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EXPERIMENTAL DATA FOR USE WITH BIOMECHANICAL MODELS
VOLUME 1

Guy S. Nusholtz
Paula Lux
Miles Janicki

INTERIM REPORT
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EXPERIMENTAL DATA FOR USE WITH BIOMECHANICAL MODELS

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by

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16. Abstract

The objective of the work presented in this report was to provide biomechanical data on the impact response of the human head, thorax, and pelvis for a variety of current modeling and impact tolerance studies. Human cadavers were used as test subjects with multiple impacts being performed on each subject.

In a typical test series a single cadaver was subjected to two frontal head impacts, a series of three to six low-velocity thorax impacts with the subject in various positions, a high-velocity lateral thorax impact, and a lateral pelvis impact. In addition to kinematic response and injury tolerance data, information concerning the repeatability of impacts to the head of a single subject was obtained.

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OVERVIEW

Impact studies using human cadavers as surrogates of the living human have been concerned with the many processes that can take place as a result of the interactions of the passenger with the vehicle interior during an accident. These processes are of interest for a variety of reasons, such as developing an understanding of the fundamental nature of the interaction due to impact, quantitatively determining the probabilities associated with the resulting injury, and applying the data for the reduction of these probabilities.

As it is neither practical nor desirable to utilize human cadavers in direct vehicle testing, the kinematic response and some modes of injury response can be obtained by blunt impact to a cadaveric subject. Once obtained, this information can be used to generate or validate mathematical and physical (ATD) models, which then can be used to evaluate the vehicle interior in terms of the protection to injury it offers in an impact environment.

The objective of the work being performed under this contract is to provide biomechanical data on the impact response of the human head, thorax, and pelvis for a variety of current NHTSA modeling and impact tolerance studies. Human cadavers are used as test subjects with multiple impacts being performed on each subject.

In a typical test series a single cadaver will be subjected to two frontal head impacts, a series of three to six low-velocity thorax impacts with the subject in various positions, a high-velocity lateral thorax impact, and a lateral pelvis impact. In addition to kinematic response and injury tolerance data, information concerning the repeatability of impacts to the head of a single subject is obtained.

METHODOLOGY

SUBJECT PREPARATION

Following transfer to UMTRI, the cadaveric subjects are stored at 4°c until subsequent use. The cadavers are sanitarily prepared and examined radiologically prior to the installation of accelerometer and pressure transducer hardware.

IMPACT TESTING

Impact events are performed with the UMTRI pendulum impact device. The free traveling mass which strikes the subject is fitted with either a 15 cm round or a 20 cm square rigid metal surface, which for different impact tests has affixed to it various materials to produce different force-time and load distribution characteristics. The impact response is obtained primarily through the use of accelerometers or accelerometer clusters which are rigidly affixed to various points on the skeletal structure. In addition, each subject is instrumented with pressure transducers located appropriately to record vascular, pulmonary, and cerebrospinal pressures at the skull-dura interface.

Acceleration Measurement - Accelerations are measured in three orthogonal directions at five sites on the thorax (T1 and T12 thoracic vertebrae, right and left fourth ribs, and upper sternum) with Endevco 2264-2000 piezoresistive accelerometers. A cluster of three accelerometers with mutually orthogonal sensitive directions (a "triax") is secured at each site (Figure 1). Three-dimensional motion determination is made possible by affixing three triaxial clusters of accelerometers to lightweight magnesium plates which are in turn rigidly attached to the skull and pelvis. Uniaxial accelerometers use an attachment scheme similar to that of the triaxial clusters. The location and mounting of the accelerometer platforms are as follows:

Head Nine-Accelerometer - Several metal self-tapping screws are threaded directly into the parietal and occipital bones of the skull through small pilot holes. Feet are attached to the magnesium accelerometer mounting plate (Figure 2) and are positioned near the screws on the exposed skull. To ensure rigidity, plastic acrylic is molded around the screws, feet, and plate such that the plate becomes rigidly attached to the skull. Three triaxial clusters of accelerometers are then attached to their positions on the plate.

Pelvis Nine-Accelerometer - Four lag bolts are screwed into the pelvis near the posterior-superior iliac spines. The mounting plate is positioned such that the CG is midway between the posterior-superior iliac spines, and plastic

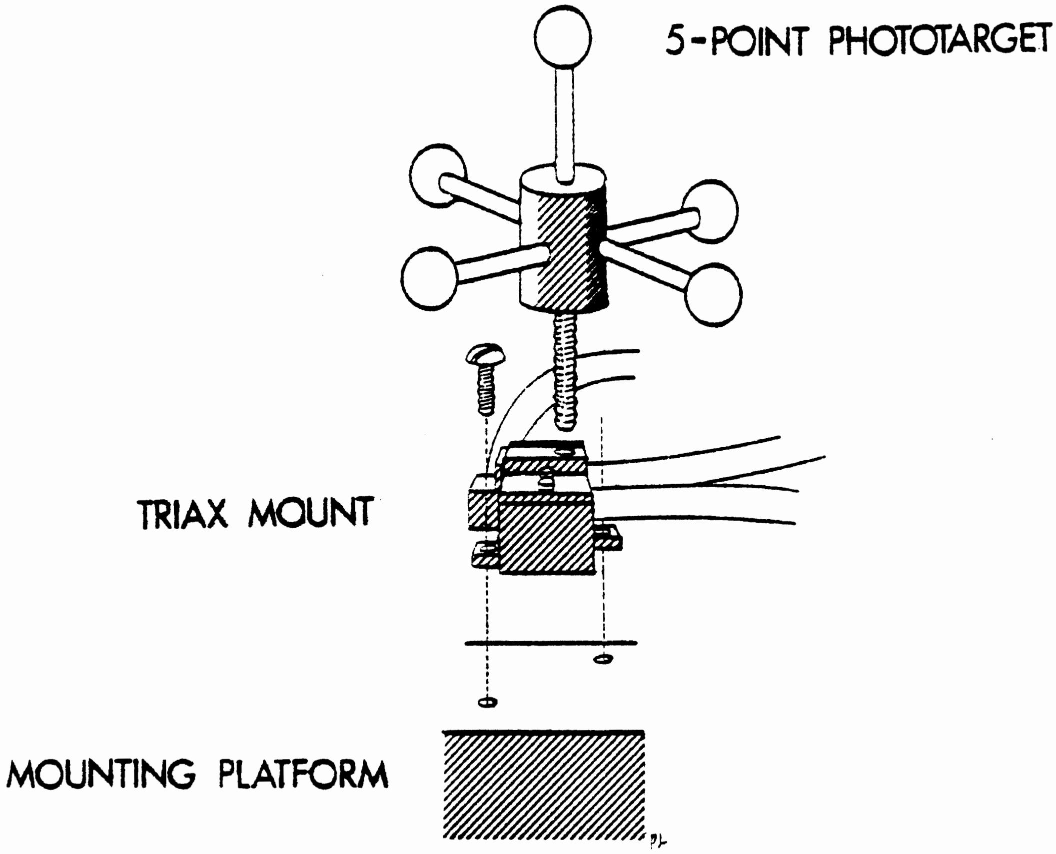


Figure 1: Schematic representation of triaxial accelerometer and 5-point phototarget

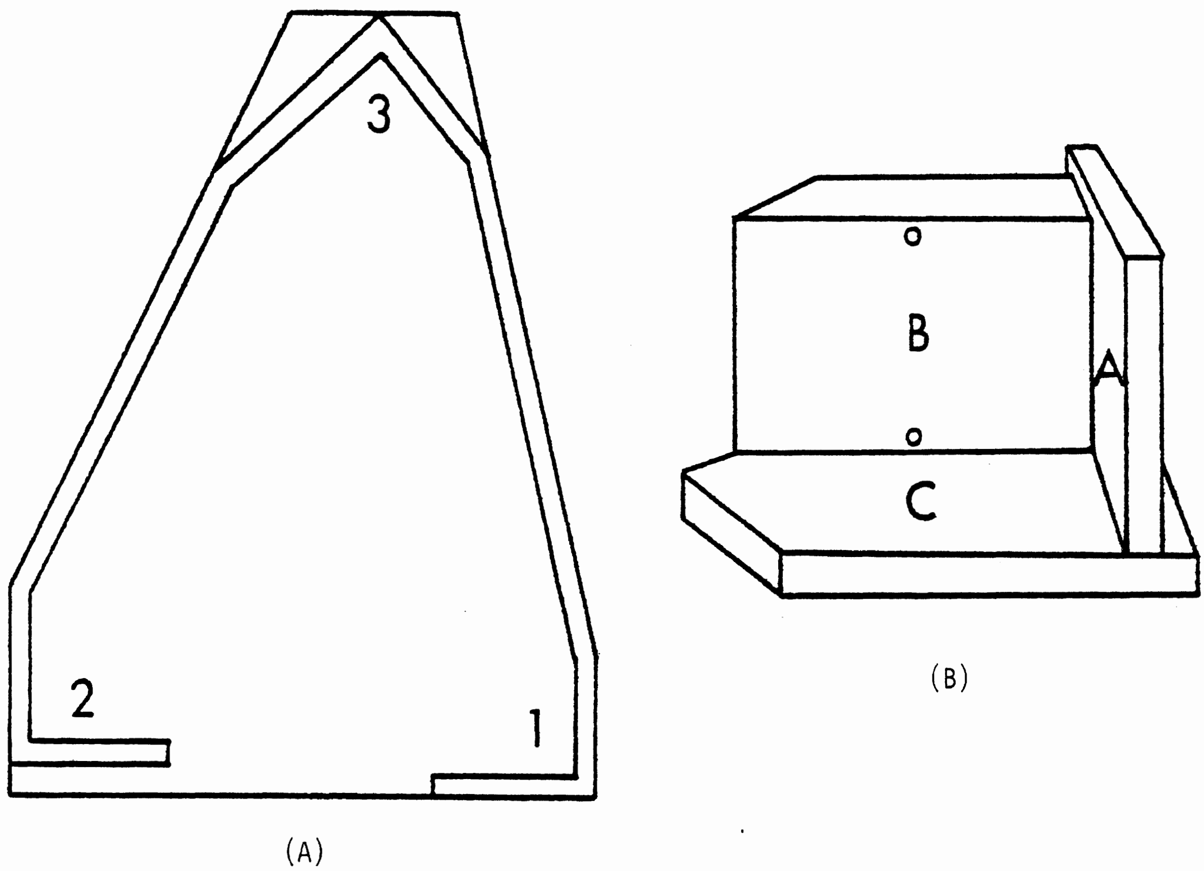


Figure 2: 9AX plate (A) and triax mount (B)

acrylic is applied to encase both the bolts and the mounting plate.

