on artery
Others:								
Glass Pipettes	*			*	*			50 micron tips broken off in arterial wall
Electric Sparks	*			*	*			Electro surgical unit with fine tip blade

Requirements: if the requirements below have been met by the marking technique, the appropriate column will contain '*

(a) adhesive
(b) non-invasive
(c) will not stimulate vascular smooth muscle
(d) water insoluble
(e) small; less that 100 microns in size
(f) high contrast with respect to the artery
(g) easy placement of many marks

APPENDIX D TISSUE PREPARATION STUDY

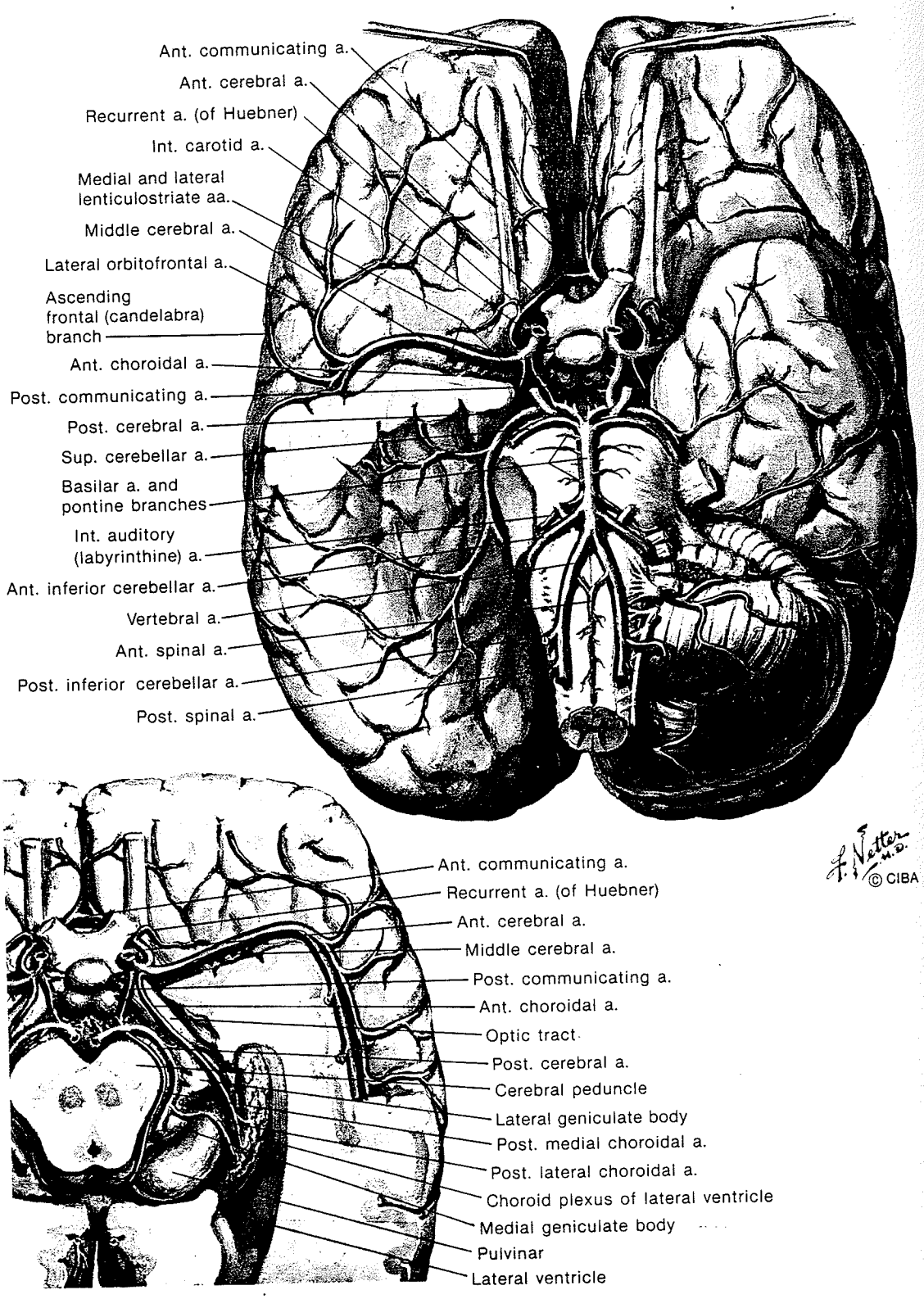


Figure D.1 Arteries of the brain, basal view. From Clinical Symposia, Vol. 33, #5, 1981.

INTRODUCTION

The selection of the appropriate tissue to be used for the study of strain measurement of vasoconstriction is presented in this appendix.

Human cerebral arteries were the initial vessels of interest to be used for the study of strain as caused by vasoconstriction. Branches of cerebral vessels are a common site of medial gaps and aneurysms in the body [Stehbens, 59]. The vessels are very reactive, as blood flow can be decreased (or increased, depending on the initial condition) up to 50 percent during normal brain function [Guyton, 1971].

Two other important reasons for interest in using cerebral vessels is that the vessels are thin walled and have very little adventitia and more media. The second factor is that the vessels traverse the surface of the base of the brain, allowing for easy viewing without disturbing the "in situ" tethering of the vessels when the brain is removed (see figure D.1).

Human cerebral arteries were unable to be used in the study of strain measurement. To ensure reactivity of the vascular smooth muscle, the cerebral tissue should be obtained as soon as possible after death. Human trachea smooth muscle has been used for electrophysiologic studies and ultrastructural studies as obtained from autopsy within five hours of death [Lichtenstien and Austens, 1977]. The

typical time from death to autopsy for the cadavers that could be used for this study was quoted as approximately 12 hours and very rarely did an autopsy occur within five hours.

Canine arteries where chosen as an alternative to human cerebral arteries. The followins sections describe the study of the canine cerebral and renal arteries.

D.1 CANINE CEREBRAL ARTERIES

Canine cerebral arteries were studied as a possible alternative to the use of human cerebral arteries. The animals used for this study were obtained from a laboratory that was studying trachea smooth muscle. The dogs were anesthetized with 30 mg/kg of sodium pentobarbital and sacrificed with an injection of calcium chloride into the heart. The trachea of the animal was removed and the rest of the animal was available for use in the strain analysis study.

The cap of the skull was removed with the use of an oscillating bone saw. Care had to be used to ensure that no damage to the brain was caused. Upon removal of the cap of the skull, the brain was gently plied out while removing the dura mater. The vertebral arteries, carotid arteries and various nerves were carefully severed so the brain could be removed from the skull. Upon removal, the brain was immersed into cooled, aerated physiologic saline solution for transportation to the Physiology laboratory.

The composition of the physiologic solution used in the study was: NaCl; 115 mM, NaHCO3; 25 mM, NaH2PO4; 1.38 mM, KCl; 2.51 mM, MgSO4; 2.46 mM, CaCl2; 1.91 mM, and Dextrose; 5.55 mM [Lockwood, 1960]. Deionized water was used to make the solution. The calcium chloride was not added to the solution until the solution had been bubbled with 5% carbon dioxide and 95% oxygen for approximately 15 minutes.

This procedure raised the pH of the solution close to 7.4 so that the calcium would not precipitate out into the solution when added. The solution was continually aerated with 5% carbon dioxide and 95% oxygen.

When in the laboratory, the brain was placed into the tissue bath within a special holding device which allowed for the cannulae to be easily secured after cannulation. The container also helped secure the brain from motion during the cannulation procedure. Cotton swabs were used to fill in the spaces between the brain and the container so there would be no motion of the brain. As discovered earlier, prior to the use of the container, the effect of the perfusion fluid on the brain tissue caused the structure of the brain to break down and without proper handling, the brain broke apart and was difficult to work with. The container offered some support to reduce the effect of this degenerative process and allowed for the continuation of work with the brain.

Cannulation of the canine cerebral vessels was very difficult. The larger arteries of the cerebral circulation, the carotid and vertebral arteries were approximately 1 mm in outside diametric size. Cannulation was done using a number 30 needle, the smallest needle available. As the pressure in the vessels increased, the size of the vessel also increased, however, the initial vessel size (without interluminal pressure) was the limiting factor when cannulating the arteries.

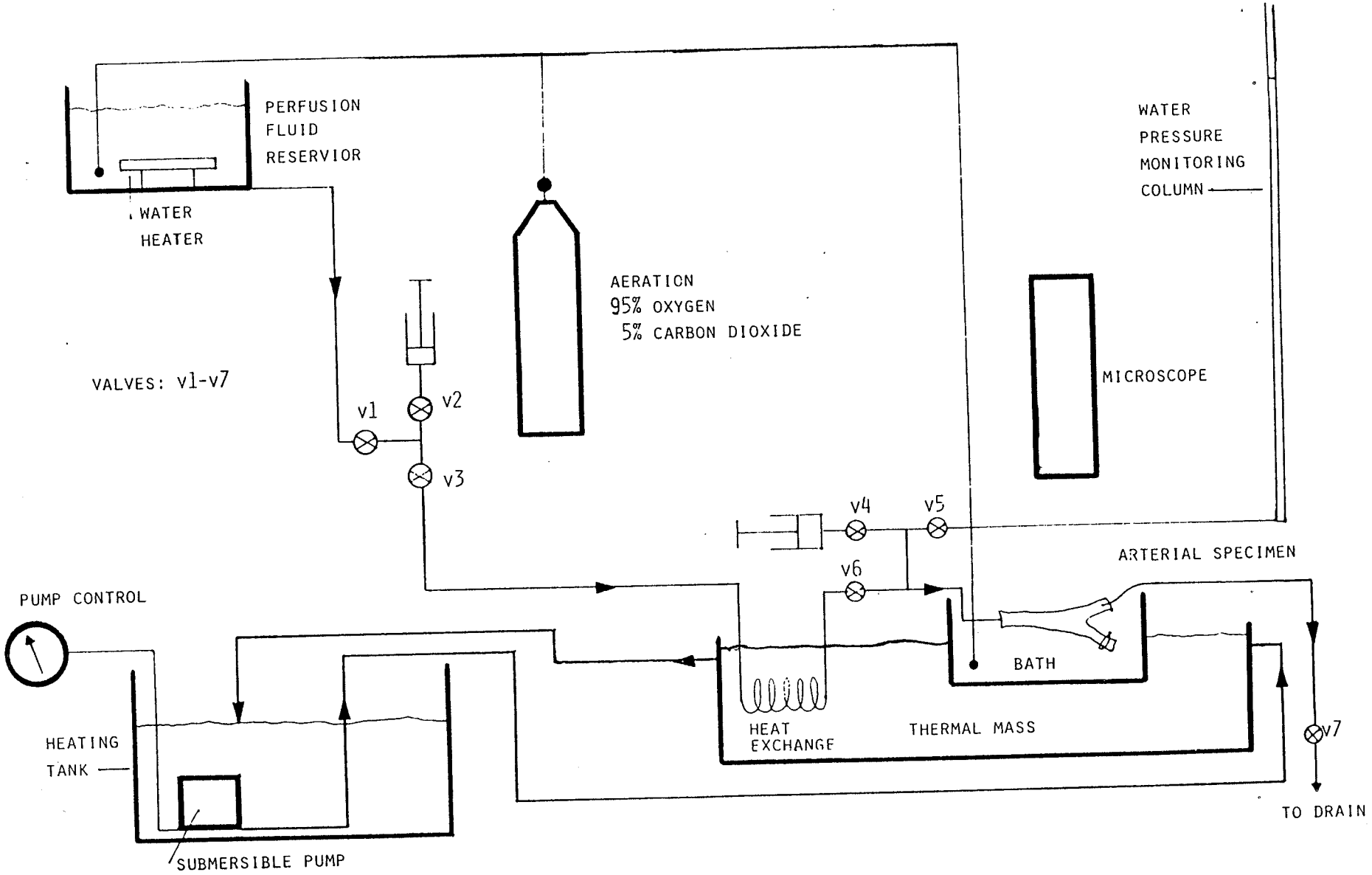


FIGURE D.2 ARTERIAL PERFUSION AND BATH SYSTEM

The cerebral arteries were noted to be very reactive. When cannulating the arteries, small pinches of the arteries caused large localized contractions which did not relax for at least one minute.

Significant problems with leaks in the cerebral circulation had great effects on the interluminal pressure. These leaks were caused when removing the arachnoid tissue from the brain to expose the cerebral circulation on the surface of the base of the brain. Small branching arteries were severed by the removal of the arachnoid and were too small to be sealed by tying. The effect of the leaks combined with the size of the cannula reduced the interluminal pressure. The interluminal pressure was not measured, as seen in the diagram of the perfusion system figure D.2. However, the reduction of the arterial size could be seen.

The size of the arteries also introduced two other significant problems when using canine cerebral arteries. The arteries were very thin walled and problems with breaking through the arterial wall during cannulation occurred frequently. As well, high magnification was needed with the dissecting microscope so that the artery could be sufficiently visualized. When using high magnifications, small motion with the brain caused large disturbances as seen through the microscope. The system was then very sensitive to motion or disturbances.

After several experiments using canine cerebral arteries, the forementioned problems could not be corrected. The cerebral arteries were decided as unsuitable for use in the study.

D.2 CANINE RENAL ARTERIES

Canine renal arteries were selected as a possible alternative to cerebral vessels. The renal arteries have several major branches at the kidney and are also reactive.

The procedure used for handling the arteries was similar to that used for handling the cerebral arteries. The left kidney of the animal was removed and transported to the Physiology laboratory in cooled physiologic saline solution. The section of renal artery used for the study was removed from the kidney and placed into the tissue bath. The "in vivo" length of the arterial segment used could not be measured, as the segment of artery was dissected from within the renal pelvis and was covered by connective tissue.

The arterial segment was cannulated and pressurized with perfusate. The artery was tethered securly to the base on which the artery lay so that no motion of the tissue would occur during the photographing procedures. Extraneous perivascular tissue and loose adventitia were removed from the arterial segment during the incubation period.

A study using canine carotid arteries tested both electrical and chemical stimulation techniques. A 60 Hertz, 0-120 volt, 20 watt variac was used as the electrical stimulation source. Two thin platinum wires were connected to the variac and secured on either side of the carotid section. Voltages between 5 and 20 volts were used with the resulting currents being recorded for each experiment.

Norepinephrine was used for chemical stimulation in concentrations of 0.2 to 20 gm/l.

Of the two stimulants tested, chemical stimulation provided a more continuous stimulation along the length of the artery. The electrical stimulation caused isolated locations of contraction. The inconsistent response to electrical stimulation may be as a result of not providing good field stimulation. As the platinum electrodes were small in comparison to the size of the artery, a continuous electrical field across the arterial smooth muscle could not be established.

Chemical stimulation using norepinephrine and dopamine hydrochloride was used in the experiments using the canine renal arteries.

APPENDIX E EXPERIMENTAL PROTOCOL

INTRODUCTION

The procedures used to conduct each experiment were many. To obtain as much consistency from experiment to experiment as possible, an experimental protocol was established. Three protocols were written: Experimental Protocol 1 was used for the initialization procedure of each experiment; Experimental Protocol 2 was used for the mixing of the Physiologic Saline Solution; and Experimental Protocol 3 was used during the execution of each experiment.

The procedure used for each experiment is described in this appendix. The three protocols that were used for the experiments are listed at the end of the appendix.

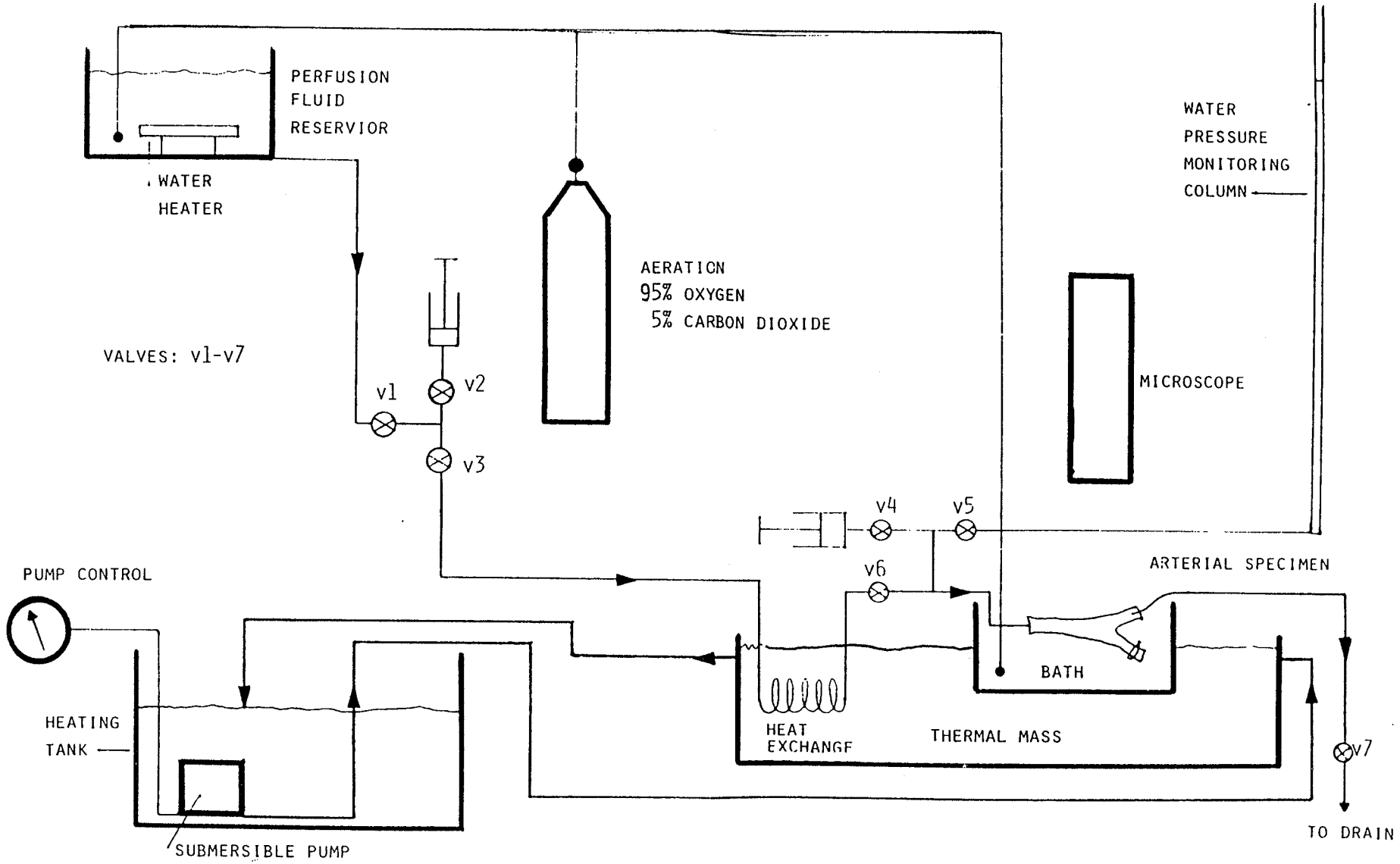


FIGURE E.1 ARTERIAL PERFUSION AND BATH SYSTEM

E.1 EXPERIMENTAL PROTOCOL

The perfusion and bath system was constructed as seen in figure E.1. Upon initialization of the experiment, this system was checked to ensure that the system was complete. After this initial check, the thermal mass system was filled with water and the water heater and water pump were turned on. The drain in the top of the thermal mass system regulat- ed the level of the water in the system. In operation, a continual siphon and pump mechanism of the water circulated the heated water through the thermal mass system. The thermal mass water heater was set to 39 degrees celsius to maintain a bath temperature of 37 degrees.

Once the thermal mass system was functioning, the physiologic saline solution (Kreb's Ringer Solution) was mixed. The plastic reservoir container was initially rinsed with deionized water and then filled with the required amount of deionized water. The required mass of each chemical was measured using a laboratory weight scale measuring to the nearest milligram. Each chemical was added to the deionized water after being measured and the solution was then mixed. This procedure was used for the addition of the chemicals, each chemical added in the order as seen in Protocol 2. The calcium chloride was not added to the solution until the solution had been bubbled with 5% carbon dioxide and 95% oxygen for at least 15 minutes. At this time the calcium chloride was mixed into the solution

and the heater was turned on. A 200 watt submersible water heater was used to heat the solution. Approximately one hour was required to raise the temperature of 10 liters of solution to 37 degrees celsius. The solution was continually bubbled with carbon dioxide and oxygen during the heating process.

Once the saline solution was properly mixed and heated, the perfusion sytem and bath were rinsed with the solution. All air bubbles were removed from the perfusion system so that no bubbles would become lodged in the arteries that were to be cannulated.

Approximately 250 ml of solution was placed into a small container and cooled to approximately 5 degrees celsius. This solution was also bubbled for approximately 5 minutes with the carbon dioxide and oxygen mixture. This solution was kept cool until the tissue was ready to be received, and was used for the transportation of the tissue from the Dissecting laboratory to the Physiology laboratory.

When in the Physiology laboratory, the tissue was removed from the container, and the required section of artery was dissected from the rest of the tissue. The artery was then flushed with the cooled solution and placed into the bath. The artery was cannulated and then slowly pressurized to approximately 160 cm of water. All open branches were tied closed so that there were no leaks in the artery. A flow through the artery of approximately 4 ml/min was started and the tissue was incubated for approximately

one hour. During this incubation period, all extraneous perivascular tissue and loose adventitia was removed from the arterial segment. This procedure resulted in well defined edges of the artery as seen in the arterial photographs and made measurements of diametric changes easier.

Also during the incubation period, the photography system was initialized. The microscope was positioned to a marked location to ensure that the artery would be in focus at the centre of the gantry rotation. The microscope was also rotated with the gantry through the desired angles that were to be used in the experiment. This check ensured that the rotation of the microscope did not disturb the artery bath and perfusion system.

After the incubation period, the artery was removed from the bath and the saphite marking procedure was conducted. When the marking of the artery was completed, the artery was returned to the bath and the final check of the entire perfusion and photgraphing systems was made.

At this time, the chemical stimulant was mixed. The desired amount of stimulant was added to deionized water and then the solution was coloured with yellow or green food dye. The dye was used so that the location of the stimulant would be known when the chemical was injected into the perfusion system.

Prior to photographing the first series of resting

state planes, the magnification of the microscope was fixed with tape (see Protocol 3) and noted. As well, the shutter speed and aperture were set and noted. A final swing of the gantry through the desired angles was made to ensure that the artery was in focus for these angles and that no disturbances would be caused during the rotation procedure. The flow through the artery was stopped and the photographing procedures were initiated.

The resting state pictures were then taken, after which the artery was stimulated. The injection procedure of the chemical stimulus was as follows. Approximately 10 cc of chemical solution was drawn into a syringe. The syringe was connected to the perfusion system at valve 4 as seen in figure E.1. The solution was slowly injected into the perfusion system, flowing back up into the reservoir system. The discharge line was then opened slightly so that the stimulant was allowed to flow into the artery. The position of the stimulant was monitored using the dye. Once the stimulant was well within the artery, the discharge line was closed and the photographing procedure was initiated. The pressure within the artery was maintained constant while the artery was photographed in both the resting and constricted state. The pressure was only reduced for a short period during the injection of the stimulant, and was then returned to the initial pressure.

After the constricted state photographs were taken, the artery was flushed with perfusion fluid and a flow

through the artery of approximately 4 ml/min was restarted. Another experimental trial was not started until the artery had incubated for approximately 30 minutes.

The above procedure was then repeated for each experimental trial that was run in the experiment. During the experiment, temperature, pressure and pH measurements were made of the bath and perfusion fluid.

At the end of the experiment, formalin was injected into the perfusion and bath system. This procedure ensured that the tissue was fixed while in a physiologic state. Ten minutes after the introduction of formalin, the artery was removed from the cannulas and placed into a small jar of formalin. The jar was appropriately marked and the tissue was stored until histological sectioning would be made.

A thorough cleaning of the bath and perfusion system was made at the end of each experiment to ensure that the formalin was washed from the system.

A list of the three protocols used during each experiment is found in the following pages.

E.1.1 Experimental Protocol 1

EXPERIMENTAL PROTOCOL 1 DATE?_____

Experiment?_____ Name?_____

Time?_____ check

Required Prior to Experiment:

Combination wrenches	_____
1-Digital Voltmeter	_____
5-10 Litres of Kreb's Solution	_____
2-36 Exp. 35mm. 400 ASA B&W Print Film	_____
several tie clamps(small)	_____
reference wire (wire wrap wire)	_____

Initialization:

Ensure Pressure and Perfusion System is Complete	_____
Prepare and Initialize Thermal Mass (TM) System	_____
Monitor TM temp. and Adjust accordingly	_____
Flush perfusion system with Kreb' Sol.	_____
Fill Bath Container with Perfusion Fluid	_____
Begin Aeration of Bath and Perfusion (see Aeration and Temp Protocol)	_____

Receiving Brain: TIME?_____

Use cooled and aerated Kreb's sol. in transport container for transporting brain to lab	_____
Upon receival, immerse brain in bath and perfuse using suitable cannulas at desired pressure	_____
See Aeration and Temp Protocol for monitoring of pH and Temp of Incubating Brain	_____

During Brain Incubation: TIME?_____

Load camera with film and set for first picture	_____
Set microscope gantry to first view position and adjust approximate horizontal and vertical positions of desired field of view	_____

Final mental check of entire system ----------

Final Preparations (after incubation period): TIME?---------

Lower bath level so that artery to be used is elevated out of the solution ----------

Pat artery dry with cotton swab ----------

Place Platinum Electrodes along side of Artery that is to be stimulated and secure ----------

Connect leads from stimualtor to electrodes and secure to bath container ----------

Lightly spray Graphite powder on artery site and check that marking is clear using microscope ----------

Make FINAL adjustment to vertical and horizontal positions so field of view is in camera field when rotating through desired angles. Monitor Gantry swing at extreme angles so that bath is not disturbed. (see notes) ----------

Proceed to EXPERIMENTAL PROTOCOL 3

Notes:

When rotating camera counter clockwise and object moves left out of field of view, then the specimen is too low!