Spine - Incisions are made over both the T1 and T12 vertebrae. The mounting platforms are screwed directly into the spinous processes of both vertebrae. Stabilizing hooks and tie wraps anchor the mount to the vertebra. Plastic acrylic is applied under and around the mounts to insure rigidity (Figures 3,4).

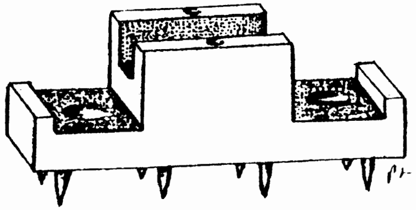
Sternum - Incisions are made just below the manubrium and just above the xyphoid process of the sternum. Small braided nails are tapped into the sternum, encased in acrylic, and the mounting platform is embedded into the sternum (Figures 3,5).

Ribs - Incisions are made over the fourth and eighth ribs on each side, such that the flat part of the exposed rib is normal to the lateral direction. To insure rigidity, the mounts are fitted with pins and tied with wire to the flat surface of each exposed rib (Figures 3,4).

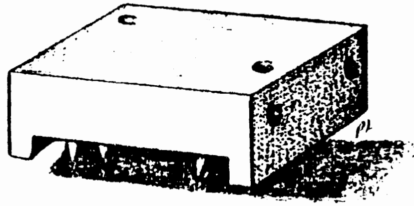
IMPACT EQUIPMENT AND INSTRUMENTATION

Pendulum - The UMTRI pendulum impact device consists of a free-falling moment-matched pendulum which strikes either a 25 kg or a 56 kg impact piston. The impactor, guided by a set of Thomson linear ball bushings, is brought to impact velocity prior to impact and travels up to 25 cm before being arrested (Figure 6).

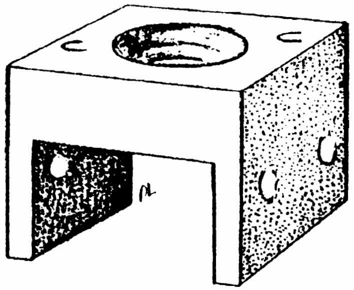
Axial loads are obtained through the use of a Setra Model 111 accelerometer rigidly fixed to the impact piston.



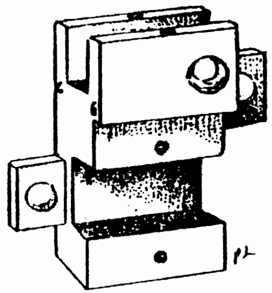
UNIAX MOUNTING PLATFORM



TRIAX MOUNTING PLATFORM



SPINAL TRIAX
MOUNTING PLATFORM



TRIAX MOUNT

Figure 3: Mounting platforms and triax mount

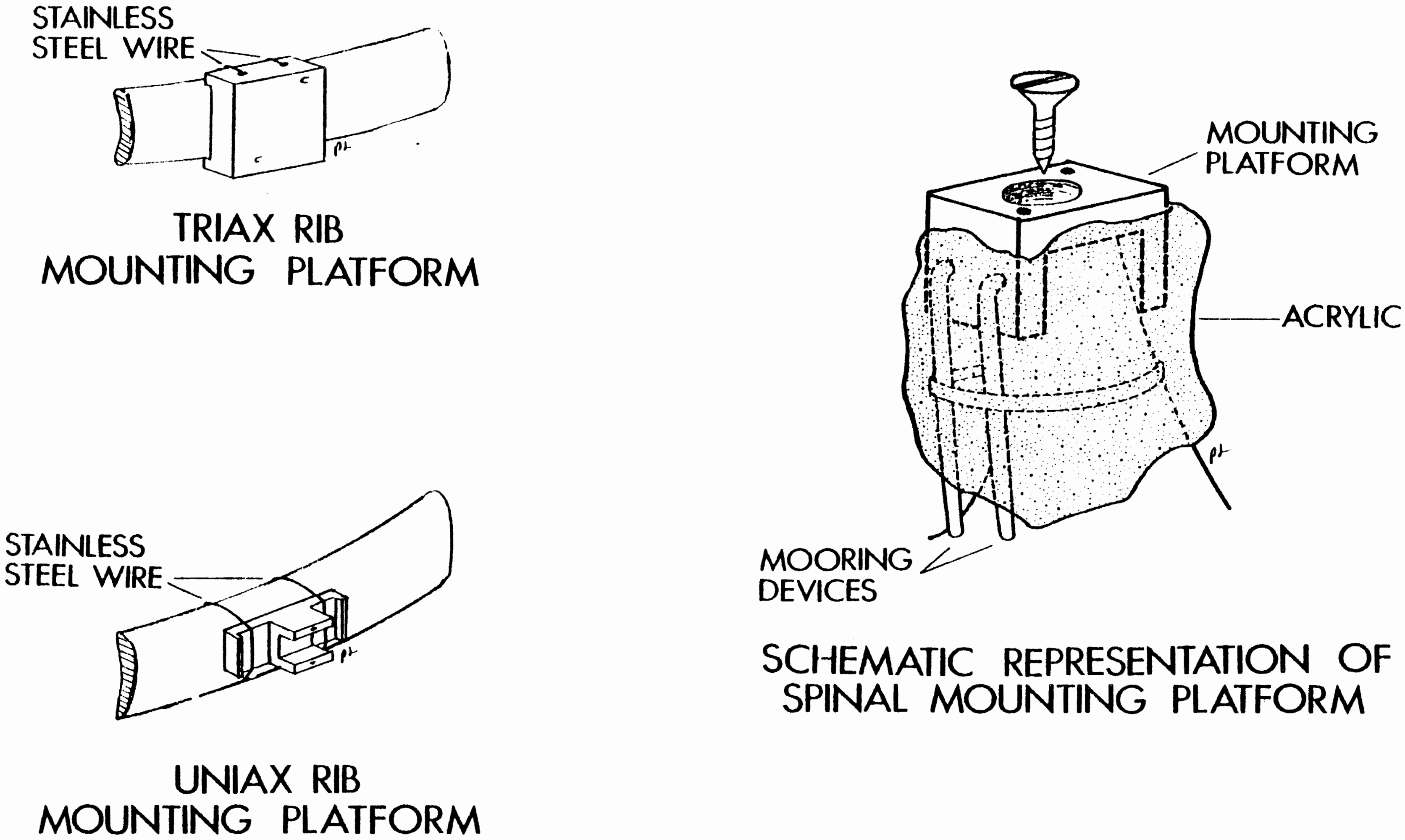


Figure 4: Schematic representations of triax rib, uniax rib, and spinal mounting platforms

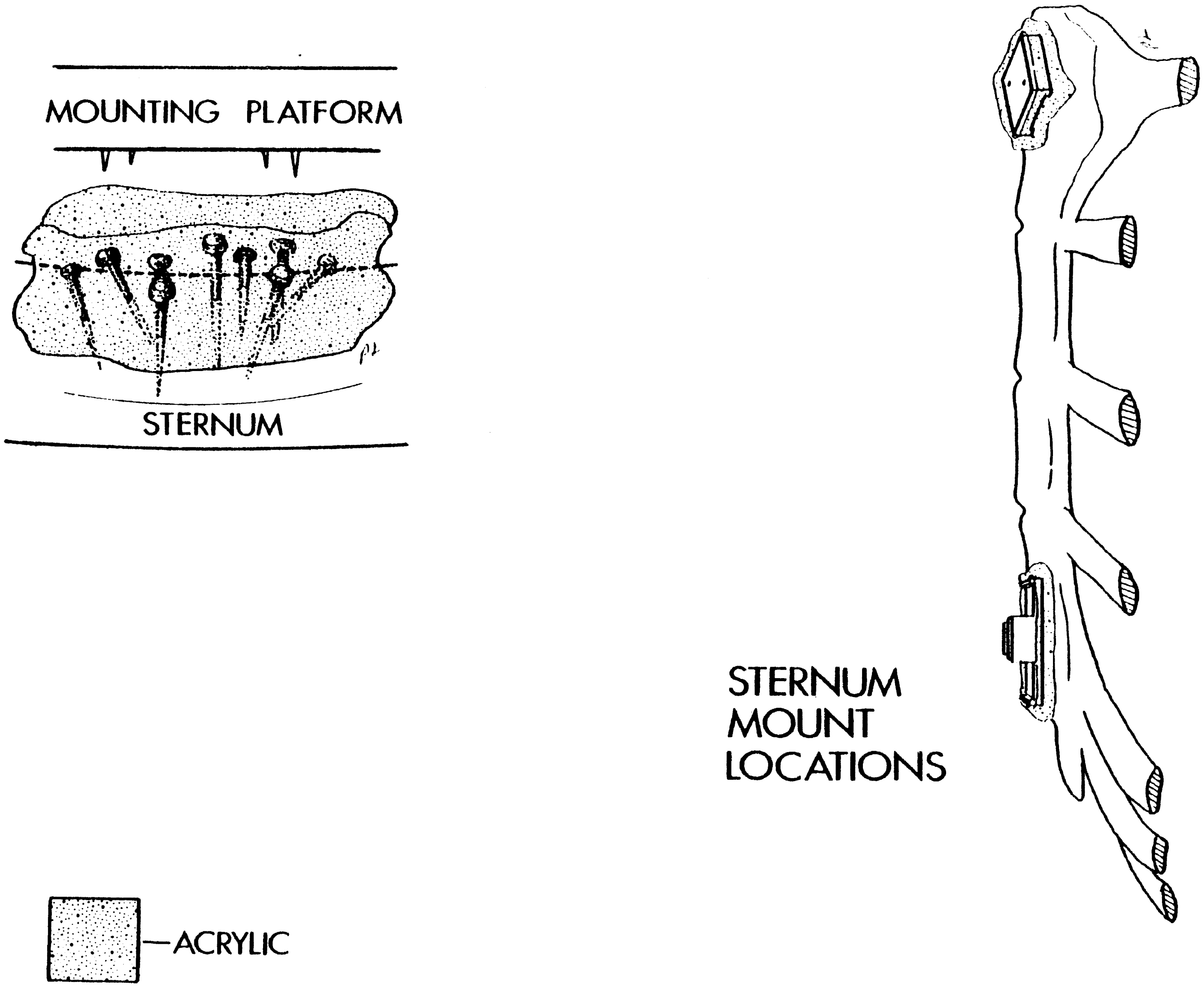


Figure 5: Schematic representation of sternum mounting platforms and sternum mount locations

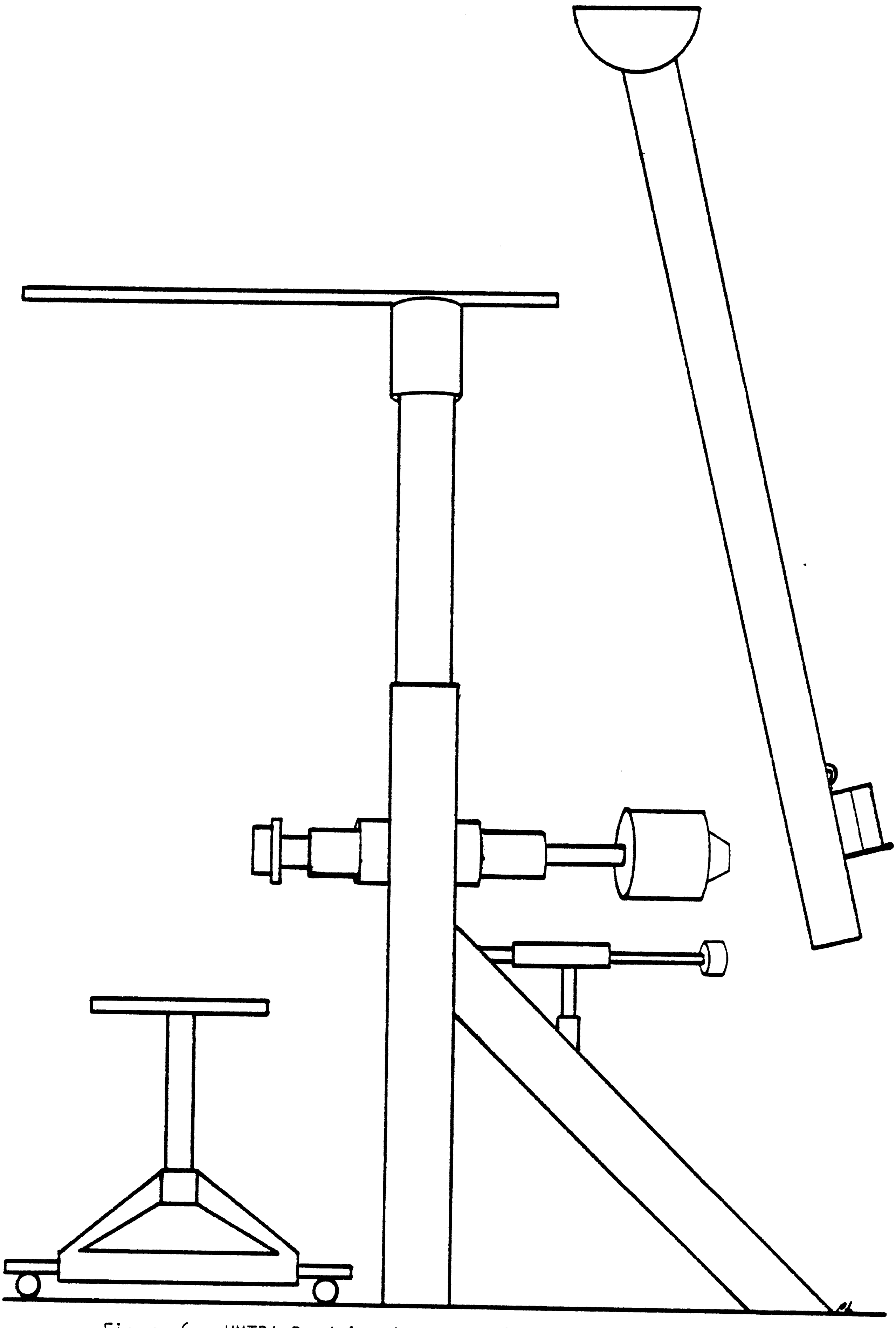


Figure 6: UMTRI Pendulum Impact Device

Although the contact force time history can be obtained more directly through the use of a force transducer such as a load cell, these transducers can require acceleration compensation which can vary from test to test depending on the type of impact surface and the padding used. The recalibrations have the disadvantage of being both time consuming, especially during multiple impact tests, and possibly inaccurate. In addition, if the impacting surface is large and off-axis loading occurs or the force transducer is loaded asymmetrically, the recorded load may differ from the actual load.

The disadvantage of an accelerometer in the piston of a pendulum impact device is that the large signals associated with the accelerations necessary to bring the piston to impact velocity before impact and to rest following impact may interfere with the signal due to the impact itself. However, sufficient hardware and software techniques have been developed to eliminate the effects of pre- and post-impact accelerations such that an accurate impact acceleration signal may be recorded and processed.

PHOTOKINEMETRICS

High speed photographic coverage of the test consists of two lateral views. A Hycam camera operating at 3000 frames per second provides a close-up view of the anatomical member being inspected, while a Photosonics 1B camera operating at 1000 frames per second is used to obtain an overall view of the test subject during impact. The motion of the subject is determined from the film by following the motion of five-point phototargets on the acromion and sternum as well as single point phototargets on the head, pelvis, and impactor piston. Since the resulting film provides a lateral view of the test, the motion observed is two-dimensional and restricted to the plane of the film.

TIMING OF IMPACT EVENTS

Three classes of operations take place before and during impact that are necessary for the documentation of the impact event: Events associated with photokinemetrics documentation, events associated with recording of electro-mechanical transducer output, and events associated with the pendulum impactor. The event sequence is initiated by an operator-controlled manual switch and from then on controlled by signals generated by a specially constructed "timer box." The detailed relationships among the various signals or group of signals are diagrammed in Figure 7. In this diagram each signal or group of signals is represented by a line which has a raised section which represents the time during which the function associated with the signal was operational. The timing requirements of the events associated with these signals are:

Photokinemetrics - The lights, Hycam, and Photosonics camera must be synchronized such that both cameras are running at the correct speed and the test subject is fully illuminated at the time of impact. In addition, the cameras are sequenced such that they are operational for a minimum