E.1.2 Experimental Protocol 2

EXPERIMENTAL PROTOCOL 2 Date?_____

Name?_____

Experiment?_____

Time?_____

Kreb's Henseleit Solution Preparation:

Chemical	s/21		41		81		10 l	
NaCl (115mM)	13.44	---	26.88	---	53.76	---	67.20	---
KCl (2.51mM)	.374	---	.748	---	1.496	---	1.870	---
MgSO4 (2.46mM)	.592	---	1.184	---	2.368	---	2.960	---
NaH2PO4 (1.38mM)	.334	---	.668	---	1.336	---	1.670	---
NaHCO3 (25mM)	4.20	---	8.40	---	16.80	---	21.0	---
CaCl2 (1.91mM)	.551	---	.848	---	1.696	---	2.120	---
Dextrose (5.55mM)	2.0	---	4.0	---	8.0	---	10.0	---

Note: Add the chemicals to the deionized water and mix in the same order as given above.

Add CaCl2 after the other chemicals have been mixed.

Gas solution with 5% CO2 and 95% O2 to a pH of approx. 7.4

Notes:

Aeration and Temperature Monitoring:

Time aeration commenced?_____

Time?_____ Air Flow?_____

Perfusion:
Temp.?_____

pH?_____ PCO2?_____ PO2?_____

Bath:
Temp.?_____

pH?_____ PCO2?_____ PO2?_____

Time?_____ Air Flow?_____

Perfusion:
Temp.?_____

pH?_____ PCO2?_____ PO2?_____

Bath:
Temp.?_____

pH?_____ PCO2?_____ PO2?_____

Time?_____ Air Flow?_____

Perfusion:
Temp.?_____

pH?_____ PCO2?_____ PO2?_____

Bath:
Temp.?_____

pH?_____ PCO2?_____ PO2?_____

E.1.3 Experimental Protocol 3

EXPERIMENTAL PROTOCOL 3

DATE?_____ NAME?_____

EXPERIMENT?_____

	check
-Prepare Camera for first Picture	
film loaded	_____
position no.	_____
protection plate out	_____
-Focus Using Camera Eyepiece	_____
-Note Magnification?_____	_____
-Fix MAGNIFICATION with tape	_____
-Swing Gantry through desired view Angles to ensure correct field of vision	_____
-Secure Gantry to Position 1	_____
-Depth of Field?	_____
-Shutter Speed?	_____

Notes:

RESTING STATE

Time?_____ Pressure?_____ Bath Temp.?_____

View?_____ Angle?_____ Picture?_____

Reference Wire in Place? _____

Sufficient Light? _____

TAKE PICTURE _____

-Press release button and advance film _____
-Remove light source _____
-Advance Gantry to next positon _____
-Replace light source _____
-Adjust focus _____

Time?_____ Pressure?_____ Bath Temp?_____

View?_____ Angle?_____ Picture?_____

Reference Wire in Place? _____

Sufficient Light? _____

TAKE PICTURE _____

-Press release button and advance film _____
-Remove light source _____
-Advance Gantry to next positon _____
-Replace light source _____
-Adjust focus _____

Notes:

STIMULATION OF ARTERIES

-IF ELECTRIC STIMULATION-Connect Variac with Ammeter to Electro Leads. ----------

---

Time?---------- Voltage Setting?---------- [Adr.]?----------

Notes:

Pressure?---------- Bath Temp?----------

View?---------- Angle?---------- Picture?----------

Reference Wire in Place? ----------

Sufficient Light? ----------

APPLY STIMULUS !! ----------

Current?----------

Time?----------

TAKE PICTURE ----------

-Press release button and advance film ----------
-Remove light source ----------
-Advance Gantry to next positon ----------
-Replace light source ----------
-Adjust focus ----------

View?---------- Angle?---------- Picture?----------

Current?----------

Time?----------

TAKE PICTURE ----------

-Press release button and advance film ----------

Notes:

DURING AND AFTER STIMULATION

Time?_____

Current?_____ Pressure?_____ Bath Temp?_____

View?_____ Angle?_____ Picture?_____

Reference Wire in Place? _____

Sufficient Light? _____

TAKE PICTURE _____

-Press release button and advance film _____
-Remove light source _____
-Advance Gantry to next positon _____
-Replace light source _____
-Adjust focus _____

Pressure?_____ Bath Temp?_____

View?_____ Angle?_____ Picture?_____

Reference Wire in Place? _____

Sufficient Light? _____

Time?_____

Current?_____

TAKE PICTURE _____

-Press release button and advance film _____

Notes:

Time?_____

Current?_____ Pressure?_____ Bath Temp?_____

View?_____ Angle?_____ Picture?_____

Reference Wire in Place? _____

Sufficient Light? _____

TAKE PICTURE _____

-Press release button and advance film _____
-Remove light source _____
-Advance Gantry to next positon _____
-Replace light source _____
-Adjust focus _____

Pressure?_____ Bath Temp?_____

View?_____ Angle?_____ Picture?_____

Reference Wire in Place? _____

Sufficient Light? _____

Time?_____

Current?_____

TAKE PICTURE _____

-Press release button and advance film _____

Notes:

APPENDIX F SERIAL COMMUNCIATION LINK, DATA TRANSMISSION

F.1 OPERATING INSTRUCTIONS

Upon receipt of the developed negatives of the multiplane photographs for each experiment, the negatives were mounted into glass slide frames. The appropriate slides were then projected upon paper using a slide projector and sketches of the enlarged slides were made. The sketches include the artery outline and the points that were seen on the artery (artery markings). Once the sketches of the different plane views of each experimental trial were completed, including both resting state series and constricted state series, the sketches were digitized.

The objective of the digitizing procedure was to produce the two dimensional coordinates of the desired points of each plane view of each trial state. For example, in trial A of experiment B3, there were two views for each state, resting and constricted. The common points in the views of the resting state were chosen and numbered. The same points were then identified and numbered in the constricted state views. In all views, the appropriate location of the reference line were marked for digitization as well as the locations that were used for magnification of each view. Once all of the sketches were ready for digitizing, the communication link between the main computer system and the digitizing computer was established.

The asychronous serial communication protocol using RS 232 was as follows:

Main Computer System;

Digital, Minc 23

Serial Input Line 1

300 baud

8 data bits (8th bit set high)

1 stop bit

no parity

Main Computer Modem;

Hayes Smart 300,

300 baud

full duplex

Auto answer, ring 1

Digitizing Computer Modem;

Rixon T212A,

300 baud

full duplex

Pin 20 tied to High

Note: all front panel buttons should be in the 'out' position.

Digitizing Computer;

Talos System Inc., using Smart 3.3.0 Software

300 baud

Point Mode

RST Mode (communication to both output ports)

When all communication devices were initialized and the appropriate lines were established, the digitizing modem was used to dial the main computer modem. When the telephone

link was established, the serial communication program in the main computer system was ready to receive the start characters.

The serial line unit input-output program written for the serial communication link is listed in the followins pages. This program ran in the main computer and was started at any time during the initialization of the communciation link. The data communication format was as follows:

To initialize the communication once the SLUIO program was running, enter into the Talos terminal;

ESC (escape)

CR (carriage return)

LF (line feed).

The main computer would then respond with;

'Enter the complete file name'.

This file name was the file which was to be created on 8 1/2 inch floppy disk within the main computer system. The program would store in this file all the data that was received from the Talos digitizer.

The complete file name would be entered using the Talos system as follows;

L:(file name).dat

CR

LF.

Any error in receiving the file name or creating the file would result in repeating the command 'enter complete file

name'. When the file was successfully created, the main computer would respond with;

'Minc is ready for data transmission'.

At this point, the main computer system was ready to receive and store on file all the following information. The format for entry of data for each file was set up as shown below.

Enter: No. of Views (m), No. of Points (n)

Block I:

Enter: View No. (I), Angle of View I (degrees)

Digitize: Coordinates of the two points required for Magnification calculation.

Digitize: Coordinates of points on the reference wire

Digitize: The coordinates of the N points of the Jth view

Repeat Block I for the M views of this particular series of sketches.

Each file consisted of the points required to reconstruct the artery in the given state. At the end of the transmission of the data for the M views of this state, the file was closed. To close the file, the following was transmitted;

CR

LF.

The main computer would then respond with;

'Do you wish to continue? Y-N'.

To continue with the entry of data into a new file, enter;

Y

CR

LF.

To discontinue the communication program, enter any other character. If continuation was desired, the above format would be repeated for the new file. The SLUIO program did not terminate the communication link with the Talos Digitizer upon the negative response to the last question. If for some reason a new file was required after the 'no' answer was transmitted, entry of the initialize starting characters would repeat the complete communication program format. The SLUIO program is listed in the following pages.

F.2 PROGRAM LISTING: SERIAL I/O

```
C-------------------------------------------------------------------------
C       SERIAL I/O PROGRAM
C
C       VERSION:        9-MAR-84
C
C       THIS PROGRAM IS DESIGNED TO RECIEVE SERIAL DATA  FROM  ONE
C       OF THE SLU PORTS OF THE  MINC.   THE  DATA  IS  STORED  IN
C       MENMORY AND WHEN COMMUNICATION IS COMPLETED, IS TRANSFERED TO
C       MAGNETIC DISK
C
C-------------------------------------------------------------------------
        PROGRAM SLUIO
        BYTE IARRAY(80),IBARRY(30),ICARRY(28),IDARRY(38),NAME1(16)
        BYTE ITERMI,ITERMO,IERRAY(3),IFRRAY(24)
        BYTE IARAY(11),IBRAY(12)
C
        DATA IARAY,IBRAY/'C','I','N',' ','E','R','R','O','R',13,10
     &                  ,'C','O','U','T',' ','E','R','R','O','R',13,10/
C
        DATA IBARRY,ICARRY/'E','N','T','E','R',' ','T','H','E',' ',
     &  'C','O','M','P','L','E','T','E',' ','F','I','L','E',' ',
     &  'N','A','M','E',13,10,'D','O',' ','Y','O','U',' ','W',
     &  'I','S','H',' ','T','O',' ','C','O','N','T','I','N','U',
     &  'E',' ','Y', '/','N',' '/
        DATA IDARRY/'M','I','N','C',' ','I','S',' ','R','E','A',
     &  'D','Y',' ','F','O','R',' ','D','A','T','A',' ','T','R',
     &   'A','N','S','M','I','S','S','I','O','N',' ',13,10/
        DATA IERRAY/64,13,07/
        DATA IFRRAY/'E','N','D',' ','O','F',' ','D','A','T','A',
     &  ' ','T','R','A','N','S','M','I','S','S','I','O','N'/
C
C
        TYPE 10
10      FORMAT(//,' SERIAL I/O PROGRAM ',//
        1 ' THIS PROGRAM RECIEVES SERIAL DATA FROM THE',/
        2 ' NUMBER 1 SLU PORT.  THE DATA IS THEN STORED',/
        3 ' ON MAGNETIC DISK.',//
        4 ' DATA IS TRANSMITTED UPON RECEIVING "CR,LF".'/
        5 ' DATA COMMUNICATION IS TERMINATED UPON RECEIVAL',/
        6  '  OF  NO  DATA  ENTERED  WITH  "//,CR,LF".'//
        7 ' TO EXIT FROM TRANS OF NAME ENTER "ESC" UNTIL',/
        8 ' THE PROMP RETURNS.',//
        9  '  TO  START  PROGRAM  ENTER  "ESC,CR,LF"',//)
C
        IDIM=80
        ITERMI='012
C
C       USING SLU NUMBER 1
C
        ICHAN=1
C
C       READY TO START --
C
        PAUSE   'TYPE  RETURN  TO  START  COMMUNICATION!'
C
C       WAITING FOR STARTING CHARACTERS
C
100     CALL  CIN(ISW,NCHAR,ICHAN,IARRAY,IDIM,1,,ITERMI)
        IF(IARRAY(NCHAR-1).NE.'033 .AND. IARRAY(NCHAR).NE.'015)GOTO 100
        TYPE *,'RECEIVED TERMINATION'
C
C       FIND FILE NAME
C
200     MODE=4      ! SYCHRONOUS PROCESSING
        CALL  COUT(ISW,NCHAR,ICHAN,IBARRY,30,MODE)
        IF(ISW.NE.1)CALL  ERROR(2,ICOUNT,IARAY,IBRAY)
C
        CALL  CIN(ISW,NCHAR,ICHAN,NAME1,16,1,,ITERMI)
        IF(ISW.NE.1)CALL  ERROR(1,ICOUNT,IARAY,IBRAY)
C
```

```
C       CHECK FOR INPUT ERRORS!!
        IF(NAME1(NCHAR).EQ.'033)GOTO 200
C
        TYPE *,'NUMBER OF CHARACTERS IN THE RECIEVED NAME',NCHAR
        NAME1(NCHAR)=0
        OPEN(UNIT=2,NAME=NAME1,TYPE='UNKNOWN',ERR=1000)
C
C       MINC READY FOR DATA TRANSMISSION
C
        CALL  COUT(ISW,NCHAR,ICHAN,IDARRY,38,1+4)
C
        K=0
C
C       USING MODE  1 ==> TERMINATES WITH LINE FEED
C
250     CALL COUT(ISW,NCHAR,ICHAN,IERRAY,3,4)  !  PSEUDO  CURSER
        IF(ISW.NE.1)CALL  ERROR(2,ICOUNT,IARAY,IBRAY)
        CALL  CIN(ISW,NCHAR,ICHAN,IARRAY,IDIM,1,,ITERMI)
C
C       TEST FOR INPUT ERRORS
C
        IF(ISW.NE.1)CALL  ERROR(1,ICOUNT,IARAY,IBRAY)
        TYPE *,'NUMBER OF CHARCTERS RECIEVED ARE  ',NCHAR
C
        TYPE *,'INFORMATION RECEIVED'
        IF(NCHAR.EQ.1)GOTO 350
        WRITE(2,30) (IARRAY(I),I=1,NCHAR-1)
        WRITE(7,30) (IARRAY(I),I=1,NCHAR-1)
30      FORMAT(' ',80A1)
C
C       LOOPING CIN UNTIL TERMINATION
C
        GOTO 250
350     CLOSE(UNIT=2)
C
C       TRANSMIT -- DO YOU WISH TO CONTINUE Y/N?
C
        CALL COUT(ISW,NCHAR,ICHAN,ICARRY,28,4)
        IF(ISW.NE.1)CALL  ERROR(2,ICOUNT,IARAY,IBRAY)
C
        CALL  CIN(ISW,NCHAR,ICHAN,IARRAY,IDIM,1,,ITERMI)
        IF(ISW.NE.1)CALL  ERROR(1,ICOUNT,IARAY,IBRAY)
C
C       IF ANS IS YES REPEAT PROGRAM
C
        IF(IARRAY(1).EQ.'171)IARRAY(1)='131
        IF(IARRAY(1).EQ.'131)GOTO 200  ! YES
C
C
C       TRANSMIT -- ' END OF TRANSMISSION '
C
300     CALL COUT(ISW,NCHAR,ICHAN,IFRRAY,24,1+4)

        GOTO 100
        STOP ' END OF SERIAL INPUT '
C
1000    TYPE *,'FILE OPENING ERROR'
        GOTO 200
        END


        SUBROUTINE ERROR(K,ICOUNT,IARAY,IBRAY)
C
C       SUBROUTINE FOR HANDLING CIN/COUT ERRORS
C       ONLY 3 ERRORS ALLOWED BEFORE STOPPING PROGRAM
C
        IF(K.EQ.2)GOTO 2
        TYPE *,'INPUT ERROR ON SERIAL LINE #',ICHAN,' STATUS
        1 CODE=',ISW
        ICOUNT=ICOUNT+1
        IF(ICOUNT.GT.3)STOP  'TOO  MANY  I/O  ERRORS'
```

```
      CALL COUT(ISW,NCHAR,1,IARAY,11,4)
      IF(ISW.NE.1)GOTO 2
      RETURN
2     TYPE *,'OUTPUT ERROR  ON  SERIAL  LINE  #',ICHAN,'  STATUS
     1 CODE=',ISW
      ICOUNT=ICOUNT+1
      IF(ICOUNT.GT.3)STOP  'TOO  MANY  I/O  ERRORS'
      CALL COUT(ISW,NCHAR,1,IBRAY,12,4)
      IF(ISW.NE.1)GOTO 2
      RETURN
      END
```

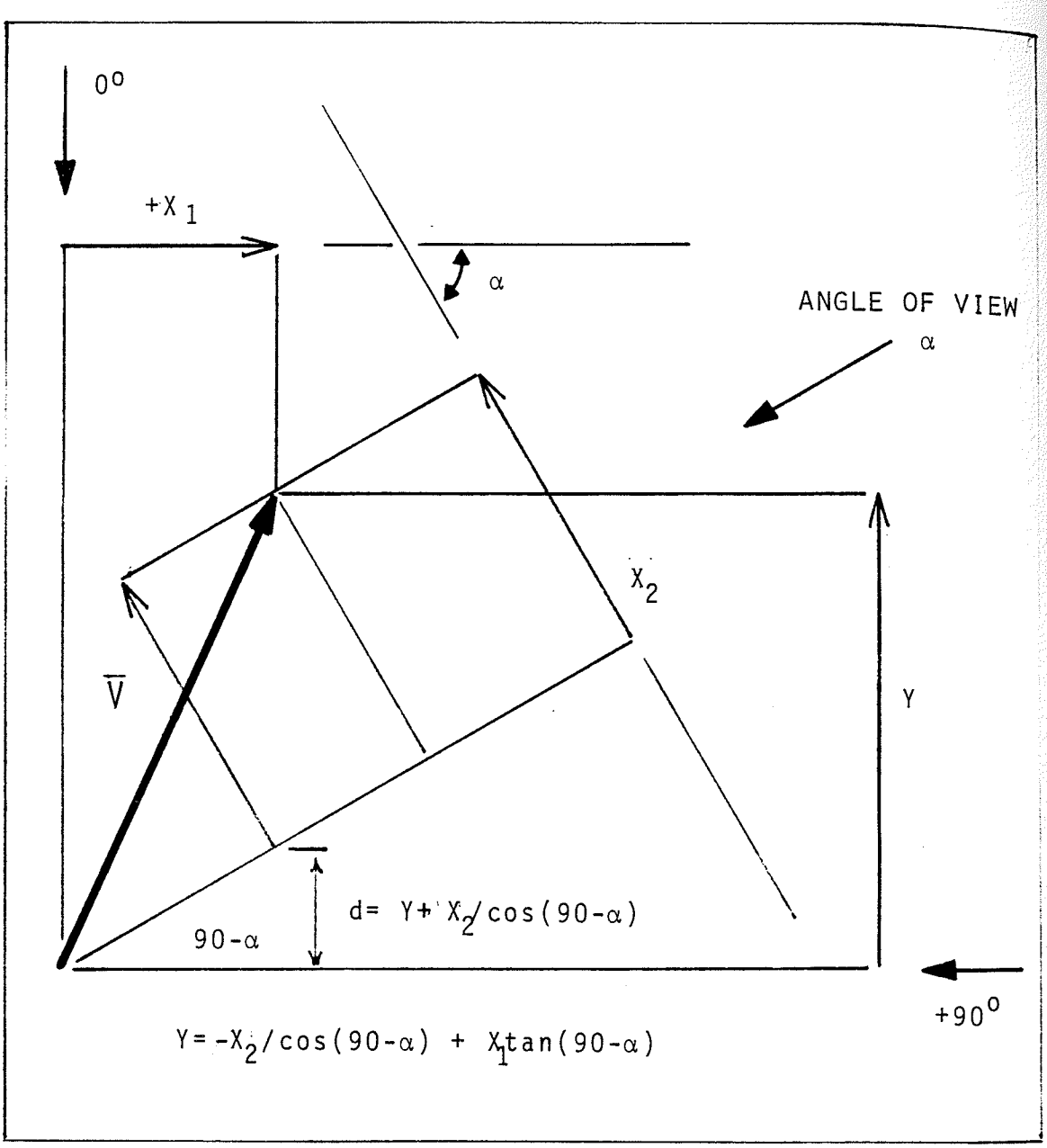


Figure G.1 Three dimensional reconstruction. The vector $\overline{V}$ has components X and Y when viewed from 0^{o} and 90^{o}. The Y component can be calculated for any other angle of view. Clockwise rotation is positive.

APPENDIX G RECONSTRUCTION TECHNIQUE

G.1 THREE DIMENSIONAL RECONSTRUCTION

The two dimensional coordinates of the points of each view taken of an artery in a particular state are used to reconstruct the three dimensional coordinates of those points in that state. The calculation of the three dimensional coordinates is:

$$X = X1, \tag{G.1}$$

$$Y = -X2/COS(90-\alpha) + X1*TAN(90-\alpha), \tag{G.2}$$

$$Z = Y1 = Y2, \tag{G.3}$$

where;

X1 - X coordinate of the first view of the point,

Y1 - Y coordinate of the first view of the point,

X2 - X coordinate of the second view of the point,

Y2 - Y coordinate of the second view of the point,

and

α - angle between each view and the first view.

The above equations are derived from figure G.1.

The best angle for the calculation of the Y coordinate can be seen to be 90 degrees. At this angle, any error in the X coordinate of the first view will not contaminate the calculation of the Y coordinate. However, when photographing the points on the artery, any angle greater than 60 degrees makes the recognition of the points from one view to the next difficult. At times, depending on the surface of the artery, even 60 degrees presents recognition problems.

A computer algorithm was written to calculate the three dimensional coordinates from the two dimensional coordinates of the multiple views. The program accepts the data from the existing artery files (format as described in Appendix F) and using "user" input, calculates the three dimensional coordinates.

The user's interaction with the program was designed so that a constant monitoring of the data manipulation could be obtained. The user must first specify the data file to be used and then the point to which all points in each view will be referenced. Once the points have been referenced, each view is automatically rotated into the proper orientation so that the Y axis is parallel to the axis of rotation of the microscope gantry.

The algorithm then calculates the three dimensional coordinates using each given view with respect to the first view and averages the final coordinates from the total number of coordinates calculated. For example, if there were three views of the artery in the resting state, the first view at the zero angle, the second at - 30 degrees from the horizontal and the third at - 60 degrees from the horizontal, the coordinates would be calculated using the 0,-30 combination and then the 0,-60 combination. The final coordinates would then be averaged from these two calculations.

Before the three dimensional coordinates are calculated, each view's magnification is referenced to the

first view. The use of the reference wire photographed in each view ensures that the digitized points of each view of an experiment (resting state and constricted states) are scaled to the same value. The magnification calculation can be made using either the reference wire, or the relationship between the common Z values of each view (Y coordinates of each plane view).

After the three dimensional coordinates are calculated, the reconstruction program plots the points and point numbers on the terminal by plane views; X-Y plane, X-Z plane, and Y-Z plane. From these views, the user can determine what orientation the coordinate system has with the artery and then translate and/or rotate to any new orientation. The translation and rotation programs require point numbers when calculating the new orientation. For example, as seen in figure G.2, the X-Y plane should be oriented so that the X-Z plane is on the surface of the artery. From the figure, the points 1 and 8 describe the new X axis that is desired. Entering these two points into the program when requested will yield the desired rotation.

The points that are used for reference of the resting state reconstruction, as well as any points used for translation and rotation, should also be used when reconstructing the corresponding constricted state views. As well, the same procedure used in reconstructing the resting state should be used when reconstructing the corresponding

constricted state artery.

The computer program that was written for the reconstruction procedure is listed in the following pages. A block diagram of the program is seen in figure G.3 and G.4.

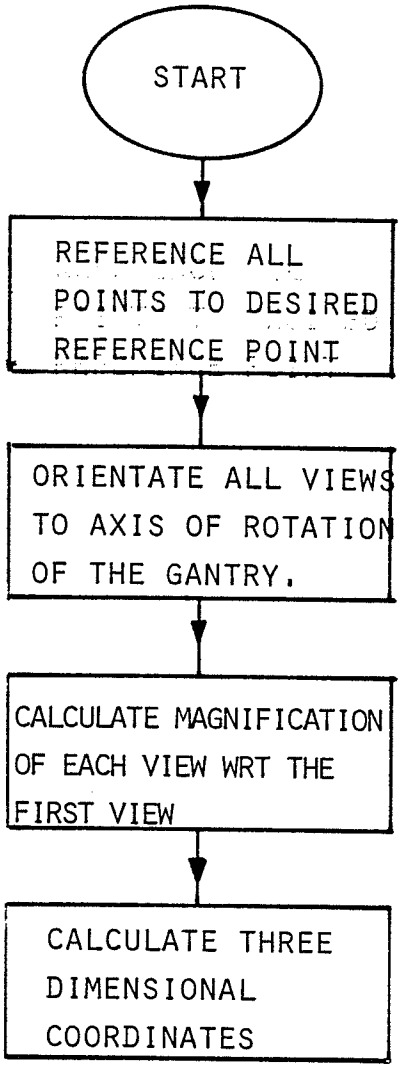


Figure G.4 Block diagram of three dimensional reconstruction. This block diagram represents the process used in the computer program call to reconstruct the three dimensional coordinates.