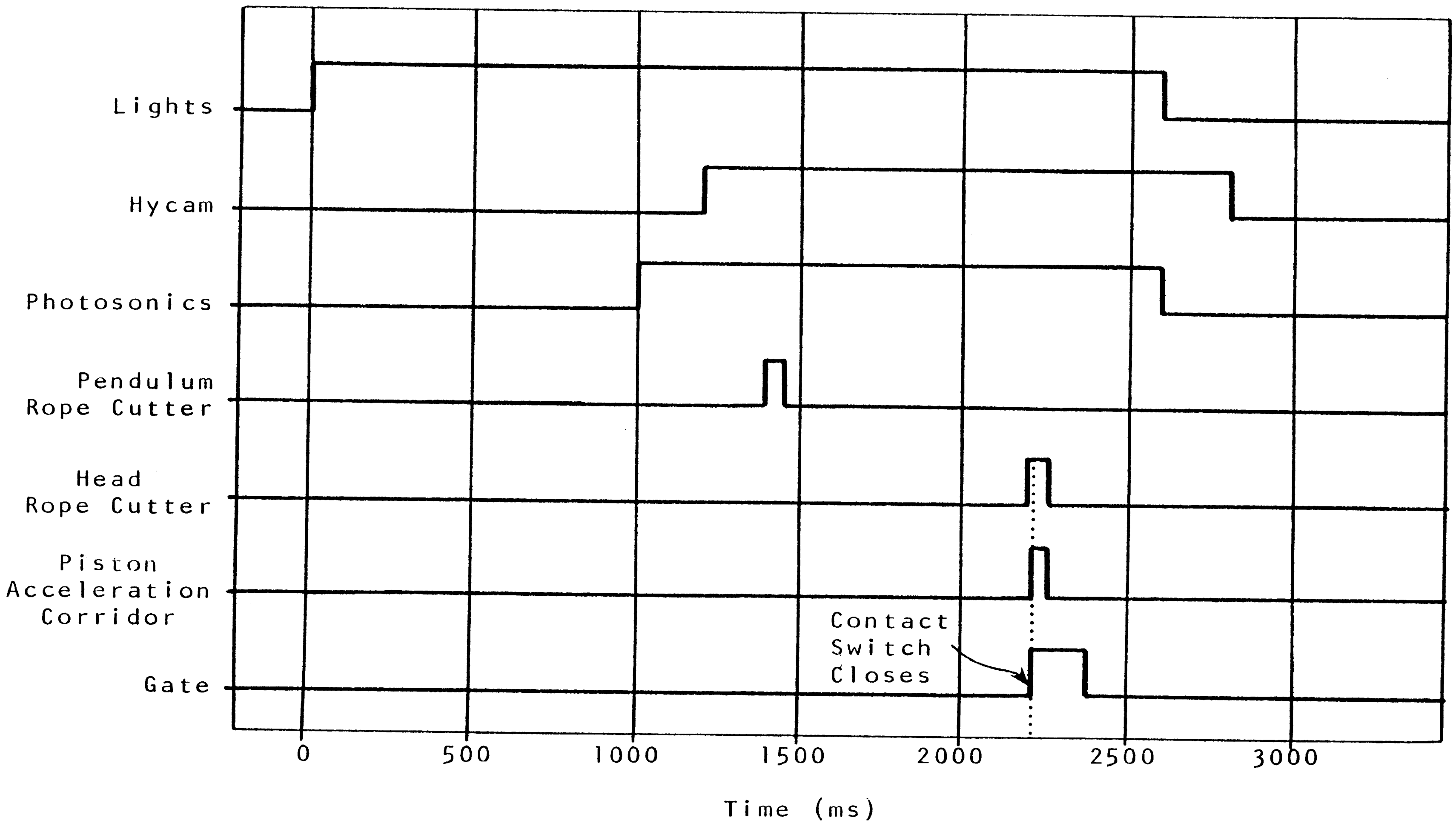


Figure 7: Sequencing of impact events

amount of time. This minimizes the amount of effort associated with photokinemetric documentation (changing film, etc.) and allows for a smooth-running test sequence.

Electro-mechanical transducers - The recording equipment must be at operational speed before the pendulum is released. Additional events which must occur just prior to impact are the release of the subject from the restrained position and the activation of the sequencing gate. During the impact event, the output of the piston accelerometer must be fit into a "corridor" or window such that the pre-impact acceleration from rest and post-impact deceleration from end-of-stroke are not recorded. Also, the synchronizing contact strobe which places simultaneous electrical and photographic signals on the analog tape and high-speed film, respectively, must occur near the beginning of impact.

Impact pendulum - The pendulum must be released in such a manner that impact will occur within the assigned time corridor.

A schematic diagram of the test equipment and a wiring diagram are included in Figures 8 and 9.

INITIAL CONDITIONS AND POSITIONING

For all tests, the subject is placed in a restraint harness which is in turn suspended from an overhead pulley system. For head and thorax impact tests the head is suspended in a normal position by a rope attached to the same pulley which is threaded through an electric rope