G.2 PROGRAM LISTING: CONSTRUCTION

```
      PROGRAM CONSTR
C                              VERSION: 28-MAR-84
CCCCCCCC
CCCCCCCC
CCCCCCCC
CCCCCCCC
CCCCCCCC
CCCCCCCC
C
      COMMON X(10,50),Z(10,50),X1(50),Y1(50),Z1(50),M,N,IREFPT,
     &          ALPHA(50)
      COMMON/BLOCK4/INT(50)
      DIMENSION  SUM1(6),SUM2(6),SUM3(6),NAME1(15)
      BYTE NAME1
      NAME1(15)=0
C
      TYPE *,'ENTER LOGICAL UNIT-- 6 PRINTER, 7-TERMINAL'
      ACCEPT *,LU
      IF(LU.EQ.6)OPEN(UNIT=6,NAME='LS:',CARRIAGECONTROL='FORTRAN')
C
101   K=0
      DO 102,I=1,6
      SUM1(I)=0.
      SUM2(I)=0.
102   SUM3(I)=0.
C
C     INPUT DATA FROM EXISTING FILE
C
      CALL INPUT
      CALL RECONS(LU)
2     CALL VIEWIT
C
      TYPE *,'DO YOU WISH TO TRANSLATE AND ROTATE THE POINTS? Y/N'
      TYPE *,'IF ROTATION ONLY ENTER R'
      ACCEPT 1,ANS
1     FORMAT(A2)
      IF(ANS.NE.'Y'.AND.ANS.NE.'R')GOTO 3
      IF(ANS.EQ.'Y')GOTO 4
      TYPE *,'ENTER, IN RADIANS, THE VALUES OF THETA, PHI AND GAMMA'
      TYPE *,'NOTE:  CAN  ROTATE  IN  ONE  PLANE  ONLY'
      ACCEPT *,THETA,PHI,GAMMA
      GOTO 5
4     CALL TRANSL(THETA,PHI,GAMMA)
5     CALL ROTATE(THETA,PHI,GAMMA)
      K=K+1
      SUM1(K)=THETA
      SUM2(K)=PHI
      SUM3(K)=GAMMA
      GOTO 2
3     CALL OUTPUT(NAME1)
      WRITE(LU,33)NAME1
33    FORMAT('1',/,' FILE: ',15A1)
      WRITE(LU,6)IREFPT
6     FORMAT(' REFERNCE POINT',I2)
      DO 7,I=1,K
      WRITE(LU,8) I,SUM1(I),SUM2(I),SUM3(I)
8     FORMAT(' ',I2,' ROTATE X-Y ',F7.4,' RADIANS',/,11X,'X-Z ',F7.4,
     &       /,11X,'Y-Z ',F7.4)
7     CONTINUE
      WRITE(LU,*)'PT#    X          Y          Z'
      DO 10,I=1,N
      IF(INT(I).NE.I)GOTO 34
      WRITE(LU,45)I,X1(I),Y1(I),Z1(I),INT(I)
      GOTO 10
34    WRITE(LU,40)I,X1(I),Y1(I),Z1(I)
10    CONTINUE
40    FORMAT(' ',I2,F8.3,2X,F8.3,2X,F8.3)
45    FORMAT(' ',I2,F8.3,2X,F8.3,2X,F8.3,' POINT #',I2,' IS NOT COMMON')
      WRITE(LU,150)
150   FORMAT('1')
```

```
TYPE *,'DO YOU WISH TO CONTINUE? Y/N'
ACCEPT 1,ANS
IF(ANS.EQ.'Y')GOTO 101
STOP '--END OF CONSTRUCTION--'
END
```

```
      SUBROUTINE INPUT
C
C     VERSION 4-JAN-84
C
C     ROUTINE TO INPUT DATA FROM AN EXISTING FILE
C
      BYTE NAME1
      DIMENSION NAME1(15)
      COMMON X(10,50),Z(10,50),X1(50),Y1(50),Z1(50),M,N,IREFPT,
     &       ALPHA(50)
      COMMON/BLOCK2/RMAGX1(10),RMAGX2(10),RMAGY1(10),RMAGY2(10),
     &             RMAG
      COMMON/BLOCK3/REFX1(10),REFY1(10),REFX2(10),REFY2(10)
C
1     TYPE *,'ENTER COMPLETE NAME OF INPUT FILE'
      ACCEPT 5,NAME1
5     FORMAT(15A1)
      NAME1(15)=0
      OPEN(UNIT=2,NAME=NAME1,TYPE='OLD',ERR=20)
      READ(2,*) M,N
      DO 15,K=1,M
       READ(2,*) J,ALPHA(J),L,RMAGX1(K),RMAGY1(K),L,RMAGX2(K),
     &           RMAGY2(K)
       READ(2,*) L,REFX1(K),REFY1(K),L,REFX2(K),REFY2(K)
      DO 10,I=1,N
       READ(2,*) L,X(J,I),Z(J,I)   !NOTE L IS A DUMMY VARIABLE
10    CONTINUE
15    CONTINUE
C
C     CLOSE INPUT FILE
C
      CLOSE(UNIT=2)
C
      RETURN
20    STOP 'FILE OPENING ERROR'
      END
```

```
      SUBROUTINE RECONS(LU)
C                                  version:  23-05-84
CC
CC    THIS SUBROUTINE CALCULATES THE COORDINATES OF A THREE DIMENSIONAL
CC    VIEW BY WORKING WITH THE X-Y COORDINATES OF TWO TWO DIMENSIONAL
CC    VIEWS
CC
CC
C
      COMMON X(10,50),Z(10,50),X1(50),Y1(50),Z1(50),M,N,IREFPT,
     &          ALPHA(50)
      COMMON/BLOCK2/RMAGX1(10),RMAGX2(10),RMAGY1(10),RMAGY2(10),
     &               RMAG
      COMMON/BLOCK4/INT(50)
      DIMENSION Y(10,50)
C
C     ZEROING 'NOT COMMON' VECTOR!
      DO 4,I=1,N
4     INT(I)=0
CC
CC    REFERENCING TO DESIRED POINT OF VIEW #1,NOTE, VIEW #1 ASSUMED
CC    TO BE INITIAL VIEW (IE. AT ZERO ANGLE)
C
      TYPE  *,'INPUT  THE  REFERENCE  POINT  NUMBER'
      ACCEPT *,IREFPT
      TYPE *,'INPUT LIMIT FOR Z IN MAG CALCULATION ( 1 IS STANDARD )'
      ACCEPT *,XLIM
C
      DO 10,J=1,M
       XREF=X(J,IREFPT)
       ZREF=Z(J,IREFPT)
      DO 5,I=1,N
        IF(X(J,I).EQ.0.AND.Z(J,I).EQ.0.)INT(I)=I
       X(J,I)=X(J,I)-XREF
       Z(J,I)=ZREF-Z(J,I)   !NEGITIVE Z AS Y=-Z FROM DIGITIZER
5     CONTINUE
10    CONTINUE
C
CC    ORIENTING ALL VIEWS USING THE REFERENCE WIRE,
CC    WILL ROTATE UNTIL Jth VIEW IS REFERNCED TO 1st.
C
      CALL REFER(LU)
C
      DO 11,J=1,M
       K=1
       IF(ALPHA(J).LT.0)K=-1
        ALPHA(J)=K*(90-K*ALPHA(J))*3.14159/180.
11    CONTINUE
C
CC    CALCULATION OF MAGNIFICATION OF Jth VIEW WRT THE FIRST VIEW
CC
CC
CC    USING REFERENCE WIRE!!
C
      RMAG=SQRT((RMAGX1(1)-RMAGX2(1))**2+(RMAGY1(1)-RMAGY2(1))**2)
C
      DO 25,J=2,M          !CALCULATION LOOP
C
        RMAGJ=RMAG/SQRT((RMAGX1(J)-RMAGX2(J))**2+
     &                                (RMAGY1(J)-RMAGY2(J))**2)
      TYPE *,'MAGNIFICATION OF VIEW # ',J,' IS  ',RMAGJ
      TYPE *,'USING REFERERENCE WIRE!'
      IF(LU.EQ.6)WRITE(LU,1010)J,RMAGJ
1010  FORMAT(' ',/,' MAGNIFICATION OF VIEW # ',I2,' IS ',F7.3,/,
     &' USING REFERERENCE WIRE!')
C
CC
CC
CC    USING AVERAGE OF Z VALUES OF ALL VIEWS!!
CC
C
```

```
      RMAG2=0.
      SUM1=0.
      NI=N
      DO 100,I=1,N
       ZP=Z(J,I)
       IF(ABS(ZP).LE.XLIM)GOTO 98  !REMOVES SMALL VALUES FROM CALCULATION
       IF(INT(I).NE.I)GOTO 99     !REMOVES UNCOMMON POINTS
98     NI=NI-1        !  NI USED SO THAT N WOULD NOT BE MODIFIED
       GOTO 100
99    IF(ZP.GT.0..AND.Z(1,I).LT.0)TYPE  *,'PROBLEM  AT  I=',I
      IF(ZP.LT.0..AND.Z(1,I).GT.0)TYPE *,'PROBLEM AT I=',I
      RMAG2=Z(1,I)/ZP + RMAG2
      SUM1=(Z(1,I)/ZP)**2 + SUM1
100   CONTINUE
      SD=SQRT((NI*SUM1-RMAG2**2)/(NI*(NI-1)))
      RMAG2=RMAG2/NI
      TYPE *,'MAGNIFICATION OF VIEW # ',J,' IS ',RMAG2,'SD= ',SD
      TYPE *,'USING AVERAGING FROM Z VALUES OF',NI,' POINTS'
      IF(LU.EQ.6)WRITE(LU,1011)J,RMAG2,SD,NI,XLIM
1011  FORMAT(' ',/,' MAGNIFICATION OF VIEW # ',I2,' IS ',F7.3,
     & ' +/- ',F6.3,' SD.',/,' USING AVERAGING FROM Z VALUES OF ',
     & I2,' POINTS, WITH Z LIMIT = ',F5.2,/)
C
      TYPE *,'ENTER 1 OR 0 FOR CHOICE OF MAG CAL., REF WIRE'
      TYPE *,'OR Z VALUES RESPECTIVELY'
      ACCEPT *,K
      IF(K.EQ.1)GOTO 1012
      RMAGJ=RMAG2
      IF(LU.EQ.6)WRITE(LU,*)'USING Z VALUE FOR MAGNIFCATION!'
C
C     CALCULATION OF Y
C
1012  IF(K.EQ.1)WRITE(LU,*)'USING REF. WIRE FOR MAGNIFCATION!'
       DO 20,I=1,N
C
C
        Y(J,I)=-X(J,I)/COS(ALPHA(J))*RMAGJ+X(1,I)*SIN(ALPHA(J))
     &          /COS(ALPHA(J))
        Z(J,I)=(Z(1,I)+RMAGJ*Z(J,I))/2
20    CONTINUE
25    CONTINUE
C
C     AVERAGING Z AND Y FROM THE M VIEWS
C
      TYPE *,'PT.#   X      Y      Z'
      DO 35, I=1,N
       Y(1,I)=0.
      DO 30, J=2,M
       Z(1,I)=Z(J,I)+Z(1,I)
       Y(1,I)=Y(J,I)+Y(1,I)
30    CONTINUE
C
      X1(I)=X(1,I)
      Y1(I)=Y(1,I)/(M-1)
      Z1(I)=Z(1,I)/M
C
      IF(INT(I).NE.I)GOTO 34
       X1(I)=0.
       Y1(I)=0.
       Z1(I)=0.
      TYPE 45,I,X1(I),Y1(I),Z1(I),INT(I)
      GOTO 35
34    TYPE 40,I,X1(I),Y1(I),Z1(I)
35    CONTINUE
40    FORMAT(' ',I2,F7.3,2X,F7.3,2X,F7.3)
45    FORMAT(' ',I2,F7.3,2X,F7.3,2X,F7.3,' POINT #',I2,' IS NOT COMMON')
      RETURN
      END
```

```
      SUBROUTINE OUTPUT(NAME1)
C
C     VERSION: 6-DEC-83
C
C     ROUTINE TO OUTPUT DATA TO AN EXISTING FILE
C
      BYTE NAME1
      DIMENSION NAME1(15)
      COMMON X(10,50),Z(10,50),X1(50),Y1(50),Z1(50),M,N,IREFPT,
     &       ALPHA(50)
      COMMON/BLOCK2/RMAGX1(10),RMAGX2(10),RMAGY1(10),RMAGY2(10),
     &              RMAG
C
1     TYPE *,'ENTER COMPLETE NAME OF OUTPUT FILE'
      ACCEPT 5,NAME1
5     FORMAT(15A1)
      NAME1(15)=0
      OPEN(UNIT=2,NAME=NAME1,TYPE='UNKNOWN',ERR=20)
      WRITE(2,*) IREFPT,N,RMAG
      DO 10,I=1,N
       WRITE(2,6) X1(I),Y1(I),Z1(I)
6     FORMAT(F7.3,1X,F7.3,1X,F7.3)
10    CONTINUE
C
C     CLOSE INPUT FILE
C
      CLOSE(UNIT=2)
C
      RETURN
20    STOP 'FILE OPENING ERROR'
      END
```

```
      SUBROUTINE VIEWIT
C
C     VERSION: 6-DEC-83
C
C     THIS SUBPROGRAM PREPARES THE DATA FOR PLOTING
C
      COMMON X(10,50),Z(10,50),X1(50),Y1(50),Z1(50),M,N,IREFPT,
     &       ALPHA(50)
      DIMENSION IXX(50),IYY(50),IZZ(50)
C
      IAXISX='X'
      IAXISY='Y'
      IAXISZ='Z'
C
      DO 5,I=1,N
       IXX(I)=1000*X1(I)
       IYY(I)=1000*Y1(I)
5      IZZ(I)=1000*Z1(I)
C
C     FINDING THE MAXIMUM AND MINIMUM OF EACH VECTOR
C
      IMAXX=IXX(1)
      IMINX=IXX(1)
      IMAXY=IYY(1)
      IMINY=IYY(1)
      IMAXZ=IZZ(1)
      IMINZ=IZZ(1)
      DO 10,I=2,N
       IF(IXX(I).GT.IMAXX)IMAXX=IXX(I)
       IF(IXX(I).LT.IMINX)IMINX=IXX(I)
       IF(IYY(I).GT.IMAXY)IMAXY=IYY(I)
       IF(IYY(I).LT.IMINY)IMINY=IYY(I)
       IF(IZZ(I).GT.IMAXZ)IMAXZ=IZZ(I)
       IF(IZZ(I).LT.IMINZ)IMINZ=IZZ(I)
10    CONTINUE
C
C     DETERMINING NORMALIZING FACTOR
C
      IMAXX=IMAXX-IMINX
      IMAXY=IMAXY-IMINY
      IMAXZ=IMAXZ-IMINZ
C
C     NOTE: ALTHOUGH RANGE OF POINTS IS 0-235,0-511,  THE  RANGE
C     WAS REDUCED BY 1 SO THAT THE EDGE WOULD BE EASILY  VISIBLE
C     ALSO, THE 1 WAS ADDED AFTER TO RAISE THE POINTS OF THE BOTTOM
C     OF THE SCREEN
C
      RNORM=234./IMAXX
      IF(IMAXY.GT.IMAXX)RNORM=234./IMAXY
      IF(RNORM*IMAXZ.GT.510)RNORM=510./IMAXZ
C
      DO 20,I=1,N
       IXX(I)=(IXX(I)-IMINX)*RNORM+1
       IYY(I)=(IYY(I)-IMINY)*RNORM+1
       IZZ(I)=(IZZ(I)-IMINZ)*RNORM+1
20    CONTINUE
C
25    TYPE *,'ENTER  THE  NUMBER  OF  VIEWS  TO  BE  DISPLAYED'
      ACCEPT *,K
      K=K-2
      IF(K)1,2,3
C
1     TYPE *,'ENTER THE DESIRED VIEW'
      TYPE *,'EX. X vs. Y  ENTER 1'
      TYPE *,'    X vs. Z        0'
      TYPE *,'    Y vs. Z       -1'
      ACCEPT *,K
      L=1
      IF(K) 150,100,50
C
2     TYPE *,'ENTER BOTH VIEWS DESIRED'
```

```
      TYPE *,'ES. X vs. Y  ENTER 1'
      TYPE *,'    X vs. Z        0'
      TYPE *,'    Y vs. Z       -1'
      ACCEPT *,K,L
      IF(K) 150,100,50

C
3     L=-1
50    CALL PLOTIT(IXX,IYY,N,IREFPT,IAXISX,IAXISY)
      IF(L.EQ.1)GOTO 200
100   CALL PLOTIT(IZZ,IXX,N,IREFPT,IAXISZ,IAXISX)
      IF(L.NE.-1)GOTO 200
150   CALL PLOTIT(IZZ,IYY,N,IREFPT,IAXISZ,IAXISY)
200   CALL CLRSCN
      TYPE *,'DO YOU WANT ANOTHER VIEW?  Y/N'
      ACCEPT 4,ANS
4     FORMAT(A2)
      IF(ANS.EQ.'Y')GOTO 25
      RETURN
      END
```

```
C
C
C       SUBROUTINE PLOTIT
C
C       VERSION: 6-DEC-83
C
C       THIS SUBROUTINE PLOTS THE  POINTS  OF  TWO  VECTORS  IN  A
C       X-Y PLANE AND NUMBERS EACH POINT
C
        SUBROUTINE PLOTIT(IX1,IY1,N,IREFPT,IAXISX,IAXISY)
C
        DIMENSION NUMBER(10),IX1(1),IY1(1)
        BYTE NUMBER,IANSI(2),IVT52(5)
        DATA IVT52/"033,"133,"077,"062,"154/
        DATA IANSI/"033,"074/
        DATA NUMBER/'1','2','3','4','5','6','7','8','9','0'/
C
C       CHANGE TERMINAL TO PLOT MODE
C
        WRITE(5,3)IVT52
3       FORMAT(1X,5A1)
C
C
C       INITIALIZATION OF GRAPH SOFTWARE
C
        CALL CLRSCN
        CALL PLOT55(1,0,)
        CALL PLOT55(2,1+2+32+64+512,)
C
C       CALCULATING AXISES LABEL POSITIONS
C
        IXY=IX1(IREFPT)*79./511.
        IYY=0
C
        IYX=23-(IY1(IREFPT)*23./235.)
        IXX=71
C
C       PLOT COORDINATE AXES AND LABEL
C
        CALL PLOT55(9,IXX,IYX)
        CALL PLOT55(12,1,IAXISX)
C
        CALL PLOT55(9,IXY,IYY)
        CALL PLOT55(12,1,IAXISY)
C
        CALL PLOT55(4,1,IY1(IREFPT))
        CALL PLOT55(5,IX1(IREFPT),1)
C
C       PLOT THE POINTS
C
        J=0
        K=0
        DO 10,I=1,N
        K=K+1
         IXX=IX1(I)*79./511.
         IF(IXX.GT.71)IXX=71
         IYX=23-IY1(I)*23./235.
         IF(IYX.EQ.0)IYX=IYX+2
         IYX=IYX-2
        IF(IXX.EQ.0)IXX=1
        IXX1=IXX-1
         CALL PLOT55(9,IXX,IYX)
         CALL PLOT55(12,1,NUMBER(K))
        IF(K.EQ.10)J=J+1
        IF(K.EQ.10)K=K-10
         CALL PLOT55(9,IXX1,IYX)
        IF(J.EQ.0)GOTO 10
        IF(J.EQ.1)CALL PLOT55(12,1,'1')
        IF(J.EQ.2)CALL PLOT55(12,1,'2')
        IF(J.EQ.3)CALL PLOT55(12,1,'3')
10      CONTINUE
```

```
C
      DO 15,I=1,N
       CALL PLOT55(3,IX1(I),IY1(I))
15    CONTINUE
C
C
      ACCEPT 5,KR
5     FORMAT(A2)
      CALL CLRSCN
C
C     RETURN TO ANSI MODE
C
      WRITE(5,3)IANSI
C
      RETURN
      END


      SUBROUTINE CLRSCN
C
C     CLEAR SCREEN OF GRAPHICS
C
      CALL PLOT55(1,0,)
      CALL PLOT55(2,512,)
      CALL PLOT55(1,1,)
      CALL PLOT55(2,512,)
      CALL PLOT55(13,72,)
      CALL PLOT55(13,74,)
      CALL PLOT55(2,,1)
      RETURN
      END
```

```
      SUBROUTINE TRANSL(THETA,PHI,GAMMA)
C
C     VERSION: 6-DEC-83
C
C     THIS SUBROUTINE  REQUIRES  USER  INPUT  TO  CALCULATE  THE
C     NEW REFERENCE  POINT  AND  ANGLE  THE  DESIRED  AXIS  WILL
C     MAKE WITH THE PREVIOUS AXIS.
C
      COMMON X(10,50),Z(10,50),X1(50),Y1(50),Z1(50),M,N,IREFPT,
     &       ALPHA(50)
      TYPE *,'ENTER THE VIEW THAT  IS  TO  BE  ROTATED'
      TYPE *,'EX.  X vs. Y ENTER -1'
      TYPE *,'     X vs. Z        0'
      TYPE *,'     Y vs. Z        1'
      ACCEPT *,K
      TYPE *,'ENTER THE NEW REFERENCE POINT NUMBER AND'
      TYPE *,'A SECOND PT # WHICH LIES ON THE DESIRED AXIS'
      ACCEPT *,IREFPT,INEWPT
C
C     TRANSLATION TO NEW REF. PT.
C
      XREF=X1(IREFPT)
      YREF=Y1(IREFPT)
      ZREF=Z1(IREFPT)
      DO 10,I=1,N
       X1(I)=X1(I)-XREF
       Y1(I)=Y1(I)-YREF
       Z1(I)=Z1(I)-ZREF
10    CONTINUE
C
C     CALCULATING ROTATION ANGLE DEPENDING ON THE VIEW
C
      XO1=X1(INEWPT)
      YO1=Y1(INEWPT)
      ZO1=Z1(INEWPT)
C
      IF(K.NE.-1)GOTO 15
      THETA=0.
      IF(XO1.NE.0.)THETA=ATAN((YO1/XO1))
      PHI=0.
      GAMMA=0.
15    IF(K.NE.0)GOTO 20
      THETA=0.
      PHI=0.
      IF(ZO1.NE.0.)PHI=ATAN((XO1/ZO1))
      GAMMA=0.
20    IF(K.NE.1)GOTO 25
      THETA=0.
      PHI=0.
      GAMMA=0.
      IF(ZO1.NE.0.)GAMMA=ATAN((YO1/ZO1))
25    RETURN
      END
```

```
C-----------------------------------------------------------------
C
C       SUBROUTINE REFER
C
C       VERSION: 84-05-12
C
C       THIS SUBROUTINE IS  DESIGNED  TO  ROTATE  Jth  VIEW  UNTIL
C       THE X  COORDINATES  ARE  IN  LINE  WITH  THE  ORINGINAL  Z
C       AXIS, THE AXIS OF ROTATION OF THE N VIEWS
C
C
C-----------------------------------------------------------------
        SUBROUTINE REFER(LU)
C
        DIMENSION A(2,2),B(2,50),R(2,50)
        COMMON X(10,50),Z(10,50),X1(50),Y1(50),Z1(50),M,N,IREFPT,
     &         ALPHA(50)
        COMMON/BLOCK3/REFX1(10),REFY1(10),REFX2(10),REFY2(10)
C
        TYPE *,'DO YOU WISH THE ROTATED VALUES TO BE PRINTED? Y-N'
        ACCEPT 111,ANS
111     FORMAT(A2)
        PI=3.1415926
        DO 20,J=1,M
C
C       DETERMINE ANGLE OF ROTATION C.C IS POSITVE
C
        PHI=PI/2.
        IF(ABS(REFY2(J)-REFY1(J)).LE.(1.0E-4))GOTO  1
        PHI=ATAN((REFX2(J)-REFX1(J))/(REFY2(J)-REFY1(J)))
C
1       TYPE  *,'ROTATION  OF  VIEW  #',J,'  :  ',PHI,'  RADIANS.'
        IF(LU.EQ.6)WRITE(6,15)J,PHI
15      FORMAT(' ',/,' ROTATION OF VIEW #',I2,' : ',F6.3,' RADIANS.')
C       ROTATION MATRIX
C
        A(1,1)=COS(PHI)
        A(2,2)=A(1,1)
        A(1,2)=SIN(PHI)
        A(2,1)=-A(1,2)
C
        DO 5,I=1,N
        B(1,I)=X(J,I)
        B(2,I)=-Z(J,I)    !AS  Z  IS  -Y  FROM  DIGITIZER
5       CONTINUE
C
        CALL MPRD(A,B,R,2,2,0,0,N)
C
        DO 10,I=1,N
        X(J,I)=R(1,I)
        Z(J,I)=-R(2,I)
C
        IF(ANS.NE.'Y')GOTO 10
        TYPE *,X(J,I),Z(J,I)
        IF(LU.EQ.6)WRITE(6,25) I,X(J,I),Z(J,I)
25      FORMAT(' ',I2,2X,F7.3,2X,F7.3)
10      CONTINUE
20      CONTINUE
        RETURN
        END
```

APPENDIX H STRAIN CALCULATION

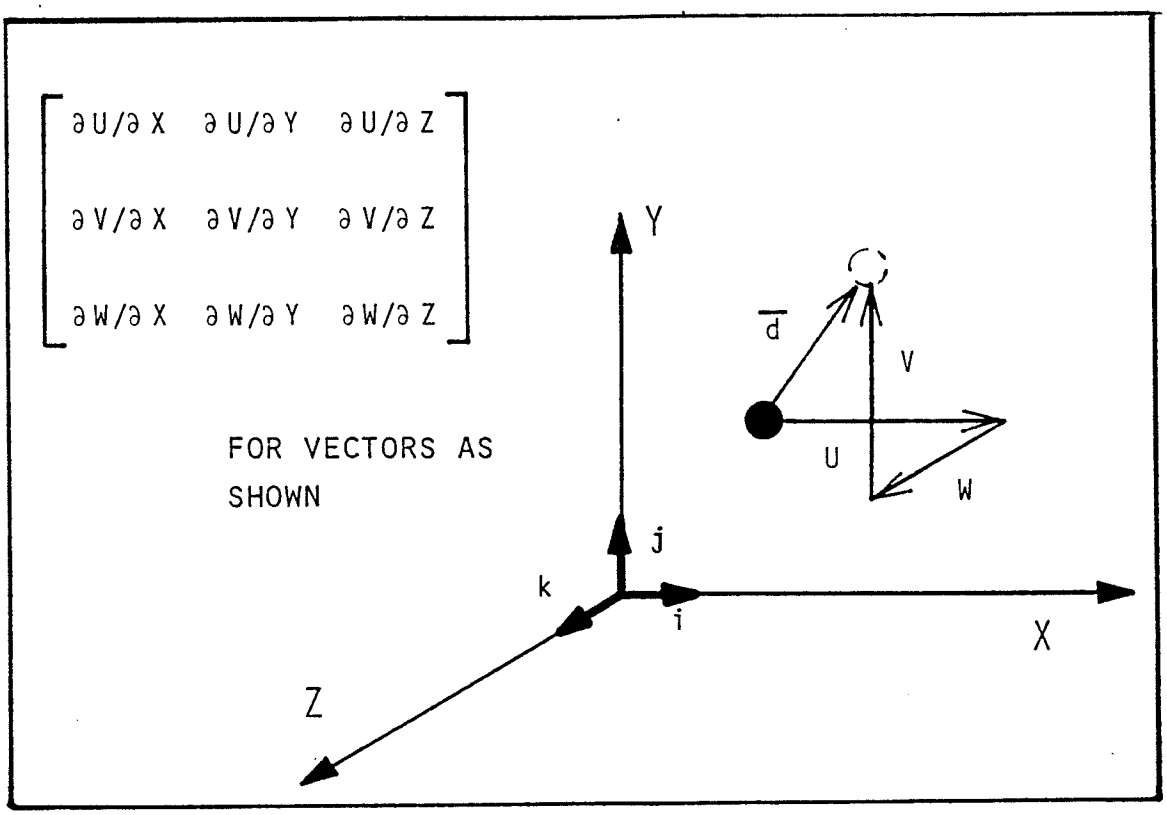


Figure H.1 Nine first derivatives of the displacement field - the Deformation matrix.

$$\begin{bmatrix} \partial U/\partial X & \frac{1}{2}(\partial U/\partial Y+\partial V/\partial X) & \frac{1}{2}(\partial U/\partial Z+\partial W/\partial X) \\ \frac{1}{2}(\partial V/\partial X+\partial U/\partial Y) & \partial V/\partial Y & \frac{1}{2}(\partial V/\partial Z+\partial W/\partial Y) \\ \frac{1}{2}(\partial U/\partial Z+\partial W/\partial X) & \frac{1}{2}(\partial V/\partial Z+\partial W/\partial Y) & \partial W/\partial Z \end{bmatrix}$$

Figure H.2 Matrix of Infinitesimal Strain. The matrix is calculated using the elements of the deformation matrix, the first nine derivatives of the displacement field.

H.1 STRAIN CALCULATION

The definitions of deformation, normal strain and shearing strain that have been adopted for this study are defined by Histon et al [1967, pg. 48]. 'When the size or shape of a body is altered, the change in any dimension is termed a deformation, d, and the normal strain, E, is defined as the deformation per unit length. The shearing strain, γ , is defined as the change in angle between two planes which in the unstressed material are orthogonal.'

Funs [1969] defines the nine first derivatives of the displacement field as the deformation gradients. These derivatives are listed in figure H.1 in matrix form. The deformation gradients can then be used to calculate the matrix of infinitesimal strain [Funs, 1969] as seen in figure H.2. The elements of the diagonal of the matrix are the normal strains and the off diagonal elements are the shear strain components.

The nine first derivatives of displacement needed to calculate the normal and shear strain can be calculated using a first order approximation to the Taylor series expansion of deformation [Fenton et al, 1978]. Figure H.3 shows the Taylor expansion of a deformation in a vector U and the first order approximation to this expansion. When using this first order approximation to deformation of vectors in all three axes, X, Y, and Z, the deformation matrix can be calculated as seen in figure H.4.

TAYLOR SERIES EXPANSION OF VECTOR U

$$U_j = U_i + \partial U/\partial X * \Delta X_{ji} + \partial U/\partial Y * \Delta Y_{ji} + \partial U/\partial Z * \Delta Z_{ji}$$
$$+ \partial^2 U/\partial X^2 * \Delta X_{ji}^2 + \partial^2 U/\partial Y^2 * \Delta Y_{ji}^2 + \partial^2 U/\partial Z^2 * \Delta Z_{ji}^2 +$$
$$\frac{1}{2} \partial U/\partial X \, \partial U/\partial Y * \Delta X_{ji} \Delta Y_{ji} + \frac{1}{2} \partial U/\partial Z \partial U/\partial X * \Delta Z_{ji} \Delta X_{ji} +$$
$$\frac{1}{2} \partial U/\partial Y \, \partial U/\partial Z * \Delta Y_{ji} \Delta Z_{ji} + \ldots\ldots\ldots\ldots$$

FIRST ORDER APPROXIMATION

$$U_j = U_i + \partial U/\partial X * \Delta X_{ji} + \partial U/\partial Y * \Delta Y_{ji} + \partial U/\partial Z * \Delta Z_{ji}$$

Figure H.3 Taylor series expansion of a deformation vector U_j. The first order approximation that is used for strain analysis is shown.

$$\begin{bmatrix} U_{ji_1} & U_{ji_2} & U_{ji_3} \\ V_{ji_1} & V_{ji_2} & V_{ji_3} \\ W_{ji_1} & W_{ji_2} & W_{ji_3} \end{bmatrix} = \begin{bmatrix} \partial U/\partial X & \partial U/\partial Y & \partial U/\partial Z \\ \partial V/\partial X & \partial V/\partial Y & \partial V/\partial Z \\ \partial W/\partial X & \partial W/\partial Y & \partial W/\partial Z \end{bmatrix} \cdot \begin{bmatrix} \Delta X_{ji_1} & \Delta X_{ji_2} & \Delta X_{ji_3} \\ \Delta Y_{ji_1} & \Delta Y_{ji_2} & \Delta Y_{ji_3} \\ \Delta Z_{ji_1} & \Delta Z_{ji_2} & \Delta Z_{ji_3} \end{bmatrix}$$

A B C

Figure H.4 Calculation of the Deformation matrix.
Matrix A - displacement matrix,
Matrix B - deformation matrix,
Matrix C - distance matrix. $B = A * C^{-1}$
The calculation of the deformation matrix requires three pairs of points within a given area of analysis.

These calculations of the deformation matrix and strain matrix can also be made for each two dimensional plane as seen in figure H.5. When using the two dimensional plane strain calculations, the principle strains in these planes can be calculated. 'The maximum and minimum normal stresses (strains) at a point in a body are defined as principle stresses (strains), and the planes on which they act are called the principle planes.' [Hisdon et al, 1967]. These principle strains and planes are calculated using Mohr's circle (see figure H.6).

A computer program was written to calculate the nine first derivatives of the deformation matrix. This algorithm required three pairs of points for the calculation. The three pairs were chosen from within a small area so that there would be minimum error due to change in strain within this area. Points within a distance of approximately 0.5 mm. of each other (one fifth of the arterial diameter) was arbitrarily decided as an appropriate distance for the calculation of the elements in the arterial strain calculations. The algorithm calculated the three dimensional deformation matrix, as well as each plane deformation matrix. The principle strains and planes were calculated from each plane deformation matrix.

The computer program of the strain calculation algorithm is listed in the following pages.

X-Y PLANE

$$\begin{bmatrix} \Delta U_{ji_1} & \Delta U_{ji_2} \\ \Delta V_{ji_1} & \Delta V_{ji_2} \end{bmatrix} = \begin{bmatrix} \partial U/\partial X & \partial U/\partial Y \\ \partial V/\partial X & \partial V/\partial Y \end{bmatrix} \cdot \begin{bmatrix} \Delta X_1 & \Delta X_2 \\ \Delta Y_1 & \Delta Y_2 \end{bmatrix}$$

A B C

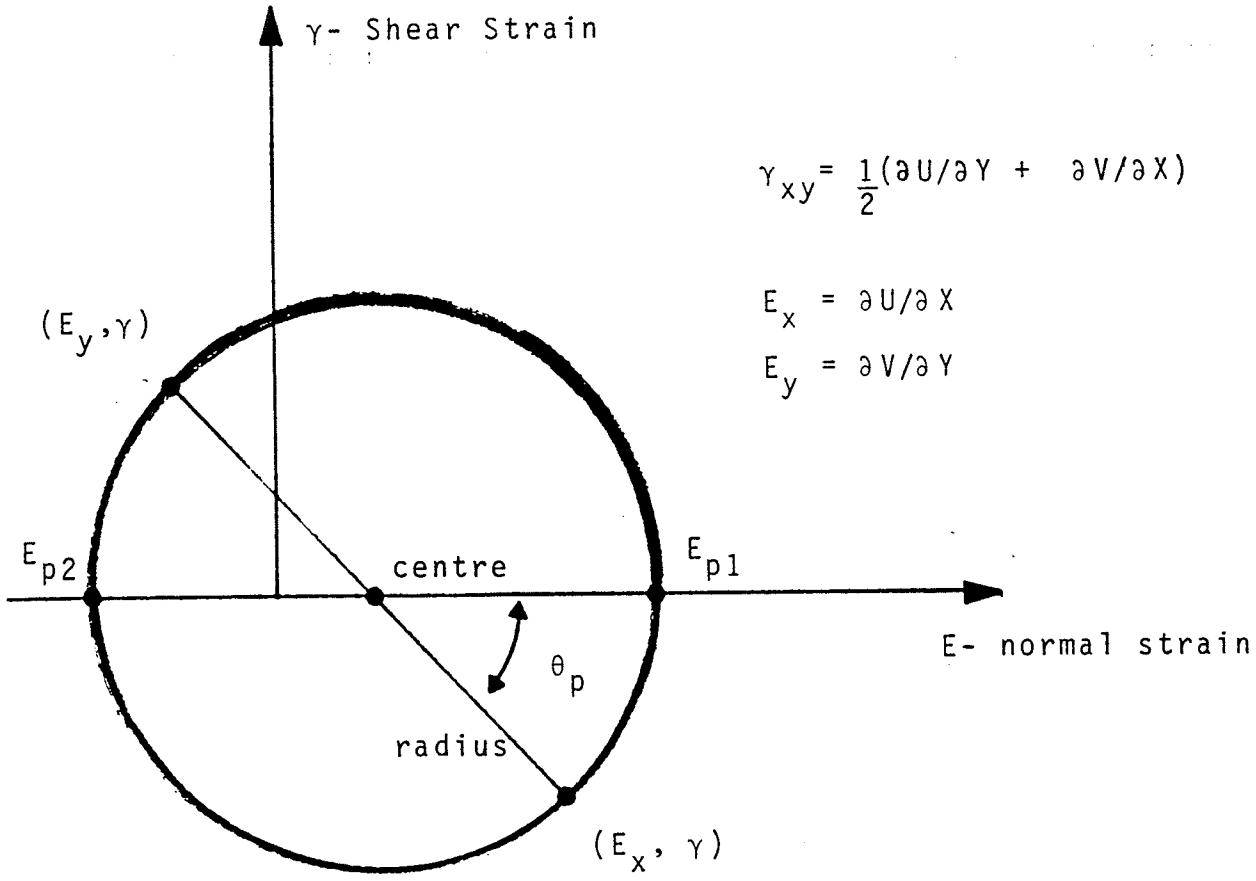
Y-Z PLANE

$$\begin{bmatrix} \Delta V_{ji_1} & \Delta V_{ji_2} \\ \Delta W_{ji_1} & \Delta W_{ji_2} \end{bmatrix} = \begin{bmatrix} \partial V/\partial Y & \partial V/\partial Z \\ \partial W/\partial Y & \partial W/\partial Z \end{bmatrix} \cdot \begin{bmatrix} \Delta Y_1 & \Delta Y_2 \\ \Delta Z_1 & \Delta Z_2 \end{bmatrix}$$

X-Z PLANE

$$\begin{bmatrix} \Delta U_{ji_1} & \Delta U_{ji_2} \\ \Delta W_{ji_1} & \Delta W_{ji_2} \end{bmatrix} = \begin{bmatrix} \partial U/\partial X & \partial U/\partial Z \\ \partial W/\partial X & \partial W/\partial Z \end{bmatrix} \cdot \begin{bmatrix} \Delta X_1 & \Delta X_2 \\ \Delta Z_1 & \Delta Z_2 \end{bmatrix}$$

Figure H.5 Two dimensional calculation of the deformation matrix. $B=A*C^{-1}$, each calculation requires two pairs of points. Matrix A- displacement matrix, Matrix B- deformation matrix, Matrix C- distance matrix.



$$\text{radius} = \sqrt{(E_x - E_y)^2 + \gamma_{xy}^2} \;/\; 2 \;, \quad \text{centre} = (E_x + E_y)/2$$

$$E_{p1} = \text{centre} + \text{radius}$$

$$E_{p2} = \text{centre} - \text{radius}$$

$$\theta_p = \frac{1}{2} \text{Tan}^{-1}(\gamma_{xy}/(E_x - E_y))$$

Figure H.6 Mohr's Circle for principle strain calculations. E_x is plotted below the axis for positive shear, and principle angle is positive counter clockwise.

H.2 PROGRAM LISTING: STRAIN

```
C
C-----------------------------------------------------------------------
C
C       PROGRAM  STRAIN                    VERSION:  84-06-06
C
C       THIS PROGRAM CALCULATES THE 3-DIMENSIONAL STRAIN MATRIX USING
C       3 PAIRS OF POINTS AS DISCRIBED BY X,Y, AND Z  CORRDINATES.
C
C       THEORETICAL EQUATIONS ARE:
C
C              Uj-Ui = dU/dX * dXji +  dU/dY  *  dYji  +  dU/dZ  *  dZji
C              Vj-Vi = dV/dX * dXji +  dV/dY  *  dYji  +  dV/dZ  *  dZji
C              Wj-Wi = dW/dX * dXji +  dW/dY  *  dYji  +  dW/dZ  *  dZji
C
C                     where:  U,V,W  are  displacement  vector  components
C                             in x,y,z respectively.
C                             dXji,dYji,dZji are distance between j th
C                             and i th points.
C
C
C       THECNIQUE: using matrix manipulation, solve for strain matrix R.
C
C                           B = R * A
C
C              where:  B is displacement vector
C                      R is strain matrix
C                      A is distance vector
C
C       THE STRAIN MATRIX IS THEN CALCULATED AS:
C                           -1
C                      R=B*A
C
C-----------------------------------------------------------------------
C
      PROGRAM STRAIN
C
      BYTE NAME1
      DIMENSION A(3,3),B(3,3),R(3,3),L(3),M(3),NAME1(15)
      COMMON  X(50),XS(50),YS(50),Y(50),Z(50),ZS(50),
     &       I(3),J(3),LU,LV
C
      TYPE *,'ENTER LOGICAL UNIT NUMBER; 6-PRINTER, 7-TERMINAL'
      ACCEPT *,LU
      TYPE *,'ENTER LEVEL OF PRINTED OUTPUT; 0-RESULTS'
      TYPE *,'                               1-MAXIMUM INFORMATION'
      ACCEPT *,LV
C
C     MUST OPEN TO USE CARRIAGECONTROLS-AUTO PATCH NOT DONE  YET
C
      IF(LU.EQ.6)OPEN(UNIT=6,NAME='LS:',CARRIAGECONTROL='FORTRAN')
C
55    TYPE *,'ENTER COMPLETE NAME  OF  UNSTRAINED  INPUT  FILE'
      ACCEPT 5,NAME1
5     FORMAT(15A1)
      OPEN(UNIT=2,NAME=NAME1,TYPE='OLD',ERR=30)
      READ(2,*)IREFPT,N,RMAG
      DO 6,K=1,N
6      READ(2,*)X(K),Y(K),Z(K)
      CLOSE(UNIT=2)
C
66    TYPE *,'ENTER  COMPLETE  NAME  OF  STRAINED  INPUT  FILE'
      ACCEPT 5,NAME1
      OPEN(UNIT=2,NAME=NAME1,TYPE='OLD',ERR=35)
      READ(2,*)IREFPT,N,RMAGS
      RMAG=RMAG/RMAGS     !  REFERENCING MAGNIFICATIONS
C
      DO 7,K=1,N
       READ(2,*)XS(K),YS(K),ZS(K)
       XS(K)=XS(K)*RMAG
       YS(K)=YS(K)*RMAG
7      ZS(K)=ZS(K)*RMAG
```

```
C
      CLOSE(UNIT=2)
C
C     PRINTING OUT DATA
C
      IF(LU.EQ.6)WRITE(6,88)NAME1
      TYPE 88,NAME1
88    FORMAT('1',/,' FILE: ',15A1)
C
8     TYPE *,'ENTER THE THREE PAIRS OF POINTS  TO  BE  USED  TO'
      TYPE *,'CALCULATED THE STRAIN.'
      ACCEPT *,I(1),J(1),I(2),J(2),I(3),J(3)
C
      IF(LV.EQ.1)WRITE(LU,*)
      IF(LV.EQ.1)WRITE(LU,*)'PT#   X,Y,Z (UNSTRAINED)    XS,YS,ZS
     & (STRAINED)'
C
      DO 10,K=1,3
C
      IF(LV.EQ.1)WRITE(LU,110)I(K),X(I(K)),Y(I(K)),Z(I(K)),XS(I(K)),
     &                    YS(I(K)),ZS(I(K))
      IF(LV.EQ.1)WRITE(LU,110)J(K),X(J(K)),Y(J(K)),Z(J(K)),XS(J(K)),
     &                    YS(J(K)),ZS(J(K))
110   FORMAT(' ',I5,3F7.3,2X,3F7.3)
C
        B(1,K)=(XS(J(K))-X(J(K)))-(XS(I(K))-X(I(K)))
        B(2,K)=(YS(J(K))-Y(J(K)))-(YS(I(K))-Y(I(K)))
        B(3,K)=(ZS(J(K))-Z(J(K)))-(ZS(I(K))-Z(I(K)))
C
       A(1,K)=X(J(K))-X(I(K))
       A(2,K)=Y(J(K))-Y(I(K))
       A(3,K)=Z(J(K))-Z(I(K))
10    CONTINUE
C
      IF(LV.NE.1)GOTO 13
      WRITE(LU,*)
      WRITE(LU,*)'DISPLACEMENT MATRIX'
      DO 11,K=1,3
11    WRITE(LU,*)B(K,1),B(K,2),B(K,3)
C
      WRITE(LU,*)
      WRITE(LU,*)'DISTANCE MATRIX'
      DO 12,K=1,3
12    WRITE(LU,*)A(K,1),A(K,2),A(K,3)

C
C      INVERT A
CC
13    CALL MINV(A,3,D,L,M)
      IF(D.EQ.0)GOTO 26
C
133   IF(LV.NE.1)GOTO 16
      WRITE(LU,*)
      WRITE(LU,*)'INVERSE OF DISTANCE MATRIX'
      DO 14,K=1,3
14    WRITE(LU,*)A(K,1),A(K,2),A(K,3)
      PAUSE 'ENTER CR TO CONTINUE'
C
C     CALCULATE STRAIN MATRIX
C
16    CALL MPRD(B,A,R,3,3,0,0,3)
C
26    IF(LU.EQ.6)WRITE(LU,*)'USING POINTS'
      WRITE(7,*)'USING POINTS'
      DO 20,K=1,3
      WRITE(7,25)I(K),J(K)
20    IF(LU.EQ.6)WRITE(LU,25)I(K),J(K)
25    FORMAT(' ',I2,'-',I2)
C
      IF(D.NE.0.)GOTO 250
      IF(LU.EQ.6)WRITE(6,*)'-- DISTANCE MATRIX IS SINGULAR--'
```

```
      TYPE  *,'--DISTANCE  MATRIX  IS  SINGULAR--'
      GOTO 126
C
250   IF(LU.EQ.6)WRITE(LU,*)'STRAIN MATRIX'
      WRITE(7,*)'STRAIN MATRIX'
      IF(LU.EQ.6)WRITE(LU,15)R(1,1),R(1,2),R(1,3),R(2,1),
     &  R(2,2),R(2,3),R(3,1),R(3,2),R(3,3)
      WRITE(7,15)R(1,1),R(1,2),R(1,3),R(2,1),R(2,2),R(2,3),R(3,1),
     &           R(3,2),R(3,3)
15    FORMAT(' dU/dX  dU/dY  dU/dZ   ',E12.5,1X,E12.5,1X,E12.5,/,
     &       ' dV/dX  dV/dY  dV/dZ = ',E12.5,1X,E12.5,1X,E12.5,/,
     &       ' dw/dX  dW/dY  dW/dZ   ',E12.5,1X,E12.5,1X,E12.5,/,/)
C
126   TYPE *,'DO YOU WISH 2-DIMMENSIONAL STRAIN ANALYSIS? Y/N'
      ACCEPT 27,ANS
      IF(ANS.NE.'Y')GOTO 127
      CALL TWODXY             ! IN X-Y
      CALL TWODXZ             ! IN X-Z
      CALL TWODYZ             ! IN Y-Z
C
127   TYPE *,'DO YOU WISH TO RECALCULATE WITH DIFFERENT POINTS? Y/N'
      ACCEPT 27,ANS
27    FORMAT(A1)
      IF(ANS.EQ.'Y')GOTO 8
C
      TYPE *,'DO YOU WISH TO  USE  ANOTHER  FILE?  Y/N'
      ACCEPT 27,ANS
      IF(ANS.EQ.'Y')GOTO 55
      STOP '--END OF STRAIN CALCULATION--'
C
30    TYPE *,'--FILE OPENING ERROR--'
      CLOSE(UNIT=2)
      GOTO 55
35    TYPE *,'--FILE OPENING ERROR--'
      CLOSE(UNIT=2)
      GOTO 66
C
      END

      SUBROUTINE TWODXY

C
C
C     THIS SUBROUTINE CALCULATES THE STRAIN MATRIX  AS  OBTAINED
C     USING TWO DIMENSIONAL ANALYSIS.
C     X-Y
C
      DIMENSION  A(2,2),B(2,2),R(2,2),L(2),M(2)
      COMMON  X(50),XS(50),YS(50),Y(50),Z(50),ZS(50),
     &        I(3),J(3),LU,LV
C
      TYPE *,'WORKING IN X-Y PLANE'
      DO 10,K=1,2
        B(1,K)=(XS(J(K))-X(J(K)))-(XS(I(K))-X(I(K)))
        B(2,K)=(YS(J(K))-Y(J(K)))-(YS(I(K))-Y(I(K)))
C
       A(1,K)=X(J(K))-X(I(K))
       A(2,K)=Y(J(K))-Y(I(K))
10    CONTINUE
C
      WRITE(LU,*)
      WRITE(LU,*)'                        WORKING IN X-Y PLANE'
      IF(LV.NE.1)GOTO 13
      WRITE(LU,*)'DISPLACEMENT MATRIX'
      DO 11,K=1,2
11    WRITE(LU,*)B(K,1),B(K,2)
C
      WRITE(LU,*)
      WRITE(LU,*)'DISTANCE MATRIX'
      DO 12,K=1,2
12    WRITE(LU,*)A(K,1),A(K,2)
```

```
C
C        INVERT A
C
13      CALL MINV(A,2,D,L,M)
        IF(D.EQ.0.)GOTO 26
C
133     IF(LV.NE.1)GOTO 16
        WRITE(LU,*)
        WRITE(LU,*)'INVERSE OF DISTANCE MATRIX'
        DO 14,K=1,2
14      WRITE(LU,*)A(K,1),A(K,2)
        PAUSE 'ENTER CR TO CONTINUE'
C
C       CALCULATE STRAIN MATRIX
C
16      CALL MPRD(B,A,R,2,2,0,0,2)
C
26      IF(LU.EQ.6)WRITE(LU,*)'USING POINTS'
        WRITE(7,*)'USING POINTS'
        DO 20,K=1,2
        WRITE(7,25)I(K),J(K)
20      IF(LU.EQ.6)WRITE(LU,25)I(K),J(K)
25      FORMAT(' ',I2,'-',I2)
C
        IF(D.NE.0.)GOTO 250
        IF(LU.EQ.6)WRITE(6,*)'-- DISTANCE MATRIX IS SINGULAR--'
        TYPE  *,'--DISTANCE  MATRIX  IS  SINGULAR--'
        GOTO 126
C
250     IF(LU.EQ.6)WRITE(LU,*)'STRAIN MATRIX'
        WRITE(7,*)'STRAIN MATRIX'
        IF(LU.EQ.6)WRITE(LU,15)R(1,1),R(1,2),R(2,1),R(2,2)
        WRITE(7,15)R(1,1),R(1,2),R(2,1),R(2,2)
C
15      FORMAT(' dU/dX  dU/dY    ',E12.5,1X,E12.5,/,
     &          '  dV/dX   dV/dY   =  ',E12.5,1X,E12.5,/)
C
C
C       CALCULATION OF PRINCIPLE STRAINS AND ANGLE
C
        EPSX=R(1,1)
        EPSY=R(2,2)
        SIGMA=R(1,2)+R(2,1)
C
        CENTRE=(EPSX+EPSY)/2.
        RADIUS=SQRT((EPSX-EPSY)**2  +  SIGMA**2)/2.
C
        EPSPI =CENTRE+RADIUS
        EPSPII=CENTRE-RADIUS
C
C       CHECKING FOR ZEROES
C
        SIGN=1.
        IF(SIGMA.LT.0.)SIGN=-1.
        IF(ABS(EPSX-EPSY).GT.(1.0E-4))GOTO 30
        THATAP=90.*SIGN/2
        GOTO 35
30      THATAP=ATAN(SIGMA/ABS(EPSX-EPSY))/2.    !  RADIANS
        THATAP=THATAP/3.14159*180.              !  DEGREES
35      IF(EPSX.LT.EPSY)THATAP=SIGN*90.-THATAP
C
        IF(LU.EQ.6)WRITE(LU,*)'PRINCIPLE STRAINS AND ANGLE'
        WRITE(7,*)'PRINCIPLE STRAINS AND ANGLE'
        IF(LU.EQ.6)WRITE(LU,150)EPSPI,EPSPII,THATAP
        WRITE(7,150)EPSPI,EPSPII,THATAP
C
150     FORMAT('  ',/,'  EPI  =  ',E11.4,'     EPII  =  ',E11.4,
     &          '     THATA P = ', E11.4,'   degrees',/,/)
        PAUSE 'CR TO CONTINUE'
126     RETURN
```

```
      END


      SUBROUTINE TWODXZ

C
C
C     THIS SUBROUTINE CALCULATES THE STRAIN MATRIX  AS  OBTAINED
C     USING TWO DIMENSIONAL ANALYSIS.
C     X-Z
C
      DIMENSION  A(2,2),B(2,2),R(2,2),L(2),M(2)
      COMMON  X(50),XS(50),YS(50),Y(50),Z(50),ZS(50),
     &        I(3),J(3),LU,LV
C
      TYPE *,'WORKING IN X-Z PLANE'
      DO 10,K=1,2
        B(1,K)=(XS(J(K))-X(J(K)))-(XS(I(K))-X(I(K)))
        B(2,K)=-((ZS(J(K))-Z(J(K)))-(ZS(I(K))-Z(I(K))))
C
       A(1,K)=X(J(K))-X(I(K))
       A(2,K)=-(Z(J(K))-Z(I(K)))
10    CONTINUE
C
      WRITE(LU,*)
      WRITE(LU,*)'                          WORKING IN X-Z PLANE'
      IF(LV.NE.1)GOTO 13
      WRITE(LU,*)'DISPLACEMENT MATRIX'
      DO 11,K=1,2
11    WRITE(LU,*)B(K,1),B(K,2)
C
      WRITE(LU,*)
      WRITE(LU,*)'DISTANCE MATRIX'
      DO 12,K=1,2
12    WRITE(LU,*)A(K,1),A(K,2)

C
C      INVERT A
C
13    CALL MINV(A,2,D,L,M)
      IF(D.EQ.0.)GOTO 26
C
133   IF(LV.NE.1)GOTO 16
      WRITE(LU,*)
      WRITE(LU,*)'INVERSE OF DISTANCE MATRIX'
      DO 14,K=1,2
14    WRITE(LU,*)A(K,1),A(K,2)
      PAUSE 'ENTER CR TO CONTINUE'
C
C     CALCULATE STRAIN MATRIX
C
16    CALL MPRD(B,A,R,2,2,0,0,2)
C
26    IF(LU.EQ.6)WRITE(LU,*)'USING POINTS'
     WRITE(7,**)(I(K),J(K),K=1,2)
      DO 20,K=1,2
      WRITE(7,25)I(K),J(K)
20    IF(LU.EQ.6)WRITE(LU,25)I(K),J(K)
25    FORMAT(' ',I2,'-',I2)
C
      IF(D.NE.0.)GOTO 250
      IF(LU.EQ.6)WRITE(6,*)'-- DISTANCE MATRIX IS SINGULAR--'
      TYPE  *,'--DISTANCE  MATRIX  IS  SINGULAR--'
      GOTO 126
C
250   IF(LU.EQ.6)WRITE(LU,*)'STRAIN MATRIX'
      WRITE(7,*)'STRAIN MATRIX'
      IF(LU.EQ.6)WRITE(LU,15)R(1,1),R(1,2),R(2,1),R(2,2)
      WRITE(7,15)R(1,1),R(1,2),R(2,1),R(2,2)
C
15    FORMAT(' dU/dX  dU/dZ    ',E12.5,1X,E12.5,/,
```

```
     &          '  dW/dX   dW/dZ   =  ',E12.5,1X,E12.5,/)
C
C
C
C       CALCULATION OF PRINCIPLE STRAINS AND ANGLE
C
        EPSX=R(1,1)
        EPSY=R(2,2)
        SIGMA=R(1,2)+R(2,1)
C
        CENTRE=(EPSX+EPSY)/2.
        RADIUS=SQRT((EPSX-EPSY)**2  +  SIGMA**2)/2.
C
        EPSPI =CENTRE+RADIUS
        EPSPII=CENTRE-RADIUS
C
C       CHECKING FOR ZEROES
C
        SIGN=1.
        IF(SIGMA.LT.0.)SIGN=-1.
        IF(ABS(EPSX-EPSY).GT.(1.0E-4))GOTO 30
        THATAP=90.*SIGN/2
        GOTO 35
30      THATAP=ATAN(SIGMA/ABS(EPSX-EPSY))/2.     !  RADIANS
        THATAP=THATAP/3.14159*180.               !  DEGREES
35      IF(EPSX.LT.EPSY)THATAP=SIGN*90.-THATAP
C
        IF(LU.EQ.6)WRITE(LU,*)'PRINCIPLE STRAINS AND ANGLE'
        WRITE(7,*)'PRINCIPLE STRAINS AND ANGLE'
        IF(LU.EQ.6)WRITE(LU,150)EPSPI,EPSPII,THATAP
        WRITE(7,150)EPSPI,EPSPII,THATAP
C
150     FORMAT('  ',/,'  EPI  =  ',E11.4,'     EPII  =  ',E11.4,
     &          '   THATA P = ', E11.4,'    degrees',/)
        PAUSE 'CR TO CONTINUE'
126     RETURN
        END


        SUBROUTINE TWODYZ
C
C
C       THIS SUBROUTINE CALCULATES THE STRAIN MATRIX  AS  OBTAINED
C       USING TWO DIMENSIONAL ANALYSIS.
C       Y-Z
C
        DIMENSION  A(2,2),B(2,2),R(2,2),L(2),M(2)
        COMMON  X(50),XS(50),YS(50),Y(50),Z(50),ZS(50),
     &        I(3),J(3),LU,LV
C
        TYPE *,'WORKING IN Y-Z PLANE'
        DO 10,K=1,2
          B(1,K)=(YS(J(K))-Y(J(K)))-(YS(I(K))-Y(I(K)))
          B(2,K)=(ZS(J(K))-Z(J(K)))-(ZS(I(K))-Z(I(K)))
C
         A(1,K)=Y(J(K))-Y(I(K))
         A(2,K)=Z(J(K))-Z(I(K))
10      CONTINUE
C
        WRITE(LU,*)
        WRITE(LU,*)'                          WORKING IN Y-Z PLANE'
        IF(LV.NE.1)GOTO 13
        WRITE(LU,*)'DISPLACEMENT MATRIX'
        DO 11,K=1,2
11      WRITE(LU,*)B(K,1),B(K,2)
C
        WRITE(LU,*)
        WRITE(LU,*)'DISTANCE MATRIX'
        DO 12,K=1,2
12      WRITE(LU,*)A(K,1),A(K,2)
```

```
C
C        INVERT A
C
13      CALL MINV(A,2,D,L,M)
        IF(D.EQ.0.)GOTO 26
C
133     IF(LV.NE.1)GOTO 16
        WRITE(LU,*)
        WRITE(LU,*)'INVERSE OF DISTANCE MATRIX'
        DO 14,K=1,2
14      WRITE(LU,*)A(K,1),A(K,2)
        PAUSE 'ENTER CR TO CONTINUE'
C
C       CALCULATE STRAIN MATRIX
C
16      CALL MPRD(B,A,R,2,2,0,0,2)
C
26      IF(LU.EQ.6)WRITE(LU,*)'USING POINTS'
        WRITE(7,*)'USING POINTS'
        DO 20,K=1,2
        WRITE(7,25)I(K),J(K)
20      IF(LU.EQ.6)WRITE(LU,25)I(K),J(K)
25      FORMAT(' ',I2,'-',I2)
C
        IF(D.NE.0.)GOTO 250
        IF(LU.EQ.6)WRITE(6,*)'-- DISTANCE MATRIX IS SINGULAR--'
        TYPE  *,'--DISTANCE  MATRIX  IS  SINGULAR--'
        GOTO 126
C
250     IF(LU.EQ.6)WRITE(LU,*)'STRAIN MATRIX'
        WRITE(7,*)'STRAIN MATRIX'
       IEEKLUWEQ66WRITEEKLW155RR1111)RR1122)RR2211)RR2222)
        WRITE(7,15)R(1,1),R(1,2),R(2,1),R(2,2)
C
15      FORMAT(' dV/dY  dV/dZ    ',E12.5,1X,E12.5,/,
     &          '  dW/dY   dW/dZ   =  ',E12.5,1X,E12.5,/)
C
C
C
C       CALCULATION OF PRINCIPLE STRAINS AND ANGLE
C
        EPSX=R(1,1)
        EPSY=R(2,2)
        SIGMA=R(1,2)+R(2,1)
C
        CENTRE=(EPSX+EPSY)/2.
        RADIUS=SQRT((EPSX-EPSY)**2  +  SIGMA**2)/2.
C
        EPSPI =CENTRE+RADIUS
        EPSPII=CENTRE-RADIUS
C
C       CHECKING FOR ZEROES
C
        SIGN=1.
        IF(SIGMA.LT.0.)SIGN=-1.
        IF(ABS(EPSX-EPSY).GT.(1.0E-4))GOTO 30
        THATAP=90.*SIGN/2
        GOTO 35
30      THATAP=ATAN(SIGMA/ABS(EPSX-EPSY))/2.    !  RADIANS
        THATAP=THATAP/3.14159*180.              !  DEGREES
35      IF(EPSX.LT.EPSY)THATAP=SIGN*90.-THATAP
C
        IF(LU.EQ.6)WRITE(LU,*)'PRINCIPLE STRAINS AND ANGLE'
        WRITE(7,*)'PRINCIPLE STRAINS AND ANGLE'
        IF(LU.EQ.6)WRITE(LU,150)EPSPI,EPSPII,THATAP
        WRITE(7,150)EPSPI,EPSPII,THATAP
C
150     FORMAT('  ',/,'  EPI  =  ',E11.4,'     EPII  =  ',E11.4,
     &          '    THATA P = ', E11.4,'    degrees',/)
        PAUSE 'CR TO CONTINUE'
126     RETURN
```