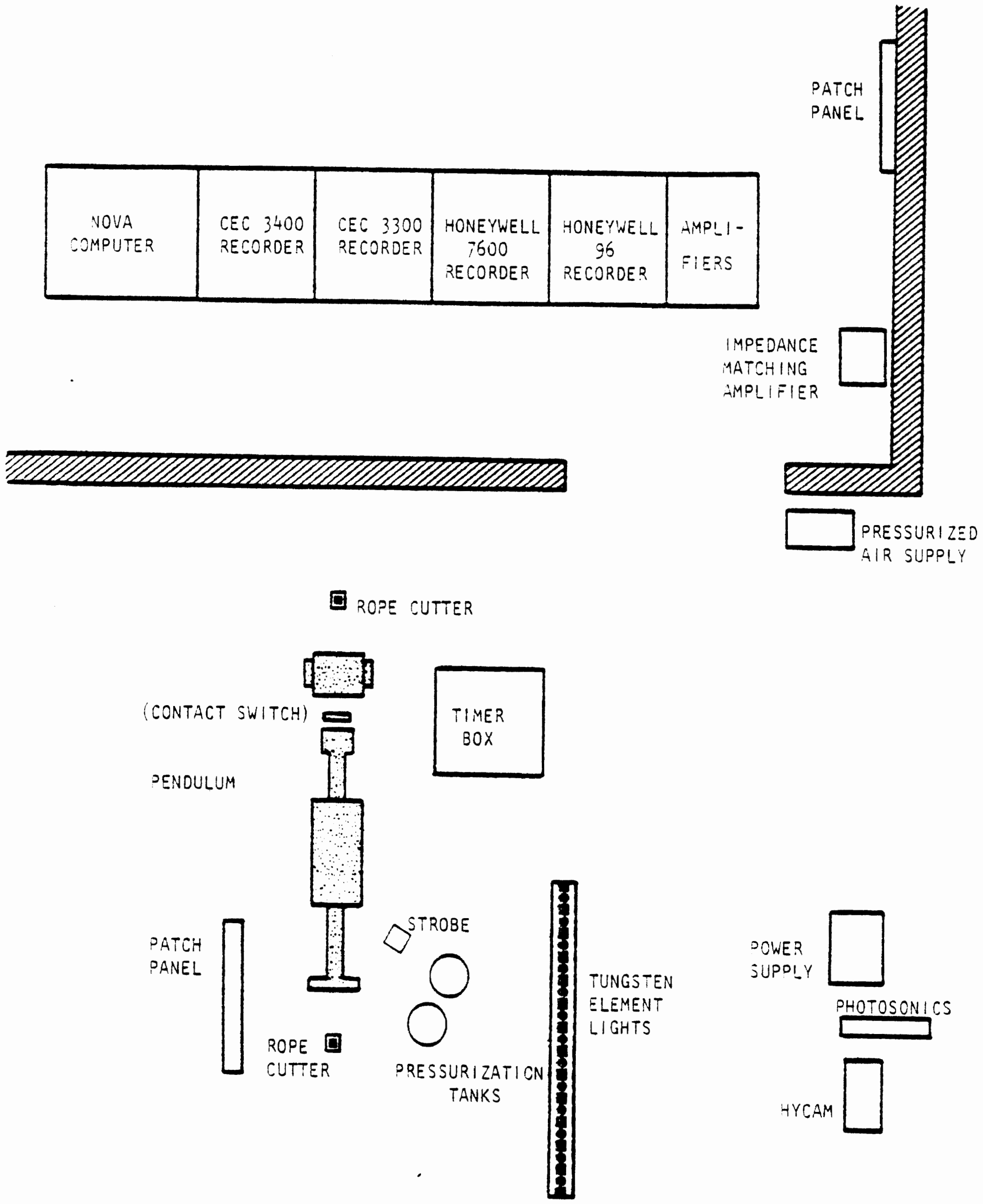


Figure 8: Schematic diagram of equipment setup

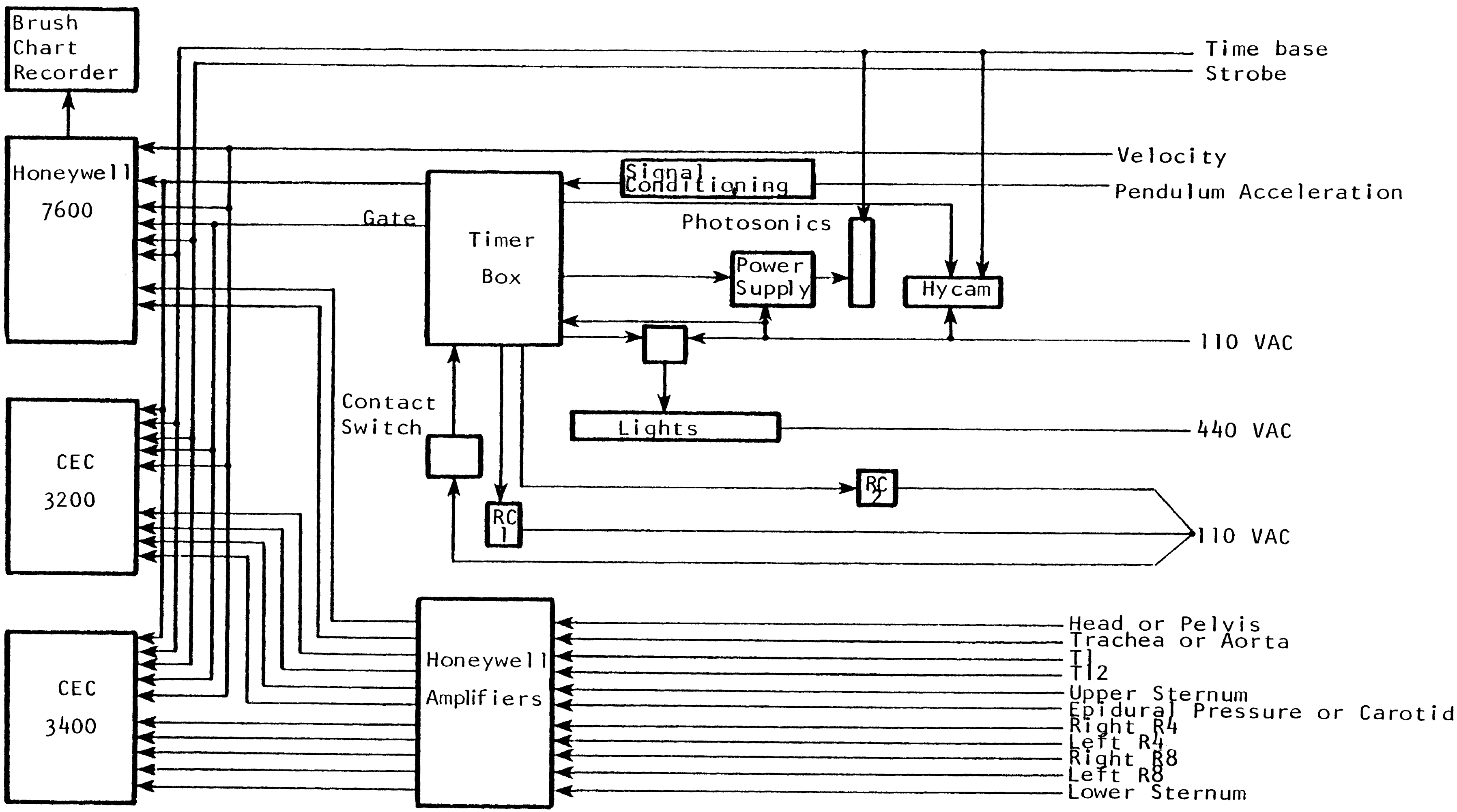


Figure 9: Schematic diagram of instrumentation for data acquisition

cutter. Just prior to impact the rope is cut by a signal sent from the timer box which allows the head to respond freely to the impact. For the pelvis impacts a slightly different configuration is used to suspend and release the subject. Positioning for all tests is shown in Figures 10 through 15.

Padding on the surface of the impactor is varied between types of tests and series of tests. Various amounts of Ensolite, Styrofoam, and combinations of the two are used.

THREE-DIMENSIONAL MOTION DOCUMENTATION

The description of the impact response of the human head requires that the kinematic quantities measured experimentally be described in reference frames which vary from one instrumentation method to another. One method for comparing mechanical responses between subjects is to refer all results to a "standard" anatomical frame which may be easily identified. However, it may be impractical to require that transducers be aligned with this anatomical frame since this creates physical problems for which satisfactory solutions may not exist.

An alternative is to mount transducers in an arbitrary and convenient reference frame, then describe the transformation necessary to convert the data from this instrumentation frame to a desired anatomical one.

A three-dimensional X-ray technique is used to accomplish this for head impacts. Four anatomical landmarks