END

APPENDIX I ERROR CHECK FOR RECONSTRUCTION AND STRAIN CALCULATIONS

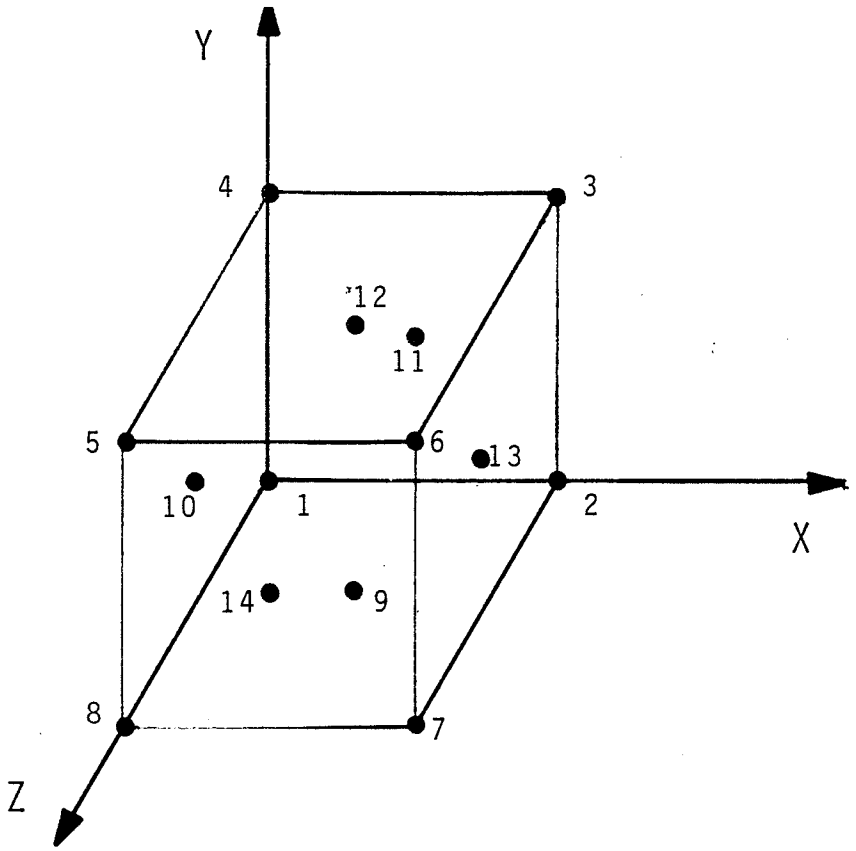


Figure I.1 Points on a cube. Diagnostics for reconstruction and strain program.

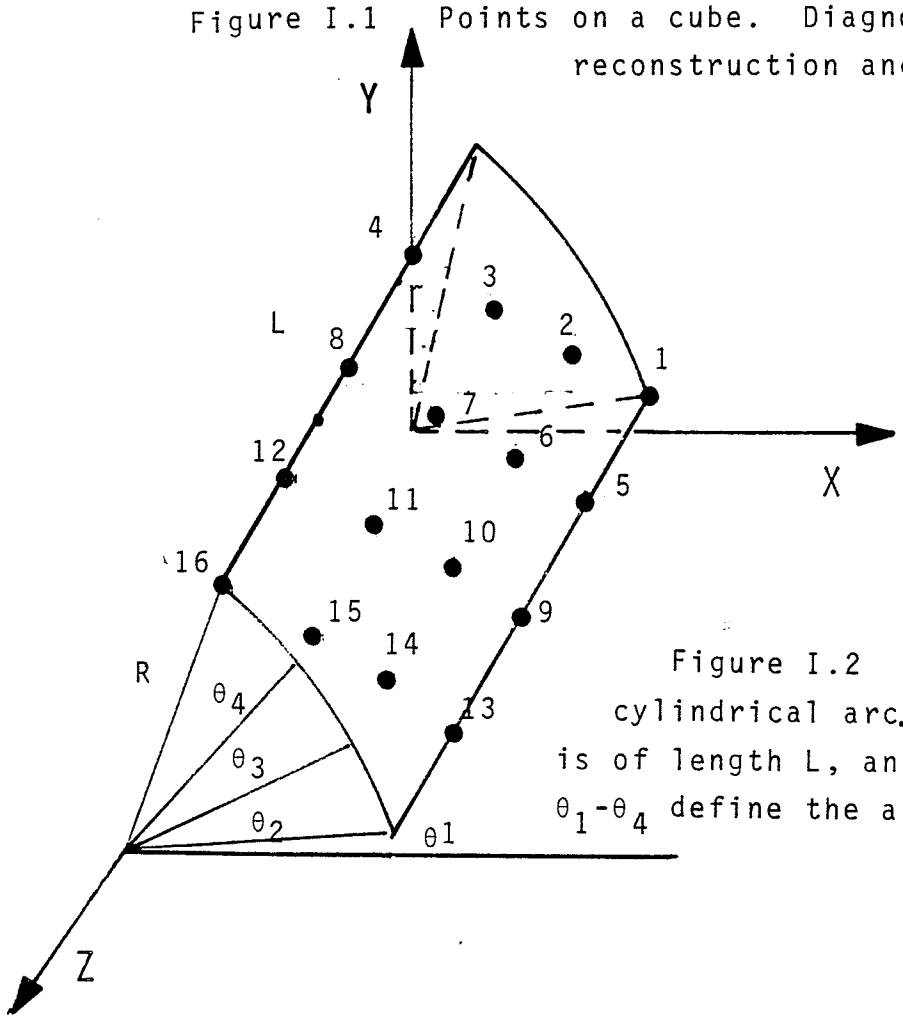


Figure I.2 Points on a cylindrical arc. The section is of length L, and radius R. θ_1-θ_4 define the angle of the arch.

I.1 ERROR CHECKING TECHNIQUES

The process of reconstructing the three dimensional coordinates of the points on the artery as obtained from the digitized plane views was tested for errors in a number of ways. The first method of determining calculation errors in the computer program was to use a hand calculator and follow the reconstruction algorithm by hand. This procedure was executed for only a small number of points for a simulated three dimensional cube (see figure I.1). The same points of the cube were plotted onto two, two dimensional views of the cube and digitized. The digitized data was then analyzed in the same procedure that was used for the analysis of the arterial reconstruction. The results indicated no error in analysis.

The testing of the strain calculations as performed by the computer algorithm made use of the same cube with points as used in the testing of the reconstruction program. A computer program was written which generated the two dimensional coordinates of any number of views of a given number of points of a cube. The amount of strain in each axis direction was chosen by the user and a strained cube was also constructed. The simulated data was then used to check the results of the strain analysis, indicating no errors.

To check for errors in the plane strain analysis of a curved object (an artery), a semi-cylinder in resting

and strained state was generated using a similar program as used for the cube generation (see figure I.2). The cylinder was identified by points along the surface and strain was introduced by decreasing (or increasing) the radius of the cylinder as well as decreasing (or increasing) the length. Figure I.2 illustrates a section of a cylinder seen in cross section. The radius of the cylinder changes by dR which results in strain of dr/r in the plane and corresponded with the results of the strain analysis of the simulated data.

When analyzing the data of each experiment used in the arterial study, different checking methods were used to ensure that the analysis procedure was correct. A visual check of the reconstructed points displayed on the terminal during the reconstruction process was made with the sketches of the slides. This ensured that there were no errors in the orientation of the slides when digitized.

When performing the strain analysis, measurements made using the arterial sketches were checked with two dimensional strain analysis using the same points. The measurements made using the sketches were one dimensional analysis, without the contribution of the other dimension within the strain analysis. Using pairs of points that were orthogonal reduced the effect of the second dimension in the two dimensional analysis so that the two different strain calculations could be compared. The results were used only as a rough check of the analysis, keeping the previously mentioned limitation in mind.

A procedure of repeated tracing of the same arterial sketch used for reconstruction of the artery was conducted to determine the error in the tracing procedure. The experiment with the largest diametric contraction, B5, was chosen for repeated strain analysis. The slides that were used for the strain analysis were redrawn five times and the strain analysis was repeated for six different combinations of points for each of the five tracings. This procedure was used to determine the total error in the measurement, a combination of both the precision of the measurement (as previously mentioned), as well as the accuracy for making these measurements. A matrix of the error calculation technique in table I.1 shows how the principle strains and angles vary from one trace and combination to another. The variance in the principle strains are the same magnitude as calculated from the resolution of the strain measuring system. Therefore the tracing procedure did not significantly decrease the resolution of the strain measuring technique.

COMBINATION	E_{P1} +/- S.D.	E_{P2} +/- S.D.	O_P +/- S.D.
1	13 +/- 3	-16 +/- 3	-21 +/- 4
2	13 +/- 1	-9 +/- 2	14 +/- 5
3	9 +/- 2	-10 +/- 2	-2 +/- 5
4	12 +/- 2	-12 +/- 2	-19 +/- 5
5	12 +/- 2	-5 +/- 2	-10 +/- 5
6	10 +/- 2	-8 +/- 2	-14 +/- 5
		E_{P1} +/- S.D.	E_{P2} +/- S.D.
average of 6 combinations from 5 trial averages.		11 +/- 1	-9 +/- 2
average of 5 trials from 6 combination averages.		12 +/- 1	-10 +/- 2

Table I.1 Average principle strains from 5 tracings of 6 different point combinations. To determine the error in sketching each artery, the same file (B5) was redrawn five times and digitized. The principle strains were calculated using 6 different combinations within a given area for all five traces. E_{P1}, E_{P2} - Principle strains, O_P - principle angle of principle strains, and S.D. - standard deviation. Principle strains are given in percent, and the principle angles are in degrees.

I.2 PROGRAM LISTING: GENERATOR

```
C
C-----------------------------------------------------------------------
C
C       PROGRAM GENERATOR               VERSION: 84-MAY-12
C
C       GENERATES THE TWO DIMENSIONAL COORDINATES OF N VIEWS FOR RECON-
C       STRUCTION. CAN WORK WITH A CUBE OR A CYLINDER.
C
C-----------------------------------------------------------------------
C
        PROGRAM GENER
C
        OPEN(UNIT=6,NAME='LS:',CARRIAGECONTROL='FORTRAN')
2       TYPE *,'GENERATE POINTS FOR CUBE OR  CYLINDER?  ENTER  1/0
     & RESPECTIVELY'
        ACCEPT *,IANS
        IF(IANS.EQ.1)CALL CUBE
        IF(IANS.EQ.0)CALL CYLIND
        TYPE *,'DO YOU WISH TO GENERATE MORE DATA        -Y/N-'
        TYPE *,'FOR A CYLINDER OR CUBE?'
        ACCEPT 1,ANS
1       FORMAT(A2)
        IF(ANS.EQ.'Y')GOTO 2
        STOP  '--  DATA  GENERATION  IS  COMPLETED  --'
        END

C
C-----------------------------------------------------------------------
C
C       SUBROUTINE CUBE
C
C       THIS SUBROUTINE GENERATES 14 POINTS OF A CUBE, ALL CORNERS AND
C       THE MIDDLE OF EACH FACE.  THE LENGTH OF THE CUBE IS DETERMINED
C       BY THE USER.  THE STRAIN IS ALSO DETERMINED BY THE USER IN EACH
C       X, Y, AND Z DIRECTION SEPARTELY.
C
C-----------------------------------------------------------------------
C
        SUBROUTINE CUBE
C
        BYTE NAME1
        DIMENSION NAME1(15),ALPHA(10),ALPHA1(10),X1(14),Y1(14),Z1(14)
        DATA X1,Y1,Z1/42*0./
        N=14
C
        TYPE *,'DO YOU WISH A PRINT OUT  OF  DATA?   Y/N'
        ACCEPT 1,ANS
1       FORMAT(A2)
        LV=0
        IF(ANS.EQ.'Y')LV=1
        IF(LV.EQ.1)TYPE *,'LEVEL OF PRINTOUT? 0-LIMITED, 1-MAXIMUM'
        IF(LV.EQ.1)ACCEPT *,LEV
2       TYPE *,'ENTER THE LENGTH OF THE CUBE'
        ACCEPT *,XL
        TYPE *,'ENTER THE PERCENTAGE OF STRAIN IN X. ie: 2% ENTER 1.02'
        ACCEPT *,STRX
        TYPE *,'ENTER THE PERCENTAGE OF STRAIN IN Y. ie: 2% ENTER 1.02'
        ACCEPT *,STRY
        TYPE *,'ENTER THE PERCENTAGE OF STRAIN IN Z. ie: 2% ENTER 1.02'
        ACCEPT *,STRZ
C
        IK=0
        DO 100,I=1,7,2
         X1(I)=XL*IK
        IK=IABS(IK-1)
100      X1(I+1)=XL*IK
C
        IK=0
        DO 110,I=1,8,4
         Y1(I)=XL*IK
         Y1(I+1)=Y1(I)
```

```
      IK=IABS(IK-1)
       Y1(I+2)=XL*IK
110    Y1(I+3)=Y1(I+2)
C
      DO 120,I=5,8
120   Z1(I)=XL
C
      DO 125,I=9,14
      X1(I)=XL/2
      Y1(I)=X1(I)
125   Z1(I)=Y1(I)
      X1(10)=0.
      Y1(9)=0.
      Z1(11)=0.
      X1(13)=XL
      Y1(12)=XL
      Z1(14)=XL
C
      DO 175,I=1,14
175   TYPE *,X1(I),Y1(I),Z1(I)
C
      TYPE *,'ENTER THE NUMBER OF VIEWS'
      ACCEPT *,M
      TYPE *,'ENTER THE CORESPONDING ANGLE OF EACH VIEW WRT THE'
      TYPE *,'FIRST VIEW. NOTE ENTER FIRST VIEW AT ANGLE 0'
      TYPE *,'                CLOCKWISE ROTATION POSITIVE'
C
C     USING (90-ALPHA) FOR CLOCKWISE ANGLES
C           (ALPHA-90) FOR C-CLOCKWISE ANGLES
C     NOTE; FOR POSITIVE ANGLE ALPHA
C
C     CONVERT TO RADIANS
C
      CONV=3.141592654/180.
C
      DO 10,I=1,M
      ACCEPT *,ALPHA1(I)
      ALPHA(I)=ALPHA1(I)
      K=1
      IF(ALPHA(I).LT.0)K=-1
10    ALPHA(I)=K*(90-K*ALPHA(I))*CONV
C
      J=1
11    IF(J.EQ.1)GOTO 12
      DO 130,I=1,N
       X1(I)=X1(I)*STRX
       Y1(I)=Y1(I)*STRY
130    Z1(I)=Z1(I)*STRZ
C
12    IF(J.EQ.1)TYPE *,'ENTER COMPLETE  NAME  OF  OUTPUT  FILE'
      IF(J.EQ.2)TYPE *,'ENTER COMPLETE NAME OF STRAINED VALUES FILE'
      ACCEPT 15,NAME1
15    FORMAT(15A1)
      OPEN(UNIT=2,NAME=NAME1,TYPE='UNKNOWN',ERR=30)
      IF(LV.NE.1)GOTO 16
       WRITE(6,101)NAME1
101   FORMAT('1',' FILE: ',15A1)
       WRITE(6,102)XL,STRX,STRY,STRZ
102   FORMAT('  CUBE  OF  SIDE  LENGTH  ',F6.2,'  units  ',/,
     &        ' A STRAIN FACTOR OF ',F4.2,' IN X',/,20X,F4.2,' IN Y',
     &        /,20X,F4.2,' IN Z',/)
       WRITE(6,105)M,N
105   FORMAT(' WORKING WITH ',I2,' VIEWS AND ',I2,' POINTS.',/)
16    WRITE(2,*)M,N
      RMAG1=1/SQRT(2.)
      RMAG2=RMAG1
      DO 20,I=1,M
       WRITE(2,*)I,ALPHA1(I)
       WRITE(2,250)1,RMAG1,RMAG2
       WRITE(2,250)2,0.,0.
       WRITE(2,250)1,1.,0.
```

```
        WRITE(2,250)2,1.,4.
        IF(LEV.EQ.1)WRITE(6,*)I,ALPHA1(I)
       DO 25,K=1,N
         AY=-Y1(K)*COS(ALPHA(I))  +  X1(K)*SIN(ALPHA(I))
        WRITE(2,250)K,AY+5.,Z1(K)+5.
25      IF(LEV.EQ.1)WRITE(6,*)AY,Z1(K)
20     CONTINUE
250    FORMAT(I2,',',F7.3,',',F7.3)
C
       CLOSE(UNIT=2)
       J=J+1
       IF(J.EQ.2)GOTO 11
       TYPE *,'DO YOU WISH TO GENERATE MORE DATA FOR CUBES?  -Y/N-'
       ACCEPT 1,ANS
       IF(ANS.EQ.'Y')GOTO 2
       RETURN
30     STOP 'FILE OPENING ERROR'
       END

C
C-------------------------------------------------------------------------
C
C      SUBROUTINE CYLINDER
CC
C      THIS SUBROUTINE GENERATES THE TWO DIMENSIONAL COORDINATES OF
C      POINTS FOR ANY VIEW ANGLE DESIRED OF A CYLINDER OF  RADIUS
C      R units AND LENGTH IN MULTIPLES OF 16 units.
C
C      ONLY 16 POINTS ARE GENERATED AND THE Z-COORDINATES ARE VARIABLE
C      IN MULTIPLES OF 16.
C
C-------------------------------------------------------------------------
C
       SUBROUTINE CYLIND
C
       BYTE NAME1
       DIMENSION  NAME1(15),ALPHA(10),PHI(4),ALPHA1(10)
       N=16
C
       TYPE *,'DO YOU WISH A PRINT OUT  OF  DATA?   Y/N'
       ACCEPT 1,ANS
1      FORMAT(A2)
       LV=0
       IF(ANS.EQ.'Y')LV=1
       IF(LV.EQ.1)TYPE *,'LEVEL OF PRINTOUT? 0-LIMITED, 1-MAXIMUM'
       IF(LV.EQ.1)ACCEPT *,LEV
       TYPE *,'ENTER RADIUS, R, OF CYLINDER IN UNITS  200 units=1mm'
       ACCEPT *,XR
       TYPE *,'ENTER THE LENGTH OF THE CYLINDER, MULTIPLES OF 16 units'
       ACCEPT *,XL
       TYPE *,'ENTER THE PERCENTAGE OF STRAIN. ie: 2% ENTER 1.02'
       ACCEPT *,STR
2      TYPE *,'ENTER THE ANGLES OF THE POINTS AS SEEN IN X-SECTION'
       TYPE *,'FROM THE HORIZONTAL. 4 ANGLES BETWEEN 0-90 DEGREES'
       ACCEPT *,PHI(1),PHI(2),PHI(3),PHI(4)
C
C      CONVERT TO RADIANS
C
       CONV=3.141592654/180.
       DO 5,I=1,4
5       PHI(I)=PHI(I)*CONV
C
       TYPE *,'ENTER THE NUMBER OF VIEWS'
       ACCEPT *,M
       TYPE *,'ENTER THE CORESPONDING ANGLE OF EACH VIEW WRT THE'
       TYPE *,'FIRST VIEW. NOTE ENTER FIRST VIEW AT ANGLE 0'
       TYPE *,'                CLOCKWISE ROTATION POSITIVE'
C
C      USING (90-ALPHA) FOR CLOCKWISE ANGLES
C            (ALPHA-90) FOR C-CLOCKWISE ANGLES
C      NOTE; FOR POSITIVE ANGLE ALPHA
```

```
C
      DO 10,I=1,M
      ACCEPT *,ALPHA1(I)
      ALPHA(I)=ALPHA1(I)
      K=1
      IF(ALPHA(I).LT.0)K=-1
10    ALPHA(I)=K*(90-K*ALPHA(I))*CONV
C
      J=1
11    STR1=STR
      IF(J.EQ.1)STR1=1.
      IF(J.EQ.1)TYPE *,'ENTER COMPLETE NAME OF OUTPUT FILE'
      IF(J.EQ.2)TYPE *,'ENTER COMPLETE NAME OF STRAINED VALUES FILE'
      ACCEPT 15,NAME1
15    FORMAT(15A1)
      OPEN(UNIT=2,NAME=NAME1,TYPE='UNKNOWN',ERR=30)
      IF(LV.NE.1)GOTO 16
       WRITE(6,100)NAME1
100   FORMAT('1',' FILE: ',15A1)
        WRITE(6,110)XR,XL*16,STR1,((PHI(I)/CONV),I=1,4)
110   FORMAT(' CYLINDER OF RADIUS ',F7.3,' units AND LENGTH ',F7.3,/,
     &         'A STRAIN FACTOR OF '
     &    ,F4.2,/,' POINTS AT ANGLES ',F5.1,2X,F5.1,2X,F5.1,2X,F5.1,/)
       WRITE(6,105)M,N
105   FORMAT(' WORKING WITH ',I2,' VIEWS AND ',I2,' POINTS.',/)
16    WRITE(2,*)M,N
C
      RMAG1=1./SQRT(2.)
      RMAG2=RMAG1
C
      DO 20,I=1,M
       WRITE(2,*)I,ALPHA1(I)
       IF(LEV.EQ.1)WRITE(6,*)I,ALPHA1(I)
       WRITE(2,250)1,RMAG1,RMAG2
       WRITE(2,250)2,0.,0.
       WRITE(2,250)1,1.,0.
       WRITE(2,250)2,1.,4.
      L=1
      DO 25,K=1,N
      IF((L/4.).GT.1.)L=L/4
       Y=XR*STR1*(-COS(ALPHA(I))*SIN(PHI(L))+SIN(ALPHA(I))*COS(PHI(L)))
       Z=STR1*XL*K
       WRITE(2,250)K,Y+5.,Z+5.
       IF(LEV.EQ.1)WRITE(6,*)Y,Z
25     L=L+1
20    CONTINUE
250   FORMAT(I2,',',F7.3,',',F7.3)
C
      CLOSE(UNIT=2)
      J=J+1
      IF(J.EQ.2)GOTO 11
      TYPE *,'DO YOU WISH TO GENERATE MORE DATA FOR CYLINDERS?  -Y/N-'
      ACCEPT 1,ANS
      IF(ANS.EQ.'Y')GOTO 2
      RETURN
30    STOP 'FILE OPENING ERROR'
      END
```

APPENDIX J EQUIPMENT

This appendix contains all necessary information pertaining to the equipment used in the study.

Dissecting Microscope and Camera Attachment:

A Wild M8 zoom dissections microscope with camera attachment was used in the study. Table J.1 gives the different magnifications possible with the resulting field diameter.

Zoom Position	Total Magnification	Field Diameter
6	6X	33.8
12	12X	17.5
25	25X	8.4
50	50X	4.2

Table J.1 M8 Microscope Magnification and Field Diameter

The camera attachment was monocular with a Wild 35mm camera. The attachment had an aperture setting that ranged between 1 and 5.

Kodak Tri-X-Pan, 400 ASA, 35mm film was used in the camera. The film could resolve a maximum of 50 line pairs/mm when using the conventional developing process.

Fiber optic, cold light illumination (150H by Volpi) was used as the light source during the study. This light source used two swan neck arms which allowed for easy placement of the light source during the experiments.

The shutter speed that was required for photographing the tissue during the experiment was determined

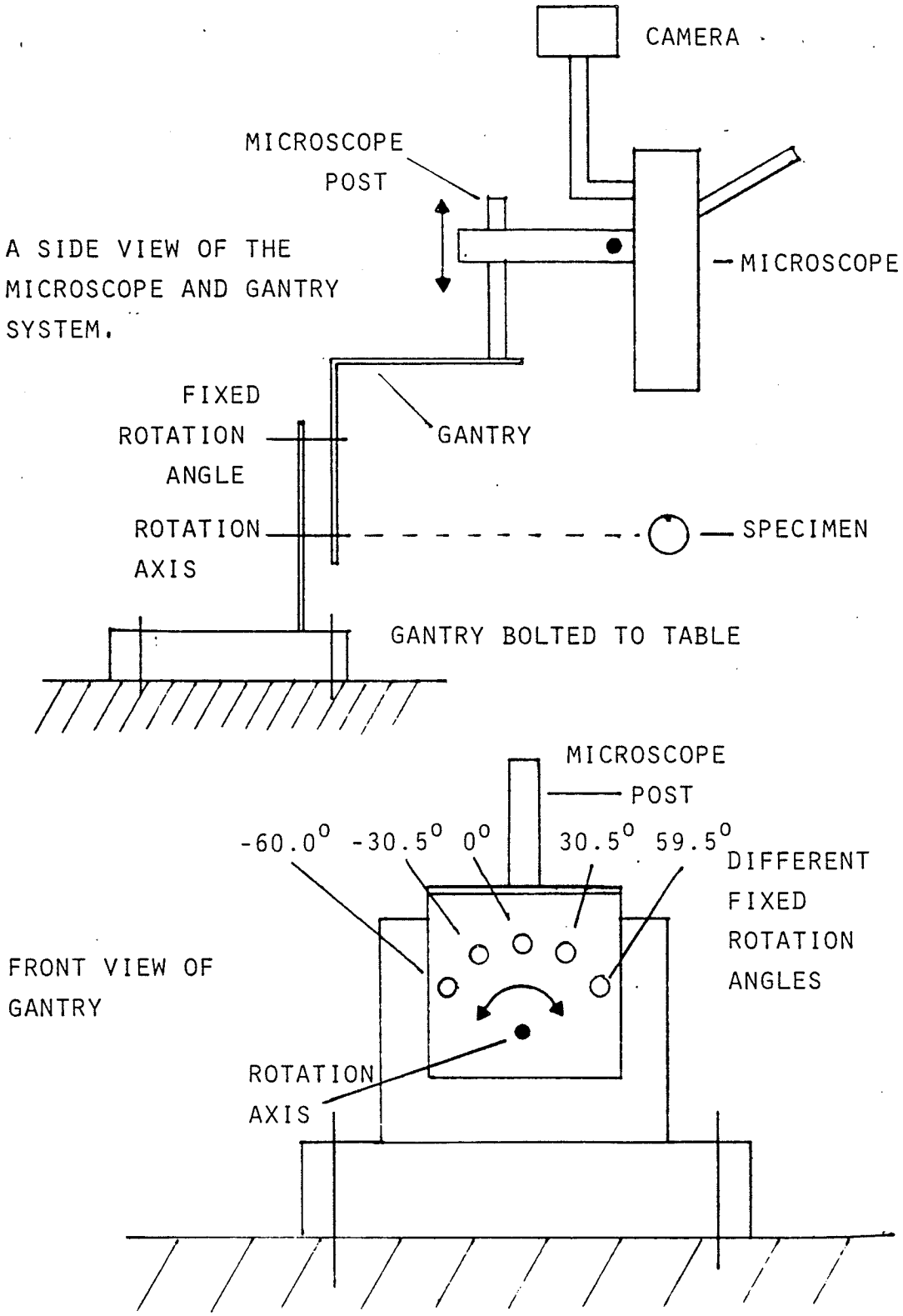


Figure J.1 Microscope and gantry system.

experimentally. A shutter speed of one quarter of a second with an aperture setting of 1 was determined as adequate and resulted in good exposure of the tissue on the film negative. The intensity of the light source was adjusted qualitatively during the experiment by noting the intensity through the microscope. A light meter that is used for measuring light intensities through a microscope was not available and was expensive. The method used during the experiment for monitoring light intensity was suitable.

Rotating Gantry:

A schematic diagram of the rotating gantry that was constructed for the study is seen in figure J.1. The gantry was constructed using one-quarter inch thick C-channel aluminium. The resulting angles that were obtained for the different positions of the gantry are noted in figure J.1.

Water Heaters:

A submersible 200 watt fish tank heater (Akva-Stabil, Denmark) was used to maintain the perfusion temperature at 37 degrees celsius. A 500 watt heating tank (Lab Line Instruments) was used for maintaining the Thermal Mass temperature at 39 degrees celsius.

Water Pump:

A submersible water pump (Little Giant Pump Co., model 1-T) with variable transformer (variac) was used to circulate the water from the heating tank into the Thermal Mass reservior.

Slide Projector:

A slide projector (Kodak Ektrasraphic 3) was used to project the slides of the arterial segments onto paper for sketchins.

Digitizins System:

A Talos System Inc. Cybersraph System, series 600 digitizer, usins SMART 3.3.0 software was used for digitizins the two dimensional views of the arteries. The Talos system was set to function at 300 baud and was set in the RST mode. This mode of operation allowed serial RS 232 communication to both the Talos terminal port, as well as to a second port which was used for communication to a external main computer system.

Modems:

Two modems where used for asychronous serial communication between the digitizins system and the main computer system. The digitizins system modem was a Rixon, model T212A modem manufactured by Rixon of Sansamo Westen.

This modem was set to 300 baud and full duplex mode (all front panel buttons in the out position) and required pin 20 to be held 'high' for "Ready to Receive/Transmit". This modem was used to "call" the main computer system modem.

The main computer modem was a Hayes Smart 300. This modem communicated serially at 300 baud, and was preset to the Auto Answer (first ring) and Full Duplex modes.

Main Computer System:

The main computer system used during the study was a Minc 23 Digital computer. This system is based on the 11/23 processor by Digital, and uses the RT-11, version 4, operating system. Fortran by Digital was the software used in the system. Two 8 1/2 inch floppy disks were used for permanent information storage.

Serial line unit (SLU) 1 was used for the asychronous serial communication with the Talos digitizing system. This line unit was set at 300 baud, 8 data bits (eighth bit high), 1 stop bit, and no parity.

APPENDIX K DATA

INTRODUCTION

This appendix contains the two dimensional coordinates of the plane views used for the strain analysis in this study. As well, the reconstructed three dimensional coordinates are listed. The appendix is organized by experiment number, starting with experiment B3 which was the first experiment used for the strain analysis of the study. At the end of each experiment section are listed the combination of points used in analysis of the different areas of the artery.

The format of the two dimensional coordinates for each experiment is given in Appendix F, Serial Communciation Link, Data Transmission. The format for the three dimensional coordinates is determined by the output of the reconstruction program, and in this format is acceptable for the input of the strain program. The magnification is the relative size of the resting state coordinates to the constricted state coordinates, with all references made to the initial or resting state file. The angle given as ROTATE, in each plane is the orientation of the data to the initial coordinate system orientation as described in Appendix G, Reconstruction. Any uncommon point described in the data implies that that point is not common between the two states, resting and constricted, and consequently, cannot be used for strain analysis.

The data following the three dimensional coordinates, for example, rotation of each view and

magnification, are used during the reconstruction program. The reconstruction of the two dimensional coordinates should use these same conditions to result in the same three dimensional information as listed in this text.

K.1 EXPERIMENT B3

EXPERIMENT B3A1

DRUG - NOREPINEPHRINE 4 mg/l.
RESTING STATE

2,50
1,0
1,+10.899,+07.292
2,+11.151,+07.502
3,+17.395,+19.124
4,+17.246,+06.278

1,+10.972,+10.189
2,+11.952,+09.907
3,+11.022,+10.534
4,+11.910,+10.700
5,+11.885,+11.223
6,+12.435,+10.800
7,+12.723,+10.634
8,+12.474,+11.701
9,+13.352,+11.113
10,+13.690,+11.032
11,+14.005,+10.892
12,+14.309,+10.497
13,+14.563,+10.395
14,+14.928,+10.396
15,+16.740,+10.194
16,+15.430,+11.091
17,+14.918,+11.416
18,+15.862,+11.385
19,+14.390,+12.440
20,+14.835,+12.401
21,+14.959,+12.807
22,+15.308,+12.238
23,+15.775,+12.355
24,+16.037,+12.271
25,+16.272,+11.974
26,+16.690,+11.945
27,+17.086,+11.652
28,+18.100,+11.940
29,+18.268,+11.676
30,+18.640,+11.424
31,+19.030,+11.449
32,+19.627,+11.553
33,+20.592,+12.409
34,+17.641,+12.866
35,+17.501,+13.072
36,+19.787,+14.171
37,+18.857,+14.893
38,+18.187,+16.925
39,+17.970,+16.375
40,+17.764,+16.057
41,+17.427,+15.740
42,+17.258,+15.364
43,+16.348,+14.459
44,+16.056,+13.889
45,+15.528,+13.257
46,+15.272,+13.923

47,+16.569,+15.522
48,+16.913,+16.678
49,+16.186,+16.124
50,+15.754,+15.452

2,-60
1,+09.151,+13.025
2,+09.245,+12.811
3,+16.468,+18.955
4,+16.051,+06.191
1,+13.630,+12.904
2,+14.453,+12.270
3,+13.130,+13.215
4,+13.759,+13.361
5,+13.015,+13.922
6,+14.301,+13.357
7,+14.604,+13.273
8,+13.388,+14.958
9,+14.861,+13.856
10,+15.092,+13.686
11,+15.348,+13.678
12,+15.779,+13.135
13,+16.026,+12.956
14, 0. , 0.
15,+17.087,+12.714
16,+16.417,+13.766
17,+16.008,+14.004
18,+16.687,+14.026
19,+15.099,+15.129
20,+15.523,+15.022
21,+15.740,+15.492
22,+16.118,+14.969
23,+16.537,+15.030
24,+16.815,+14.950
25,+16.947,+14.597
26,+17.313,+14.616
27,+17.497,+14.218
28,+18.365,+14.490
29,+18.554,+14.200
30,+18.588,+14.014
31,+18.973,+14.056
32,+19.484,+14.072
33,+20.607,+14.967
34,+18.314,+15.467
35,+18.235,+15.672
36,+20.295,+16.750

37,+19.678,+18.064
38,+18.405,+19.698
39,+18.572,+19.108
40,+18.470,+18.760
41,+18.382,+18.451
42,+18.289,+18.086
43,+17.443,+17.011
44,+17.141,+16.580
45,+16.295,+15.896
46,+16.187,+16.559
47,+17.238,+17.454
48,+17.661,+19.449
49,+17.269,+18.943
50,+16.956,+18.148

FILE: L:OB3A1.DAT
REFERNCE POINT 1 Magnification: 0.3280304
1 ROTATE X-Y -0.9451 RADIANS
X-Z 0.0000
Y-Z 0.0000

PT#	X	Y	Z	
1	0.000	0.000	0.000	
2	1.816	-0.107	0.393	
~~3~~	-0.424	0.373	-0.344	
4	1.136	0.344	-0.494	
5	0.404	0.849	-1.039	
6	2.221	0.208	-0.558	
7	2.817	0.131	-0.407	
8	1.429	0.842	-1.661	
~~9~~	3.757	0.235	-0.911	
10	4.333	0.234	-0.801	
11	4.914	0.201	-0.689	
12	5.635	0.050	-0.244	
~~13~~	6.138	-0.002	-0.116	
~~14~~	0.000	0.000	0.000	POINT #14 IS NOT COMMON
15	9.462	0.279	0.126	
16	7.469	0.116	-0.840	
17	6.540	0.160	-1.154	
18	8.201	0.124	-1.122	
19	5.141	0.534	-2.229	
20	6.022	0.446	-2.164	
21	6.385	0.342	-2.589	
22	7.100	0.248	-2.019	
23	8.006	0.171	-2.115	
24	8.551	0.099	-2.026	
25	8.913	0.123	-1.708	
26	9.713	0.061	-1.684	
27	10.294	0.125	-1.355	
28	12.226	-0.016	-1.626	
29	12.576	-0.065	-1.349	
30	12.992	0.089	-1.108	
31	13.782	-0.000	-1.131	
32	14.914	-0.080	-1.204	
33	17.072	-0.436	-2.062	
34	11.735	-0.214	-2.581	
35	11.519	-0.228	-2.791	
36	15.996	-0.627	-3.860	
37	14.462	-0.655	-4.759	
38	12.585	-0.096	-6.728	
39	12.494	-0.307	-6.161	
40	12.162	-0.325	-5.834	
41	11.707	-0.417	-5.519	
42	11.422	-0.424	-5.144	
43	9.588	-0.235	-4.199	
44	8.963	-0.152	-3.664	
45	7.547	0.211	-3.022	
46	7.201	0.155	-3.699	
47	9.647	0.011	-5.112	
48	10.502	-0.166	-6.495	
49	9.329	-0.223	-5.957	
50	8.533	-0.191	-5.251	

B3 A1

ROTATION OF VIEW # 1 : 0.012 RADIANS.

ROTATION OF VIEW # 2 : 0.033 RADIANS.

MAGNIFICATION OF VIEW # 2 IS 1.403
USING REFERERENCE WIRE!

Z limit = 1

MAGNIFICATION OF VIEW # 2 IS 1.048 +/- 0.089 SD.
USING AVERAGING FROM Z VALUES OF 33 POINTS

USING Z VALUE FOR MAGNIFCATION!

```
EXPERIMENT B3A2
DRUG - NOREPINEPHRINE 4 mg/l.
CONSTRICTED STATE

2,50
1,0
1,+06.792,+09.112
2,+07.010,+09.302
3,+15.433,+18.734
4,+15.139,+06.601

1,+08.130,+10.214
2,+09.285,+09.938
3   0.      0.
4,+09.124,+10.660
5,+08.996,+11.276
6,+09.941,+10.627
7,+10.070,+10.481
8,+09.578,+11.769
9,+10.678,+10.919
10,+10.989,+10.801
11,+11.345,+10.563
12,+11.486,+10.178
13,+11.736,+09.993
14,+12.082,+09.935
15,+13.774,+09.668
16,+12.727,+10.609
17,+12.079,+11.004
18,+13.174,+10.896
19,+11.704,+12.092
20,+12.193,+11.928
21,+12.349,+12.250
22,+12.674,+11.746
23,+13.122,+11.733
24,+13.406,+11.613
25,+13.514,+11.253
26,+13.989,+11.206
27,+14.325,+10.822
28,+15.361,+11.002
29,+15.415,+10.723
30,+15.611,+10.529
31,+16.030,+10.456
32,+16.805,+10.563
33,+17.922,+11.240
34,+14.956,+11.894
35,+14.727,+12.061
36,+17.081,+12.923
37,+16.283,+13.629
38,+15.680,+15.777
39,+15.473,+15.257
40,+15.261,+14.961
41,+14.965,+14.688
42,+14.838,+14.364
43,+13.852,+13.443
44,+13.482,+13.062
45,+13.011,+12.503
46,+12.682,+13.075
47,+14.012,+14.555
48,+14.465,+15.597
49,+13.691,+15.366
50,+13.250,+14.698

2,-60
1,+09.230,+10.687
2,+09.230,+10.382
3,+11.812,+19.107
4,+11.470,+07.590
1,+12.865,+09.798
2,+13.679,+09.180
3,+12.527,+10.323
4,+13.182,+10.223
5,+12.084,+10.907
6,+13.700,+10.177
7,+13.927,+09.985
8,+12.943,+11.809
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10,+14.285,+10.402
11,+14.538,+10.331
12,+14.780,+09.678
13,  0.0  ,  0.0
14,+15.122,+09.440
15,+15.707,+09.170
16,+15.525,+10.146
17,+15.192,+10.474
18,+15.769,+10.541
19,+14.478,+11.743
20,+14.857,+11.625
21,+15.153,+11.884
22,+15.352,+11.308
23,+15.746,+11.254
24,+16.006,+11.202
25,+16.014,+10.846
26,+16.266,+10.724
27,+16.504,+10.383
28,+17.335,+10.532
29,+17.480,+10.207
30,+17.538,+10.014
31,+18.055,+10.051
32,  0.0  ,  0.0
33,  0.0  ,  0.0
34,  0.0  ,  0.0
35,  0.0  ,  0.0
36,  0.0  ,  0.0
37,  0.0  ,  0.0
38,  0.0  ,  0.0
39,  0.0  ,  0.0
40,  0.0  ,  0.0
41,  0.0  ,  0.0
42,  0.0  ,  0.0
43,+17.171,+13.134
44,+16.748,+12.675
45,+16.039,+12.198
46,+15.974,+12.757
47,+17.077,+13.806
48,+17.441,+15.434
49,+17.097,+14.865
50,+16.707,+14.294
```

FILE: L:OB3A2.DAT
REFERNCE POINT 1 Magnification: 0.2891778
1146 = .3[illegible] = 1.135
.257
1 ROTATE X-Y -0.9174 RADIANS
X-Z 0.0000
Y-Z 0.0000

PT#	X	Y	Z	
1	0.000	0.000	0.000	
2	1.924	-0.027	0.382	
3	0.000	0.000	0.000	POINT # 3 IS NOT COMMON
4	1.361	0.223	-0.416	
5	0.292	0.899	-1.052	
6	2.686	0.236	-0.362	
7	3.015	0.143	-0.202	
8	1.705	0.565	-1.622	
9	0.000	0.000	0.000	POINT # 9 IS NOT COMMON
10	4.328	0.304	-0.523	
11	4.923	0.290	-0.319	
12	5.259	0.198	0.130	
13	0.000	0.000	0.000	POINT #13 IS NOT COMMON
14	6.183	0.234	0.383	
15	8.487	0.592	0.683	
16	7.261	0.241	-0.277	
17	6.296	0.176	-0.666	
18	7.970 (9.046)	0.270	-0.577 (-.655)	
19	5.329 (6.048)	0.478	-1.798 (-2.041)	
20	6.176	0.439	-1.636	
21	6.618	0.307	-1.934	
22	7.112	0.323	-1.411	
23	7.934	0.257	-1.377	
24	8.462	0.208	-1.268	
25	8.565 (9.721)	0.253	-0.910 (-1.033)	
26	9.289	0.296	-0.835	
27	9.838	0.287	-0.458	
28	11.682	0.185	-0.604	
29	11.851	0.115	-0.315	
30	12.101	0.164	-0.119	
31	13.002	0.000	-0.062	
32	0.000	0.000	0.000	POINT #32 IS NOT COMMON
33	0.000	0.000	0.000	POINT #33 IS NOT COMMON
34	0.000	0.000	0.000	POINT #34 IS NOT COMMON
35	0.000	0.000	0.000	POINT #35 IS NOT COMMON
36	0.000	0.000	0.000	POINT #36 IS NOT COMMON
37	0.000	0.000	0.000	POINT #37 IS NOT COMMON
38	0.000	0.000	0.000	POINT #38 IS NOT COMMON
39	0.000	0.000	0.000	POINT #39 IS NOT COMMON
40	0.000	0.000	0.000	POINT #40 IS NOT COMMON
41	0.000	0.000	0.000	POINT #41 IS NOT COMMON
42	0.000	0.000	0.000	POINT #42 IS NOT COMMON
43	10.060	-0.399	-3.087	
44	9.272	-0.273	-2.701	
45	8.119 (9.215)	0.000	-2.181 (-2.495)	
46	7.740	-0.107	-2.750	
47	10.194	-0.266	-4.080	
48	11.067	-0.332	-5.241	
49	9.918	-0.434	-4.948	
50	9.073	-0.363	-4.321	

14 not common

ROTATION OF VIEW # 1 : 0.024 RADIANS.

ROTATION OF VIEW # 2 : 0.030 RADIANS.

MAGNIFICATION OF VIEW # 2 IS 0.948
USING REFERERENCE WIRE!