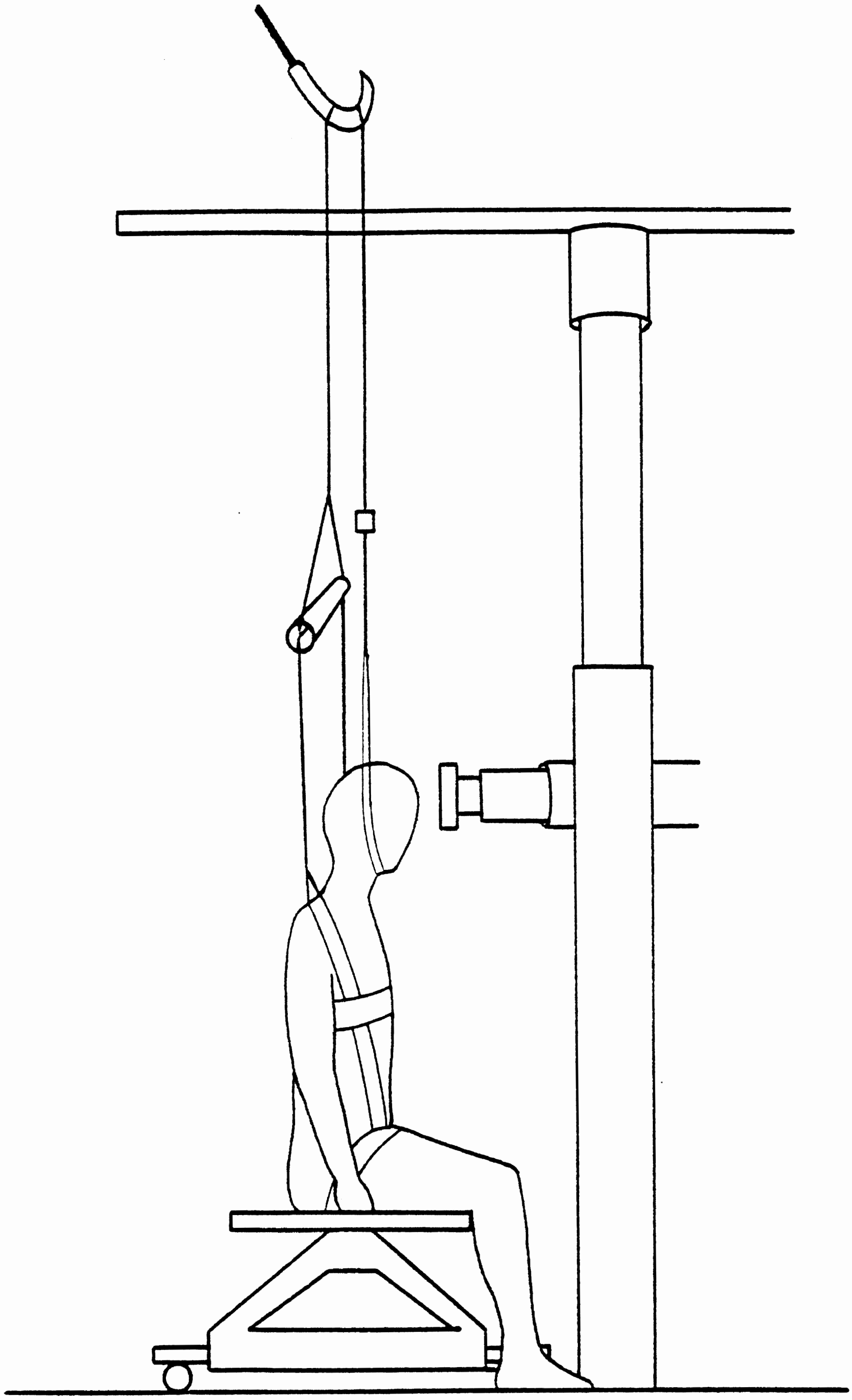


Figure 10: Test setup for head impact

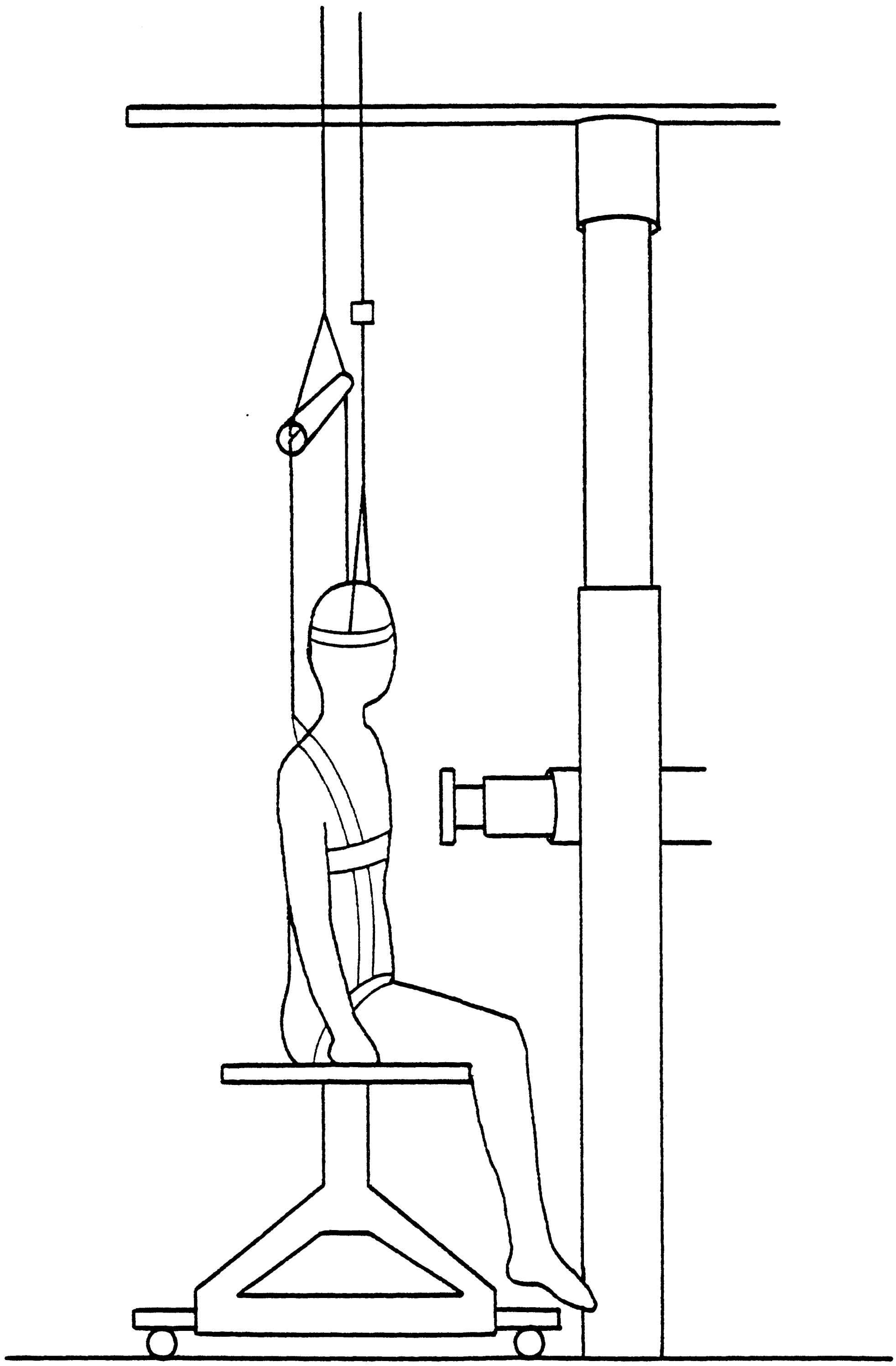


Figure 11: Test setup for frontal thorax impact

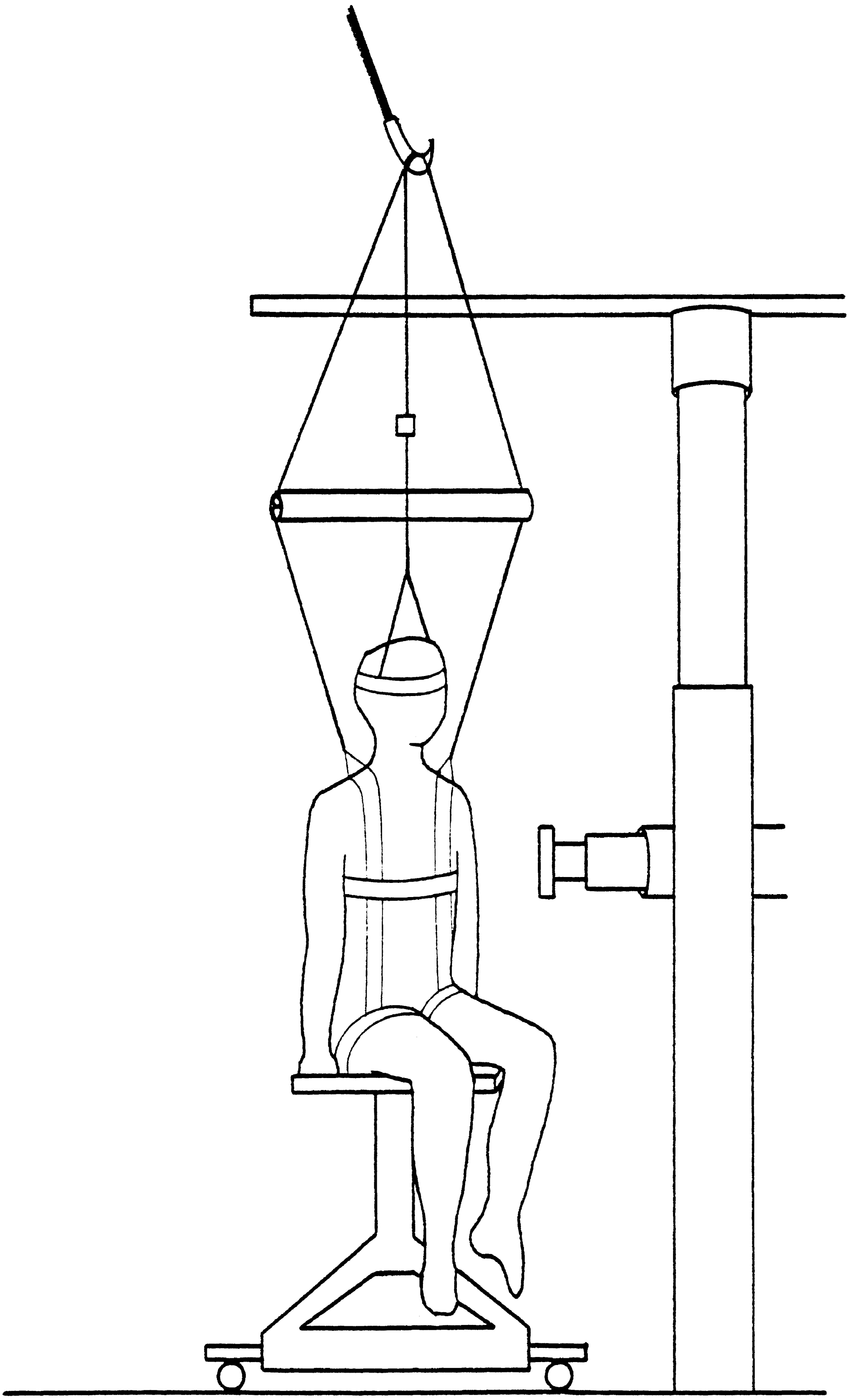


Figure 12: Test setup for 45° thorax impact

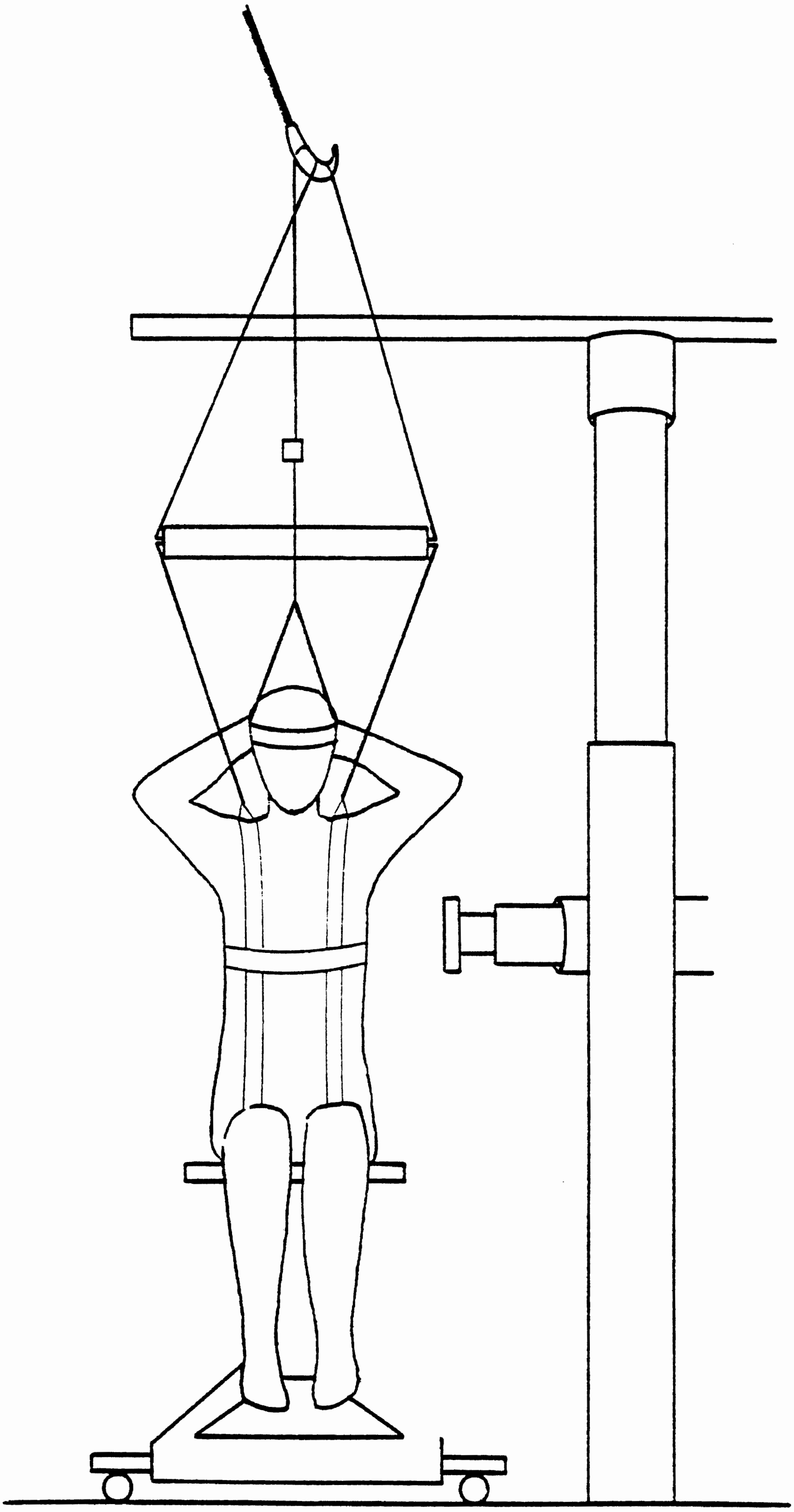


Figure 13: Test setup for arms-up lateral thorax impact

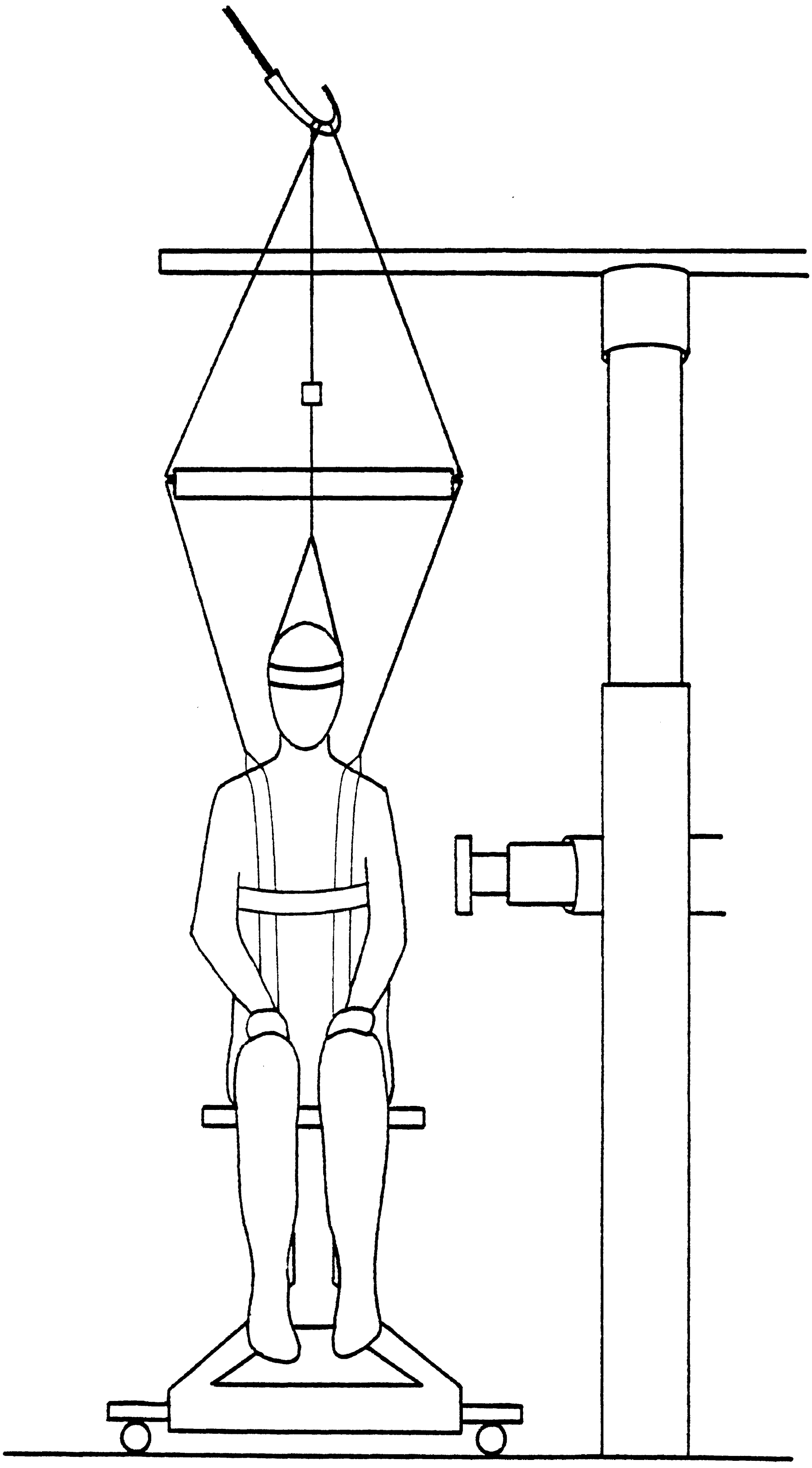


Figure 14: Test setup for arms-down lateral thorax impact

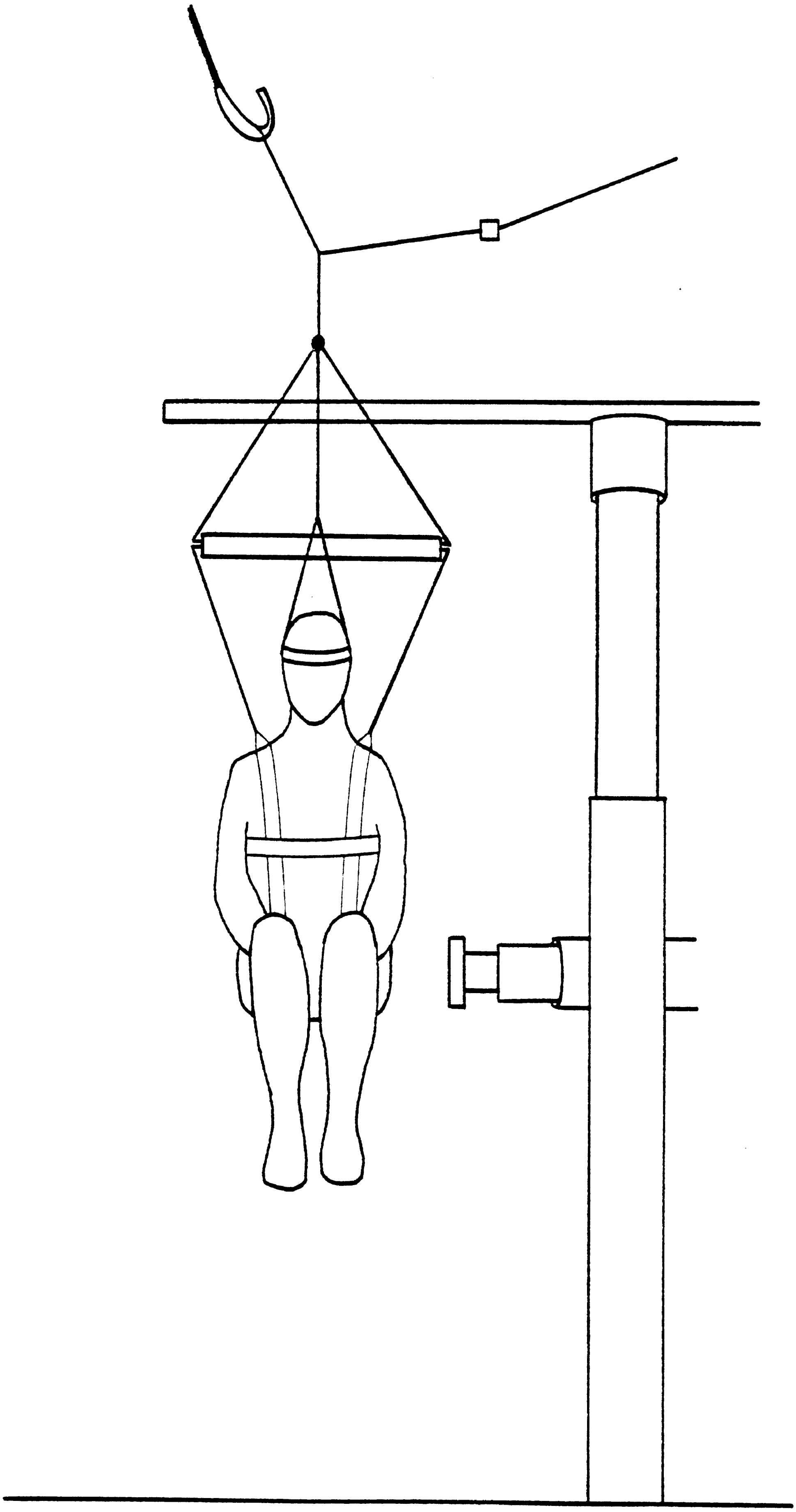


Figure 15: Test setup for pelvis impact

(two superior edges of the auditory meati and two infraorbital notches) are marked with four mutually distinguishable lead pellets. The nine-accelerometer plate is marked with lead pellets at the center of mass of each triaxial accelerometer cluster and also at the plate center of mass. The head containing this instrumentation is then radiographed in two orthogonal directions (the x-z and y-z planes). On each of the two radiographs the optical center and the laboratory vertical z-axis are simultaneously X-rayed. Distances between the plane of the X-ray film and each lead target are recorded for each view. The subsequent computations reconstruct the laboratory coordinates of each of the lead targets. The Frankfort plane is determined and the anatomical reference frame is reconstructed from the four anatomical points. The instrumentation frame and its origin are determined from the three triaxial accelerometer centers. Finally, the transformation matrix between the instrumentation frame and the anatomical frame is obtained.

Documentation of three-dimensional pelvis motion is similar to that of the head. A useful method for analyzing the motion of a material body is to analyze the motion of a point on that body. The point chosen for the pelvis is midway between the posterior-superior iliac spines (PSIS). The motion is then analyzed using the concept of a moving frame discussed elsewhere (1) and briefly summarized in the "Methods of Analysis" section of this report.

PRESSURIZATION AND PRESSURE MEASUREMENT

The vascular, pulmonary, and cerebrospinal fluid systems of each subject are repressurized according to the particular impact being performed. Pressure transducers are used to monitor both the level of initial pressurization and the system pressure during an impact event. The techniques used for repressurization and measurement are given below.