Z limit - 1

MAGNIFICATION OF VIEW # 2 IS 0.960 +/- 0.068 SD.
USING AVERAGING FROM Z VALUES OF 16 POINTS

USING Z VALUE FOR MAGNIFCATION!

EXPERIMENT B3B1
PRESSURE
RESTING STATE

2,40
1,0
1,+05.228,+10.904
2,+05.445,+11.166
3,+11.020,+20.678
4,+10.306,+07.738

1,+15.042,+14.160
2,+14.254,+14.345
3,+13.308,+14.480
4,+13.019,+09.930
5,+11.910,+09.641
6,+11.051,+09.812
7,+10.820,+10.439
8,+09.655,+10.009
9,+10.008,+10.974
10,+08.832,+11.445
11,+08.387,+11.683
12,+07.990,+12.016
13,+07.234,+12.232
14,+09.238,+13.385
15,+09.719,+13.024
16,+10.805,+13.774
17,+10.952,+12.982
18,+10.765,+11.505
19,+12.103,+13.079
20,+12.088,+12.370
21,+13.152,+12.029
22,+13.922,+12.911
23,+14.142,+11.964
24,+17.125,+11.362
25,+19.303,+11.700
26,+20.582,+12.379
27,+18.759,+13.627
28,+17.823,+14.753
29,+15.331,+14.498
30,+15.895,+15.506
31,+16.360,+15.240
32,+17.017,+15.930
33,+17.501,+16.778
34,+16.094,+16.883
35,+15.800,+16.171
36,+15.561,+15.518
37,+14.550,+15.834
38,+13.548,+13.379
39,+11.804,+13.983
40,+13.977,+15.839

2,-60

1,+09.345,+11.510
2,+09.402,+11.772
3,+13.655,+21.151
4,+13.294,+08.302
1,+17.199,+14.367
2,+16.471,+14.460
3,+15.396,+14.574
4,+14.430,+10.503
5,+14.399,+10.202
6, 0.0 , 0.0
7, 0.0 , 0.0
8,+12.805,+10.477
9,+13.015,+10.921
10,+12.305,+11.470
11,+11.878,+11.788
12,+11.197,+12.138
13,+10.570,+12.165
14,+10.748,+13.421
15,+11.801,+13.015
16,+11.849,+13.823
17,+12.799,+13.003
18,+12.832,+12.019
19,+13.706,+13.200
20,+13.943,+12.532
21,+14.644,+12.121
22,+15.331,+12.970
23,+15.854,+12.368
24,+17.589,+11.573
25,+19.946,+12.013
26,+20.784,+12.540
27,+20.259,+13.670
28,+19.778,+14.996
29,+17.760,+14.687
30, 0.0 , 0.0
31,+18.318,+15.762
32, 0.0 , 0.0
33,+19.492,+16.960
34,+18.686,+16.870
35,+18.034,+16.232
36,+17.521,+15.571
37,+16.986,+15.841
38,+14.912,+13.533
39,+13.034,+14.029
40,+16.473,+15.676

FILE: L:OB3B1.DAT
REFERNCE POINT13
1 ROTATE X-Y -0.9849 RADIANS
X-Z 0.0000
Y-Z 0.0000

Magnification: 1.051185

PT#	X	Y	Z
1	14.591	-0.454	-2.394
2	13.028	-0.373	-2.519
3	10.953	-0.139	-2.603
4	10.053	0.413	1.893
5	8.902	-0.133	2.234
6	0.000	0.000	0.000
7	0.000	0.000	0.000
8	4.934	-0.226	1.992
9	5.443	-0.205	1.136
10	3.468	-0.335	0.693
11	2.555	-0.277	0.453
12	1.427	-0.027	0.133
13	0.000	0.000	0.000
14	2.148	0.900	-1.277
15	3.741	0.443	-0.928
16	4.845	0.962	-1.747
17	6.026	0.407	-0.952
18	5.978	0.312	0.420
19	8.120	0.390	-1.131
20	8.403	0.231	-0.425
21	10.241	0.309	-0.111
22	11.657	0.234	1.031
23	12.483	0.011	-0.177
24	17.374	0.380	0.347
25	21.974	-0.085	0.130
26	24.088	0.000	-0.836
27	21.572	-0.597	0.988
28	20.017	-0.762	0.137
29	15.428	-0.685	0.747
30	0.000	0.000	0.000
31	16.981	-0.532	3.633
32	0.000	0.000	0.000
33	19.225	-0.756	5.154
34	16.954	-0.941	5.145
35	16.050	-0.647	4.427
36	15.340	-0.419	3.751
37	13.730	-0.583	4.013
38	10.804	0.320	-1.511
39	7.057	0.678	-2.008
40	12.624	-0.536	-3.946

ROTATION OF VIEW # 1 : 0.055 RADIANS.

ROTATION OF VIEW # 2 : 0.028 RADIANS.

MAGNIFICATION OF VIEW # 2 IS 1.269
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW # 2 IS 1.051 +/- 0.100 SD.
USING AVERAGING FROM Z VALUES OF 22 POINTS

USING Z VALUE FOR MAGNIFCATION!

EXPERIMENT B3B2
PRESSURE
CONSTRICTED STATE

2,40	2,-60
1,0	
1,+04.721,+12.210	1,+07.618,+14.855
2,+05.035,+12.417	2,+07.623,+14.497
3,+06.594,+20.646	3,+13.335,+20.965
4,+06.275,+08.337	4,+12.910,+08.297
1,+12.362,+15.166	1,+15.272,+16.363
2,+11.725,+15.255	2,+14.594,+16.359
3,+11.223,+15.239	3,+13.801,+16.477
4,+11.374,+12.037	4,+13.340,+13.578
5,+10.444,+11.826	5,+13.430,+13.163
6,+09.639,+12.801	6,+12.358,+13.001
7,+09.680,+12.178	7,+12.375,+13.498
8,+08.706,+12.508	8,+11.570,+13.574
9,+08.995,+13.109	9,+11.965,+14.344
10,+07.957,+13.813	10,+10.959,+14.887
11,+07.814,+13.997	11,+10.824,+14.937
12,+07.556,+14.218	12,+10.220,+15.156
13,+07.014,+14.290	13,+09.497,+15.373
14,+08.533,+15.070	14,+09.705,+16.025
15,+09.244,+14.844	15,+10.565,+15.893
16,+09.405,+15.177	16,+10.575,+16.331
17,+09.825,+14.641	17,+11.763,+15.769
18,+09.554,+13.636	18,+12.274,+14.727
19,+10.362,+14.425	19,+12.635,+15.768
20,+10.494,+14.084	20,+12.853,+15.264
21,+11.150,+13.751	21,+13.753,+14.757
22,+11.557,+14.224	22,+14.442,+14.788
23,+12.162,+13.637	23,+14.938,+14.331
24,+13.809,+12.810	24,+15.682,+13.855
25,+15.589,+12.967	25,+18.254,+14.006
26,+16.783,+13.535	26,+19.088,+14.542
27,+15.352,+14.800	27,+18.354,+15.825
28,+14.425,+16.110	28,+17.625,+17.075
29,+12.587,+15.504	29,+15.597,+16.526
30,+13.007,+16.492	30,+16.323,+17.420
31,+13.377,+16.232	31,+16.621,+17.172
32,+13.872,+16.894	32,+17.026,+17.821
33,+14.402,+17.809	33,+17.133,+18.817
34,+13.174,+17.589	34,+16.239,+18.550
35,+12.902,+17.041	35,+16.084,+17.944
36,+12.769,+16.485	36,+16.025,+17.472
37,+12.063,+16.600	37,+15.238,+17.611
38,+11.408,+14.672	38,+14.135,+15.369
39 0. , 0.	39,+11.861,+16.383
40,+11.772,+16.423	40,+14.891,+17.464

FILE: L:OB3B2.DAT
REFERNCE POINT13
1 ROTATE X-Y -1.0427 RADIANS
X-Z 0.0000
Y-Z 0.0000

Magnification: 1.002946

PT#	X	Y	Z
1	11.078	-0.297	-1.057
2	9.759	-0.268	-1.105
3	8.460	-0.090	-1.106
4	8.331	0.256	2.022
5	7.508	-0.335	2.301
6	5.610	-0.188	1.636
7	5.667	-0.156	1.977
8	3.875	-0.248	1.737
9	4.518	-0.307	1.084
10	2.436	-0.315	0.449
11	2.151	-0.320	0.302
12	1.275	-0.114	0.092
13	0.000	0.000	0.000
14	1.688	0.750	-0.779
15	3.271	0.657	-0.598
16	3.419	0.747	-0.961
17	5.060	0.292	-0.436
18	5.361	-0.167	0.580
19	6.476	0.094	-0.292
20	6.852	0.038	0.086
21	8.435	-0.116	0.442
22	9.518	-0.291	0.066
23	10.651	-0.234	0.605
24	13.083	0.279	1.306
25	17.430	-0.200	1.094
26	19.427	0.000	0.504
27	17.183	-0.386	-0.732
28	15.450	-0.487	-2.003
29	11.614	-0.359	-1.359
30	12.705	-0.539	-2.338
31	13.389	-0.502	-2.090
32	14.251	-0.451	-2.762
33	14.832	-0.204	-3.709
34	12.722	-0.388	-3.446
35	12.329	-0.458	-2.877
36	12.167	-0.500	-2.338
37	10.665	-0.445	-2.439
38	9.031	-0.192	-0.410
39	0.000	0.000	0.000
40	10.036	-0.410	-2.261

ROTATION OF VIEW # 1 : 0.026 RADIANS.

ROTATION OF VIEW # 2 : 0.034 RADIANS.

MAGNIFICATION OF VIEW # 2 IS 1.050
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW # 2 IS 1.002 +/- 0.126 SD.
USING AVERAGING FROM Z VALUES OF 21 POINTS

USING Z VALUE FOR MAGNIFCATION!

Experiment B3 A1, A2

Area 1:

(19-45,45-27,19-27), (46-19,46-27,19-27),
(46-19,46-25,19-25), (19-45,45-25,19-25).

Area 2:

(1-8,8-10,1-10), (1-8,8-11,1-11).

Area 3:

(11-19,19-18,11-18), (10-19,19-25,10-25),
(8-19,19-11,11-8), (19-27,19-11,11-27),
(10-19,19-18,10-18).

Experiment B3 B1, B2;

Area 1:

(23-28,28-25,23-25), (23-28,28-24,23-24),
(24-27,27-26,24-26), (24-33,23-25,23-33).

Area 2:

(13-14,13-18,14-18), (18-14,11-17,13-14).

Area 3:

(16-23,23-3,16-3), (17-22,3-21,17-21),
(22-3,19-2,19-3).

Area 4:

(40-34,34-31,31-40), (31-34,36-33,40-34).

K.2 EXPERIMENT B4

```
EXPERIMENT B4D2
PRESSURE
RESTING STATE

2,33
1,0
1,+01.927,+20.432
2,+18.543,+20.628
3,+01.925,+20.439
4,+02.015,+11.531
1,+15.778,+09.464
2,+15.669,+09.737
3,+15.704,+10.186
4,+14.119,+09.521
5,+14.228,+09.930
6,+13.993,+10.447
7,+13.897,+11.034
8,+14.378,+11.465
9,+15.100,+11.503
10,+14.713,+12.543
11,+14.723,+13.023
12,+15.857,+13.317
13,+16.012,+14.304
14,+17.462,+15.541
15,+16.674,+15.957
16,+14.691,+13.987
17,+13.885,+14.265
18,+14.259,+15.077
19,+13.889,+13.024
20,+13.554,+13.380
21,+13.203,+13.863
22,+12.955,+14.329
23,+12.479,+13.154
24,+11.731,+12.725
25,+12.299,+12.402
26,+12.707,+11.766
27,+12.471,+11.327
28,+13.650,+11.712
29,+12.191,+15.251
30,+13.046,+16.008
31,+13.590,+16.032
32,+13.831,+17.094
33,+13.302,+12.543

2,-30.5
1,+00.889,+19.303
2,+17.544,+19.595
3,+00.890,+19.274
4,+01.005,+11.146
1,+15.518,+09.790
2,+15.493,+09.994
3,+15.728,+10.559
4,+14.216,+09.829
5,+14.403,+10.260
6,+14.202,+10.761
7,+14.143,+11.346
8,+14.728,+11.822
9,+15.587,+11.757
10,+15.346,+12.875
11,+15.426,+13.430
12,+16.481,+13.649
13,+16.550,+14.617
14,+17.409,+15.853
15,+16.737,+16.308
16,+15.381,+14.508
17,+14.452,+14.604
18,+14.805,+15.446
19,+14.329,+13.330
20,+13.949,+13.684
21,+13.442,+14.154
22,+12.937,+14.672
23,+12.321,+13.530
24,+11.740,+13.100
25,+12.332,+12.670
26,+12.941,+12.073
27,+12.834,+11.570
28,+13.902,+12.018
29,+12.097,+15.638
30,+13.344,+16.373
31,+13.958,+16.396
32,+14.187,+17.463
33,+13.458,+12.897
```

FILE: L:OB4D2.DAT
REFERNCE POINT10 Magnification: 1.0
1 ROTATE X-Y -1.3337 RADIANS
X-Z 0.0000
Y-Z 0.0000

PT#	X	Y	Z
1	2.478	0.529	3.070
2	2.214	0.477	2.815
3	2.705	0.390	2.336
4	-3.138	0.179	3.034
5	-2.595	0.155	2.619
6	-3.446	0.114	2.109
7	-3.766	0.086	1.523
8	-1.763	0.093	1.076
9	1.240	0.109	1.055
10	0.000	0.000	0.000
11	0.148	-0.030	-0.499
12	4.289	0.132	-0.786
13	4.668	0.190	-1.769
14	8.985	0.625	-3.019
15	6.196	0.484	-3.436
16	-0.046	-0.026	-1.490
17	-3.348	-0.060	-1.713
18	-2.007	-0.008	-2.536
19	-3.517	-0.003	-0.464
20	-4.891	-0.019	-0.816
21	-6.543	0.014	-1.291
22	-7.998	0.106	-1.766
23	-10.019	0.117	-0.594
24	-12.519	-0.044	-0.157
25	-10.300	0.007	0.186
26	-8.339	-0.040	0.806
27	-8.966	-0.127	1.263
28	-4.723	0.057	0.850
29	-11.087	0.057	-2.689
30	-7.127	-0.028	-3.451
31	-4.930	0.000	-3.481
32	-4.087	0.033	-4.546
33	-6.267	0.063	0.012

```
ROTATION OF VIEW # 1 : -0.010 RADIANS.

ROTATION OF VIEW # 2 : -0.014 RADIANS.

MAGNIFICATION OF VIEW #  2 IS    0.998
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  2 IS    0.971 +/-  0.073 SD.
USING AVERAGING FROM Z VALUES OF 31 POINTS

USING REF. WIRE FOR MAGNIFCATION!
```

EXPERIMENT B4D6
PRESSURE
CONSTRICTED STATE

2,33	2,-30.5
1,0	
1,+01.897,+20.094	1,+01.896,+20.389
2,+18.620,+20.183	2,+18.575,+20.542
3,+01.904,+20.096	3,+01.882,+20.405
4,+01.947,+09.804	4,+01.997,+09.457
1, 0.0 , 0.0	1, 0.0 , 0.0
2, 0.0 , 0.0	2, 0.0 , 0.0
3, 0.0 , 0.0	3, 0.0 , 0.0
4, 0.0 , 0.0	4,+15.642,+10.218
5, 0.0 , 0.0	5,+15.675,+10.762
6, 0.0 , 0.0	6,+15.324,+11.353
7, 0.0 , 0.0	7, 0.0 , 0.0
8,+14.983,+11.879	8,+15.593,+12.399
9,+15.687,+11.943	9,+16.388,+12.501
10,+14.992,+12.930	10,+15.899,+13.372
11,+14.962,+13.408	11,+15.845,+13.908
12,+15.978,+13.750	12,+16.775,+14.346
13,+15.925,+14.722	13,+16.546,+15.170
14,+16.945,+15.958	14,+17.121,+16.364
15,+16.147,+16.216	15,+16.380,+16.608
16, 0.0 , 0.0	16,+15.531,+14.782
17, 0.0 , 0.0	17,+14.885,+14.768
18,+14.059,+15.047	18,+14.638,+15.511
19, 0.0 , 0.0	19, 0.0 , 0.0
20,+13.738,+13.338	20,+14.435,+13.797
21,+13.364,+13.700	21,+13.814,+14.358
22, 0.0 , 0.0	22, 0.0 , 0.0
23, 0.0 , 0.0	23,+12.801,+13.480
24,+12.172,+12.244	24,+12.544,+12.646
25,+12.705,+12.096	25,+13.125,+12.506
26, 0.0 , 0.0	26,+13.877,+12.120
27, 0.0 , 0.0	27,+13.820,+11.550
28,+14.274,+11.931	28, 0.0 , 0.0
29, 0.0 , 0.0	29, 0.0 , 0.0
30,+12.720,+15.631	30, 0.0 , 0.0
31,+13.229,+15.722	31,+13.816,+16.103
32,+13.390,+16.552	32, 0.0 , 0.0
33,+13.746,+12.594	33,+14.235,+13.073

```
FILE: L:OB4D6.DAT
REFERNCE POINT10          Magnification: 0.994
 1 ROTATE X-Y -1.3286 RADIANS
          X-Z  0.0000
          Y-Z  0.0000
PT#    X          Y          Z
 1    0.000      0.000      0.000 POINT # 1 IS NOT COMMON
 2    0.000      0.000      0.000 POINT # 2 IS NOT COMMON
 3    0.000      0.000      0.000 POINT # 3 IS NOT COMMON
 4    0.000      0.000      0.000 POINT # 4 IS NOT COMMON
 5    0.000      0.000      0.000 POINT # 5 IS NOT COMMON
 6    0.000      0.000      0.000 POINT # 6 IS NOT COMMON
 7    0.000      0.000      0.000 POINT # 7 IS NOT COMMON
 8   -0.576      0.138      1.033
 9    2.275      0.158      0.955
10    0.000      0.000      0.000
11   -0.175      0.010     -0.493
12    3.515      0.144     -0.865
13    2.952      0.224     -1.799
14    5.946      0.530     -3.030
15    3.012      0.432     -3.280
16    0.000      0.000      0.000 POINT #16 IS NOT COMMON
17    0.000      0.000      0.000 POINT #17 IS NOT COMMON
18   -4.239      0.077     -2.118
19    0.000      0.000      0.000 POINT #19 IS NOT COMMON
20   -5.187     -0.012     -0.405
21   -7.098      0.073     -0.814
22    0.000      0.000      0.000 POINT #22 IS NOT COMMON
23    0.000      0.000      0.000 POINT #23 IS NOT COMMON
24  -11.738     -0.002      0.714
25   -9.613      0.023      0.857
26    0.000      0.000      0.000 POINT #26 IS NOT COMMON
27    0.000      0.000      0.000 POINT #27 IS NOT COMMON
28    0.000      0.000      0.000 POINT #28 IS NOT COMMON
29    0.000      0.000      0.000 POINT #29 IS NOT COMMON
30    0.000      0.000      0.000 POINT #30 IS NOT COMMON
31   -7.400     -0.000     -2.767
32    0.000      0.000      0.000 POINT #32 IS NOT COMMON
33   -5.535      0.085      0.335
```

```
ROTATION OF VIEW # 1 : -0.004 RADIANS.

ROTATION OF VIEW # 2 : -0.011 RADIANS.

MAGNIFICATION OF VIEW #  2 IS   1.003
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  2 IS   0.979 +/-  0.095 SD.
USING AVERAGING FROM Z VALUES OF 14 POINTS

USING REF. WIRE FOR MAGNIFCATION!
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Experiment B4 D2, D6;

Area 1:

(15-12,12-14,15-14), (15-14,15-13,13-14).

Area 2:

(11-13,13-9,11-9), (11-13,11-12,12-13),
(11-9,12-9,11-12).

Area 3:

(21-9,21-33,33-9), (20-11,20-9,11-9),
(20-33,33-9,20-9).

Area 4:

(24-21,21-33,24-33), (24-20,24-33,20-33),
(24-21,21-20,24-20).
```

K.3 EXPERIMENT B5

EXPERIMENT B5A1.DAT
DRUG - DOPAMINE HYDROCHLORIDE 80 ms/l.
RESTING STATE

2,30	2,-30.5
1,0	
1,+03.369,+18.702	1,+03.836,+18.905
2,+19.802,+19.330	2,+20.395,+19.598
3,+03.350,+18.695	3,+03.829,+18.901
4,+03.746,+09.048	4,+04.256,+09.295
1,+08.251,+19.311	1, 0.0 , 0.0
2,+08.832,+20.314	2, 0.0 , 0.0
3,+09.780,+20.327	3,+13.073,+19.761
4,+11.674,+19.227	4,+14.771,+18.742
5,+12.661,+18.314	5,+15.765,+17.781
6,+14.308,+18.304	6,+16.966,+17.783
7,+14.264,+17.079	7,+17.112,+16.597
8,+13.881,+15.741	8,+16.638,+15.165
9,+14.524,+15.249	9,+17.103,+14.782
10,+15.115,+14.487	10,+17.552,+13.990
11,+14.306,+14.487	11,+17.131,+13.749
12,+13.873,+14.164	12,+16.425,+13.687
13,+13.675,+13.437	13,+15.995,+13.021
14,+13.274,+13.035	14,+15.497,+12.563
15,+14.428,+12.766	15, 0.0 , 0.0
16,+14.294,+09.546	16, 0.0 , 0.0
17,+14.589,+08.914	17, 0.0 , 0.0
18,+13.950,+08.043	18, 0.0 , 0.0
19,+13.411,+11.627	19, 0.0 , 0.0
20,+13.051,+12.467	20,+15.119,+11.913
21,+12.662,+12.903	21,+14.680,+12.387
22,+12.492,+11.358	22, 0.0 , 0.0
23,+12.310,+12.239	23,+14.376,+11.745
24,+12.882,+13.544	24, 0.0 , 0.0
25,+12.886,+14.586	25, 0.0 , 0.0
26,+10.763,+14.186	26,+13.223,+13.669
27,+11.419,+16.267	27,+14.930,+15.213
28,+09.917,+15.130	28, 0.0 , 0.0
29,+09.372,+14.703	29, 0.0 , 0.0
30,+06.446,+16.683	30, 0.0 , 0.0

FILE: L:OB5A1.DAT
REFERNCE POINT 4 Magnification: 16.44499
1 ROTATE X-Y -1.2771 RADIANS
X-Z 0.0000
Y-Z 0.0000

PT#	X	Y	Z	
1	0.000	0.000	0.000	POINT # 1 IS NOT COMMON
2	0.000	0.000	0.000	POINT # 2 IS NOT COMMON
3	-6.968	0.083	-1.000	
4	0.000	0.000	0.000	
5	3.898	-0.109	0.881	
6	9.294	-0.022	0.824	
7	9.678	-0.131	2.036	
8	8.283	-0.052	3.410	
9	10.453	-0.016	3.849	
10	12.548	0.000	4.593	
11	10.234	-0.144	4.682	
12	8.116	0.058	4.961	
13	7.046	0.206	5.682	
14	5.417	0.297	6.114	
15	0.000	0.000	0.000	POINT #15 IS NOT COMMON
16	0.000	0.000	0.000	POINT #16 IS NOT COMMON
17	0.000	0.000	0.000	POINT #17 IS NOT COMMON
18	0.000	0.000	0.000	POINT #18 IS NOT COMMON
19	0.000	0.000	0.000	POINT #19 IS NOT COMMON
20	4.383	0.402	6.712	
21	2.744	0.472	6.284	
22	0.000	0.000	0.000	POINT #22 IS NOT COMMON
23	1.608	0.477	6.955	
24	0.000	0.000	0.000	POINT #24 IS NOT COMMON
25	0.000	0.000	0.000	POINT #25 IS NOT COMMON
26	-3.819	0.420	5.080	
27	0.335	-0.241	3.099	
28	0.000	0.000	0.000	POINT #28 IS NOT COMMON
29	0.000	0.000	0.000	POINT #29 IS NOT COMMON
30	0.000	0.000	0.000	POINT #30 IS NOT COMMON

ROTATION OF VIEW # 1 : -0.041 RADIANS.

ROTATION OF VIEW # 2 : -0.044 RADIANS.

MAGNIFICATION OF VIEW # 2 IS 0.992
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW # 2 IS 0.981 +/- 0.048 SD.
USING AVERAGING FROM Z VALUES OF 16 POINTS

USING REF. WIRE FOR MAGNIFCATION!

EXPERIMENT B5A2
DRUG - DOPAMINE HYDROCHLORIDE, 80 ms/l.
CONSTRICTED STATE

2,30	2,-30.5
1,0	
1,+00.645,+17.996	1,+00.885,+15.961
2,+17.188,+19.248	2,+17.502,+17.130
3,+00.643,+17.989	3,+00.893,+15.960
4,+01.369,+08.905	4,+01.437,+08.442
1,+09.580,+19.757	1,+08.938,+19.988
2,+10.144,+20.698	2,+09.078,+20.802
3,+11.107,+20.749	3,+09.696,+20.905
4,+12.922,+20.016	4,+11.485,+20.085
5,+13.967,+19.157	5,+12.444,+19.132
6,+15.732,+19.226	6,+13.692,+19.262
7,+15.743,+18.156	7,+14.034,+18.231
8,+15.255,+16.753	8,+13.692,+16.806
9,+15.881,+16.340	9,+14.124,+16.409
10,+16.666,+15.727	10,+14.620,+15.654
11,+15.810,+15.587	11,+14.161,+15.379
12,+15.414,+15.250	12,+13.494,+15.279
13,+15.321,+14.511	13,+12.757,+14.705
14,+15.066,+14.028	14,+12.530,+14.018
15,+16.165,+13.922	15,+13.791,+13.925
16,+16.529,+10.916	16, 0.0 , 0.0
17,+16.898,+10.444	17, 0.0 , 0.0
18,+16.365,+09.338	18, 0.0 , 0.0
19,+15.538,+12.695	19, 0.0 , 0.0
20,+15.003,+13.474	20,+12.450,+13.459
21,+14.527,+13.803	21,+11.988,+13.816
22,+14.837,+12.119	22,+11.975,+12.470
23,+14.229,+12.836	23,+11.587,+12.934
24,+14.557,+14.489	24,+12.239,+14.546
25,+14.446,+15.631	25, 0.0 , 0.0
26,+12.463,+15.083	26,+10.265,+15.089
27,+12.761,+17.072	27,+11.537,+17.100
28,+11.565,+15.987	28, 0.0 , 0.0
29,+10.992,+15.586	29,+09.414,+15.707
30,+08.008,+17.161	30, 0.0 , 0.0

FILE: L:OB5A2.DAT
REFERNCE POINT 4 Magnification: 16.59031
1 ROTATE X-Y -1.2813 RADIANS
X-Z 0.0000
Y-Z 0.0000

PT#	X	Y	Z	
1	-11.096	-0.150	0.463	
2	-10.012	0.036	-0.479	
3	-7.039	0.148	-0.611	
4	0.000	0.000	0.000	
5	4.051	-0.048	0.799	
6	9.729	0.091	0.587	
7	10.694	-0.096	1.637	
8	9.530	-0.140	3.075	
9	11.650	-0.086	3.437	
10	14.273	0.000	4.027	
11	11.839	-0.154	4.259	
12	9.898	0.040	4.572	
13	8.528	0.413	5.285	
14	7.783	0.410	5.836	
15	12.272	0.225	5.851	
16	0.000	0.000	0.000	POINT #16 IS NOT COMMON
17	0.000	0.000	0.000	POINT #17 IS NOT COMMON
18	0.000	0.000	0.000	POINT #18 IS NOT COMMON
19	0.000	0.000	0.000	POINT #19 IS NOT COMMON
20	7.673	0.423	6.395	
21	5.801	0.458	6.097	
22	6.807	0.621	7.672	
23	4.748	0.542	7.064	
24	6.125	0.336	5.396	
25	0.000	0.000	0.000	POINT #25 IS NOT COMMON
26	-1.734	0.449	4.978	
27	0.644	-0.115	2.951	
28	0.000	0.000	0.000	POINT #28 IS NOT COMMON
29	-6.295	0.236	4.552	
30	0.000	0.000	0.000	POINT #30 IS NOT COMMON

ROTATION OF VIEW # 1 : -0.080 RADIANS.

ROTATION OF VIEW # 2 : -0.072 RADIANS.

MAGNIFICATION OF VIEW # 2 IS 0.996
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW # 2 IS 0.999 +/- 0.201 SD.
USING AVERAGING FROM Z VALUES OF 22 POINTS

USING REF. WIRE FOR MAGNIFCATION!

EXPERIMENT B5C1
PRESSURE
RESTING STATE

2,23	2,-30.5
1,0	
1,+04.232,+18.318	1,+01.425,+19.308
2,+20.241,+18.972	2,+17.416,+19.917
3,+04.235,+18.321	3,+01.414,+19.309
4,+04.568,+10.519	4,+01.805,+08.999
1,+08.729,+20.023	1,+11.569,+19.611
2,+09.570,+20.392	2,+12.005,+20.018
3,+10.154,+20.285	3,+12.384,+19.986
4,+10.091,+19.843	4,+12.771,+19.473
5,+11.004,+20.311	5,+13.095,+19.976
6,+11.268,+19.949	6, 0.0 , 0.0
7,+11.338,+18.807	7,+14.123,+18.483
8,+12.419,+18.866	8,+14.814,+18.534
9,+12.968,+18.724	9, 0.0 , 0.0
10,+13.420,+18.542	10,+15.910,+18.149
11,+13.271,+17.735	11,+16.009,+17.367
12,+13.957,+17.060	12, 0.0 , 0.0
13,+12.099,+14.310	13,+14.444,+13.883
14,+11.509,+13.886	14,+13.520,+13.517
15,+11.788,+13.580	15,+13.825,+13.186
16,+11.768,+12.731	16,+13.884,+12.357
17,+12.273,+10.967	17, 0.0 , 0.0
18,+10.175,+13.281	18,+11.819,+12.882
19,+11.057,+13.335	19,+13.030,+12.995
20,+11.179,+14.874	20,+13.520,+14.518
21,+10.111,+16.829	21,+13.137,+16.465
22,+11.384,+17.706	22,+14.374,+17.318
23,+11.818,+17.645	23,+14.798,+17.375

FILE: L:OB5C1.DAT
REFERNCE POINT 1 Magnification: 16.02235
1 ROTATE X-Y -1.3014 RADIANS
X-Z 0.0000
Y-Z 0.0000

PT#	X	Y	Z	
1	0.000	0.000	0.000	
2	2.368	0.202	-0.409	
3	4.209	0.303	-0.343	
4	4.898	0.067	0.114	
5	7.174	0.364	-0.394	
6	0.000	0.000	0.000	POINT # 6 IS NOT COMMON
7	9.992	-0.001	1.086	
8	13.352	0.190	0.988	
9	0.000	0.000	0.000	POINT # 9 IS NOT COMMON
10	17.391	0.126	1.284	
11	17.418	-0.000	2.088	
12	0.000	0.000	0.000	POINT #12 IS NOT COMMON
13	12.745	0.227	5.579	
14	9.929	0.412	6.015	
15	11.087	0.395	6.316	
16	11.290	0.355	7.159	
17	0.000	0.000	0.000	POINT #17 IS NOT COMMON
18	4.256	0.622	6.686	
19	8.221	0.439	6.578	
20	9.149	0.241	5.035	
21	6.092	-0.108	3.121	
22	10.730	-0.108	2.198	
23	12.362	-0.106	2.212	

```
ROTATION OF VIEW # 1 : -0.043 RADIANS.

ROTATION OF VIEW # 2 : -0.038 RADIANS.

MAGNIFICATION OF VIEW #  2 IS    1.001
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  2 IS    1.011 +/-  0.026 SD.
USING AVERAGING FROM Z VALUES OF 13 POINTS, WITH Z LIMIT =  1.00

USING REF. WIRE FOR MAGNIFCATION!
```

EXPERIMENT B5C2
PRESSURE
CONSTRICTED STATE

2,23
1,0
1,+02.687,+19.608
2,+18.648,+20.598
3,+02.677,+19.603
4,+03.364,+09.864

1,+08.063,+19.486
2,+08.802,+19.859
3,+09.382,+19.925
4,+09.381,+19.505
5,+10.201,+19.997
6,+10.413,+19.682
7,+10.612,+18.709
8,+11.415,+18.916
9,+12.128,+18.927
10,+12.489,+18.778
11,+12.486,+18.051
12,+13.145,+17.563
13,+11.716,+14.593
14,+11.004,+14.118
15,+11.443,+13.668
16,+11.603,+12.871
17,+12.345,+11.149
18,+09.960,+13.035
19,+10.798,+13.316
20,+10.359,+15.136
21,+09.722,+16.839
22,+10.789,+17.768
23,+11.179,+17.781

2,-30.5

1,+04.437,+18.240
2,+20.413,+19.207
3,+04.429,+18.244
4,+04.989,+09.602

1,+10.221,+19.254
2,+10.698,+19.537
3,+11.054,+19.689
4,+11.392,+19.235
5,+11.809,+19.608
6,+12.191,+19.328
7, 0.0 , 0.0
8,+13.324,+18.664
9,+13.927,+18.538
10,+14.242,+18.443
11,+14.424,+17.755
12,+15.043,+17.219
13,+13.452,+14.239
14,+12.528,+13.918
15,+13.106,+13.390
16,+13.381,+12.530
17, 0.0 , 0.0
18,+11.365,+12.716
19,+12.401,+12.986
20,+12.047,+14.898
21,+12.080,+16.524
22,+13.130,+17.465
23,+13.431,+17.491

FILE: L:OB5C2.DAT
REFERNCE POINT 1 Magnification: 15.99167
1 ROTATE X-Y -1.2976 RADIANS
X-Z 0.0000
Y-Z 0.0000

PT#	X	Y	Z	
1	0.000	0.000	0.000	
2	2.222	0.116	-0.396	
3	3.969	0.222	-0.520	
4	4.719	0.042	-0.098	
5	6.954	0.229	-0.609	
6	8.156	0.135	-0.321	
7	0.000	0.000	0.000	POINT # 7 IS NOT COMMON
8	12.387	0.044	0.346	
9	14.896	0.079	0.322	
10	16.209	0.096	0.433	
11	16.729	0.000	1.146	
12	19.283	0.003	1.600	
13	14.322	0.129	4.666	
14	11.325	0.266	5.154	
15	13.377	0.179	5.589	
16	14.414	0.113	6.387	
17	0.000	0.000	0.000	POINT #17 IS NOT COMMON
18	7.434	0.354	6.337	
19	10.915	0.226	5.999	
20	8.933	0.194	4.190	
21	7.358	-0.149	2.543	
22	11.131	-0.169	1.540	
23	12.437	-0.132	1.499	

```
ROTATION OF VIEW # 1 : -0.070 RADIANS.

ROTATION OF VIEW # 2 : -0.065 RADIANS.

MAGNIFICATION OF VIEW #  2 IS   0.999
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  2 IS   0.963 +/-  0.027 SD.
USING AVERAGING FROM Z VALUES OF 12 POINTS, WITH Z LIMIT =  1.00

USING REF. WIRE FOR MAGNIFCATION!
```

Experiment B5 A1, A2;

Area 1:

(5-6,6-9,5-9), (5-6,6-7,5-7),
(5-27,5-8,27-8), (5-6,6-8,5-8),
(4-27,27-8,4-8), (27-5,5-6,27-6).

Area 2:

(7-10,10-12,7-12), (26-12,5-21,5-26),
(8-12,12-10,8-10), (26-12,26-21,21-12),
(27-26,27-8,8-21), (8-26,8-12,12-26),
(8-13,13-21,8-21), (8-20,20-10,8-10),
(26-11,11-14,26-14), (26-13,13-9,26-9).

Area 3:

(3-5,5-27,3-27), (3-4,3-27,4-27),
(3-26,3-4,26-4).

Experiment B5 C1, C2;

Area 1:

(18-13,13-16,18-16), (18-14,14-16,18-16),
(20-18,20-16,18-16), (20-13,20-14,14-13).

Area 2:

(5-21,21-23,5-23), (1-5,1-21,5-21),
(1-8,8-23,1-23), (5-8,5-23,8-23),
(8-11,23-11,8-23).

K.4 EXPERIMENT B6

EXPERIMENT B6A1
DRUG - DOPAMINE HYDROCHLORIDE, 80 mg/l.
RESTING STATE

3,16	2,-30.5	3,-60
1,0.		
1,+04.424,+20.203	1,+03.174,+19.760	1,+00.124,+09.423
2,+18.997,+20.116	2,+17.733,+19.988	2,+14.636,+10.009
3,+04.430,+20.197	3,+03.184,+19.749	3,+03.248,+20.112
4,+04.402,+09.295	4,+03.387,+09.154	4,+03.587,+10.620
1,+07.483,+10.254	1,+09.149,+09.193	1, 0.0 , 0.0
2,+07.742,+11.094	2,+10.369,+10.418	2,+16.186,+10.671
3,+08.104,+11.357	3,+10.648,+10.708	3,+16.382,+10.913
4,+09.354,+11.762	4,+11.947,+11.131	4,+17.372,+11.401
5,+10.957,+11.738	5,+13.556,+11.142	5,+18.619,+11.439
6,+10.402,+13.572	6,+13.118,+13.014	6,+18.422,+13.330
7,+09.939,+14.296	7,+12.734,+13.675	7,+18.205,+13.971
8,+10.882,+15.471	8,+14.083,+14.855	8,+19.509,+15.183
9,+08.785,+15.273	9,+11.439,+14.644	9,+16.958,+14.881
10,+09.261,+15.782	10,+12.276,+15.140	10,+17.971,+15.429
11,+10.927,+16.706	11,+14.121,+16.013	11,+19.594,+16.390
12,+10.024,+16.900	12, 0.0 , 0.0	12,+18.942,+16.543
13,+09.166,+16.561	13,+12.290,+15.931	13,+18.115,+16.223
14,+07.946,+17.107	14,+10.775,+16.080	14,+16.519,+16.280
15,+08.761,+17.752	15,+11.866,+17.100	15,+17.803,+17.391
16,+10.368,+18.114	16,+13.530,+17.491	16, 0.0 , 0.0

FILE: L:OB6A1.DAT Magnification: 14.57326
REFERNCE POINT 2
1 ROTATE X-Y -1.2337 RADIANS
X-Z 0.0000
Y-Z 0.0000

PT#	X	Y	Z	
1	0.000	0.000	0.000	POINT # 1 IS NOT COMMON
2	0.000	0.000	0.000	
3	0.866	0.081	-0.266	
4	4.355	0.184	-0.696	
5	8.783	0.331	-0.698	
6	7.425	0.223	-2.547	
7	6.278	0.137	-3.245	
8	9.529	-0.000	-4.438	
9	2.739	0.157	-4.201	
10	4.722	-0.033	-4.722	
11	9.634	0.014	-5.657	
12	0.000	0.000	0.000	POINT #12 IS NOT COMMON
13	4.654	-0.107	-5.507	
14	0.657	0.002	-5.893	
15	3.481	-0.122	-6.689	
16	0.000	0.000	0.000	POINT #16 IS NOT COMMON

```
ROTATION OF VIEW # 1 :  0.003 RADIANS.

ROTATION OF VIEW # 2 : -0.019 RADIANS.

ROTATION OF VIEW # 3 : -0.036 RADIANS.

MAGNIFICATION OF VIEW #  2 IS   1.001
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  2 IS   0.985 +/-  0.034 SD.
USING AVERAGING FROM Z VALUES OF  9 POINTS, WITH Z LIMIT =  1.00

USING REF. WIRE FOR MAGNIFCATION!

MAGNIFICATION OF VIEW #  3 IS   1.003
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  3 IS   0.971 +/-  0.045 SD.
USING AVERAGING FROM Z VALUES OF  9 POINTS, WITH Z LIMIT =  1.00

USING REF. WIRE FOR MAGNIFCATION!
```

EXPERIMENT B6A2
DRUG - DOPAMINE HYDROCHLORIDE, 80 ms/l.
CONSTRICTED STATE

3,16
1,0
1,+03.928,+20.100
2,+18.491,+20.628
3,+03.932,+20.098
4,+04.362,+10.192

1,+07.718,+09.321
2,+08.039,+10.481
3,+08.329,+10.797
4,+09.475,+11.242
5,+11.074,+11.351
6,+10.422,+13.153
7,+09.907,+13.883
8,+10.768,+15.037
9,+08.660,+14.925
10,+09.154,+15.375
11,+10.714,+16.262
12,+09.835,+16.469
13,+08.988,+16.136
14,+07.639,+16.631
15,+08.481,+17.279
16,+10.068,+17.717

2,-30.5

1,+06.394,+19.362
2,+20.925,+20.066
3,+06.391,+19.375
4,+06.935,+09.263

1,+14.106,+09.462
2,+13.943,+10.572
3,+14.224,+10.887
4,+15.449,+11.341
5,+17.067,+11.475
6,+16.598,+13.255
7,+16.139,+13.998
8,+17.426,+15.194
9,+14.802,+14.943
10,+15.620,+15.454
11,+17.456,+16.404
12,+16.547,+16.567
13,+15.543,+16.259
14,+14.032,+16.378
15,+15.087,+17.447
16, 0.0 , 0.0

3,-60

1,+00.452,+19.274
2,+14.960,+19.834
3,+00.454,+19.275
4,+00.836,+08.937

1,+15.149,+08.705
2,+15.626,+10.147
3,+15.810,+10.447
4,+16.796,+10.967
5,+18.038,+10.977
6,+17.898,+12.860
7,+17.578,+13.547
8,+18.947,+14.749
9,+16.463,+14.513
10,+17.489,+15.067
11,+19.083,+15.923
12,+18.454,+16.061
13,+17.555,+15.828
14,+16.072,+15.937
15,+17.243,+17.011
16, 0.0 , 0.0

FILE: L:OB6A2.DAT
REFERNCE POINT 2 Magnification: 15.57257
1 ROTATE X-Y -1.2606 RADIANS
X-Z 0.0000
Y-Z 0.0000

PT#	X	Y	Z	
1	-0.400	-0.156	1.209	
2	0.000	0.000	0.000	
3	0.726	0.057	-0.325	
4	3.949	0.206	-0.834	
5	8.357	0.466	-0.999	
6	6.698	0.231	-2.787	
7	5.281	0.112	-3.491	
8	8.284	0.000	-4.705	
9	1.552	-0.048	-4.449	
10	3.506	-0.177	-4.955	
11	8.153	-0.071	-5.918	
12	5.711	-0.219	-6.069	
13	3.138	-0.268	-5.718	
14	-1.007	-0.377	-6.024	
15	1.682	-0.385	-6.854	
16	0.000	0.000	0.000	POINT #16 IS NOT COMMON

```
ROTATION OF VIEW # 1 : -0.043 RADIANS.

ROTATION OF VIEW # 2 : -0.054 RADIANS.

ROTATION OF VIEW # 3 : -0.037 RADIANS.

MAGNIFICATION OF VIEW #  2 IS   1.002
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  2 IS   0.995 +/-  0.036 SD.
USING AVERAGING FROM Z VALUES OF 12 POINTS, WITH Z LIMIT =  1.00

USING REF. WIRE FOR MAGNIFCATION!

MAGNIFICATION OF VIEW #  3 IS   1.004
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  3 IS   0.985 +/-  0.063 SD.
USING AVERAGING FROM Z VALUES OF 11 POINTS, WITH Z LIMIT =  1.00

USING REF. WIRE FOR MAGNIFCATION!
```

EXPERIMENT B6B1
PRESSURE
RESTING STATE

3,18
1,0

1,+02.846,+19.749
2,+18.931,+19.794
3,+02.854,+19.739
4,+02.865,+11.513

1,+05.210,+10.331
2,+04.245,+11.480
3,+05.828,+11.844
4,+06.546,+12.244
5,+07.171,+12.499
6,+06.904,+13.119
7,+08.785,+12.493
8,+09.026,+10.776
9,+07.644,+13.610
10,+09.679,+14.804
11,+07.740,+14.971
12,+06.457,+15.601
13,+06.981,+16.808
14,+08.771,+16.828
15,+07.787,+18.019
16,+10.206,+17.816
17,+05.858,+17.550
18,+06.059,+19.007

2,-30.5

1,+02.086,+20.246
2,+18.190,+20.457
3,+02.080,+20.250
4,+02.304,+08.944

1,+09.851,+09.914
2,+08.390,+10.952
3,+10.015,+11.506
4,+10.760,+11.837
5,+11.439,+12.032
6,+11.074,+12.758
7,+13.105,+12.104
8,+13.273,+10.412
9,+11.984,+13.262
10,+14.434,+14.441
11,+12.224,+14.620
12,+10.401,+15.236
13,+11.713,+16.473
14,+13.674,+16.543
15,+12.716,+17.674
16,+15.049,+17.469
17,+10.344,+17.161
18,+10.877,+18.640

3,-60

1,+04.575,+19.995
2,+21.351,+20.333
3,+04.569,+19.986
4,+04.821,+09.100

1,+14.426,+09.963
2,+12.700,+10.949
3,+14.101,+11.497
4,+14.682,+11.908
5,+15.158,+12.196
6,+14.819,+12.745
7,+16.490,+12.259
8, 0.0 , 0.0
9,+15.602,+13.382
10,+17.834,+14.557
11,+15.966,+14.726
12,+14.171,+15.302
13,+15.896,+16.563
14,+17.521,+16.610
15,+16.924,+17.777
16,+18.426,+17.680
17,+14.588,+17.247
18,+15.349,+18.722

FILE: L:OB6B1.DAT
REFERNCE POINT 1 Magnification: 16.08506
1 ROTATE X-Y -1.1954 RADIANS
X-Z 0.0000
Y-Z 0.0000

PT#	X	Y	Z	
1	0.000	0.000	0.000	
2	-3.633	0.393	-1.084	
3	0.813	0.342	-1.519	
4	2.806	0.327	-1.911	
5	4.555	0.309	-2.164	
6	3.645	0.380	-2.783	
7	9.064	0.267	-2.194	
8	0.000	0.000	0.000	POINT # 8 IS NOT COMMON
9	5.918	0.279	-3.303	
10	12.171	-0.000	-4.501	
11	6.419	0.183	-4.653	
12	1.979	0.553	-5.254	
13	4.774	0.013	-6.477	
14	9.954	-0.105	-6.523	
15	7.332	-0.131	-7.686	
16	13.692	-0.037	-7.516	
17	1.226	0.203	-7.185	
18	2.345	-0.024	-8.643	

```
ROTATION OF VIEW # 1 : -0.001 RADIANS.

ROTATION OF VIEW # 2 : -0.020 RADIANS.

ROTATION OF VIEW # 3 : -0.023 RADIANS.

MAGNIFICATION OF VIEW #  2 IS   0.999
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  2 IS   0.989 +/-  0.042 SD.
USING AVERAGING FROM Z VALUES OF 16 POINTS, WITH Z LIMIT =  1.00

USING REF. WIRE FOR MAGNIFCATION!

MAGNIFICATION OF VIEW #  3 IS   0.959
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  3 IS   0.973 +/-  0.019 SD.
USING AVERAGING FROM Z VALUES OF 15 POINTS, WITH Z LIMIT =  1.00

USING REF. WIRE FOR MAGNIFCATION!
```

```
EXPERIMENT B6B2.DAT
PRESSURE
CONSTRICTED STATE

3,18                    2,-30.5                 3,-60
1,0
1,+00.601,+18.731       1,+03.813,+18.980       1,+04.994,+19.349
2,+16.752,+18.999       2,+20.248,+19.613       2,+21.596,+19.121
3,+00.597,+18.731       3,+03.803,+18.977       3,+04.996,+19.354
4,+00.813,+09.470       4,+04.303,+09.068       4,+04.951,+08.268

1,+08.529,+12.399       1,+10.969,+12.143       1,+14.066,+12.383
2,+07.867,+12.726       2,+09.616,+12.488       2,+13.556,+13.241
3,+09.119,+13.536       3,+11.053,+13.258       3,+14.798,+13.882
4,+09.731,+13.955       4,+11.653,+13.700       4,+15.324,+14.302
5,+10.223,+14.261       5,  0.0   ,  0.0        5,+15.812,+14.555
6,+10.118,+14.684       6,+11.903,+14.415       6,+15.362,+14.978
7,+11.435,+14.289       7,+13.577,+14.067       7,+17.038,+14.483
8,+11.532,+12.753       8,+13.902,+12.513       8,+17.399,+12.839
9,+10.661,+15.418       9,+12.477,+15.138       9,+16.114,+15.549
10,+12.532,+16.581      10,+14.736,+16.350      10,+18.021,+16.717
11,+11.052,+16.582      11,+12.987,+16.391      11,+16.521,+16.798
12,+10.141,+16.879      12,+11.567,+16.634      12,+14.925,+17.133
13,+10.649,+18.180      13,+12.794,+17.958      13,+16.697,+18.098
14,+12.071,+18.455      14,+14.345,+18.282      14,+17.963,+18.614
15,+11.052,+19.537      15,+13.443,+19.306      15,+17.588,+19.654
16,+13.258,+19.454      16,+15.438,+19.330      16,  0.0   ,  0.0
17,+09.608,+18.667      17,+11.536,+18.367      17,+15.578,+18.833
18,+09.605,+19.954      18,+11.954,+19.629      18,+16.363,+20.040
```

FILE: L:OB6B2.DAT
REFERNCE POINT 1 Magnification: 16.15322
1 ROTATE X-Y -1.2022 RADIANS
X-Z 0.0000
Y-Z 0.0000

PT#	X	Y	Z	
1	0.000	0.000	0.000	
2	-2.452	0.230	-0.392	
3	1.212	0.136	-1.193	
4	2.865	0.142	-1.626	
5	0.000	0.000	0.000	POINT # 5 IS NOT COMMON
6	3.605	0.253	-2.347	
7	7.892	0.019	-1.979	
8	8.630	-0.124	-0.439	
9	5.232	0.188	-3.059	
10	10.835	-0.000	-4.268	
11	6.368	0.139	-4.252	
12	2.937	0.481	-4.520	
13	5.592	-0.033	-5.777	
14	9.652	-0.084	-6.131	
15	7.114	-0.222	-7.165	
16	0.000	0.000	0.000	POINT #16 IS NOT COMMON
17	2.359	0.088	-6.261	
18	3.046	-0.212	-7.524	

```
ROTATION OF VIEW # 1 : -0.023 RADIANS.

ROTATION OF VIEW # 2 : -0.050 RADIANS.

ROTATION OF VIEW # 3 :  0.004 RADIANS.

MAGNIFICATION OF VIEW #  2 IS   0.982
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  2 IS   0.992 +/-  0.019 SD.
USING AVERAGING FROM Z VALUES OF 13 POINTS, WITH Z LIMIT =  1.00

USING REF. WIRE FOR MAGNIFCATION!

MAGNIFICATION OF VIEW #  3 IS   0.973
USING REFERERENCE WIRE!

MAGNIFICATION OF VIEW #  3 IS   0.944 +/-  0.073 SD.
USING AVERAGING FROM Z VALUES OF 13 POINTS, WITH Z LIMIT =  1.00

USING REF. WIRE FOR MAGNIFCATION!
```

Experiment B6 A1, A2;

Area 1:

(2-6,6-5,2-5), (3-6,6-5,3-5),
(3-7,7-5,3-5), (6-4,4-5,4-6).

Area 2:

(6-9,9-8,6-8), (10-8,8-6,10-6),
(10-8,8-7,10-7), (9-8,8-7,9-7).

Area 3:

(15-11,11-10,15-10), (15-9,11-9,15-11),
(14-13,13-9,14-9).

Experiment B6 B1, B2;

Area 1:

(14-7,7-11,7-14), (14-7,11-10,11-7).

Area 2:

(15-12,12-11,15-11), (11-15,13-14,11-14).

Area 3:

(18-15,18-12,12-15), (18-12,17-15,15-12).

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