Cerebrospinal Pressure - For the head impacts performed on each subject, the subdural region surrounding the brain and spinal cord is repressurized by coring a hole in the L2 lumbar vertebra and inserting a Foley catheter under the dura of the spinal cord such that the balloon of the catheter reaches a mid-thorax level. Four small holes are drilled and tapped in the frontal, parietal, and occipital bones of the skull, and the dura is punctured under each hole. Fittings for pressure transducers are snugly threaded into the holes. The transducers for this application are Endevco series 8510 piezoresistive pressure transducers. To insure proper initial pressurization of the brain, a solution of radioopaque sodium iodide is injected through the Foley catheter and a radiograph is made of the head. Fluid flow through the ventricles may be checked in this manner. Finally, the point at which the catheter passes through the lamina of L2 is sealed with plastic acrylic.

Pulmonary Pressurization - For all tests involving an impact to the thorax, the pulmonary system of the subject is pressurized. An incision is made lengthwise along the trachea and a polyethylene catheter is snugly inserted. A T-connector with unequal-diameter branches is inserted into the end of the catheter. Through the narrower of these branches a pressurized tank maintains the lungs at approximately their normal operating pressure and volume. The larger branch is lubricated with silicone stopcock grease and plugged with a hemispherical stop. The stop is mechanically linked to a timing mechanism and is pulled out upon impact such that air may pass from the lungs at a reasonable rate. An Endevco series 8510 pressure transducer is threaded into the polyethylene tubing to monitor the pulmonary pressure.

Vascular Pressurization - Two different techniques are used to pressurize the individual vascular systems of the head and thorax, depending on which type of impact is being performed. Head impacts require the following technique. The common carotid artery is located at a point in the neck and an incision is made. A balloon catheter is inserted and positioned such that the balloon is in the internal carotid artery just above the point where the external carotid artery branches off. A narrow polyethylene tube is inserted at the same point and runs into the internal carotid artery just past the balloon. A Kulite pressure transducer is then fed through this tube such that vascular pressure may be monitored. Finally, the vertebral arteries are tied off above the clavicle such that fluid pressure in the head may be maintained (Figure 16).

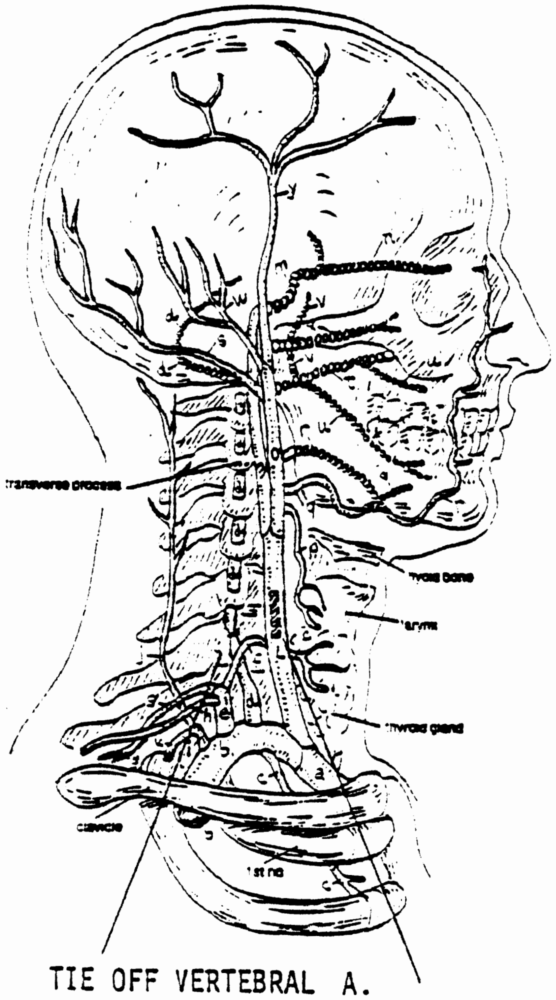


Figure 16: Location of entry point for cerebral vascular pressurization

In thorax impacts pressurization of the vascular system of the thorax requires the modification of a Foley balloon catheter. The center section is replaced with two lengths of larger-diameter polyethylene tubing. One tube allows for flow of pressurizing fluid while the balloon can be inflated through the other. A small lead pellet is inserted in the exit port of the tip such that the precise location of the catheter can be determined by radiographing the subject.

This catheter is inserted through an incision in the right common carotid artery into the descending aorta, such that the tip rests slightly above the diaphragm. Another length of polyethylene tubing is inserted into the ascending aorta, through which the Kulite pressure transducer can be positioned. Just prior to testing, a solution of India ink and water is released from a tank into the vascular system of either the head or the thorax, depending on the type of impact being performed. The pressure transducer monitors the flow such that the system may be brought to normal operating pressure just prior to impact (Figure 17).

TESTING PROCEDURE

Four groups of procedures are associated with the testing activities. They are those procedures associated with pretest preparation, surgery, impact testing, and post-test autopsy. The execution and coordination of this collection of procedures which makes up a testing sequence is assisted by the use of a detailed protocol. A typical

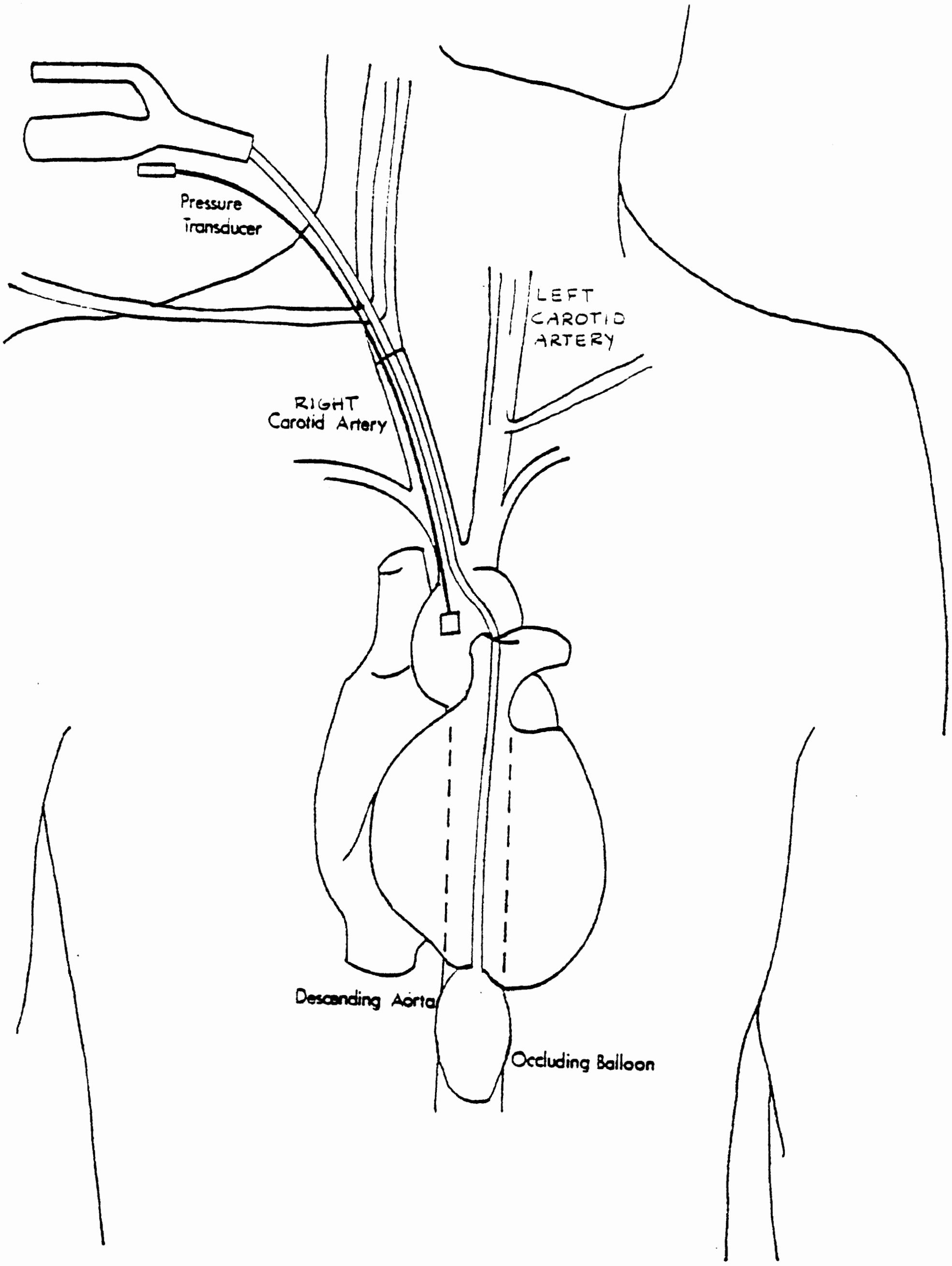


Figure 17: Location of modified Foley Catheter and pressure transducer for thoracic vascular pressurization

protocol used is included in Appendix A and outlined in the following text.

PRETEST PREPARATION

Since the arrival of a test subject usually cannot be predicted more than half a day in advance, preparation for a test series generally begins the day a subject is received. A subject requires approximately a day and a half of preparation, which is sufficient time to set up the impact lab and run trial tests. The areas requiring careful preparation are briefly described below.

Anatomy Lab - All sanitary preparation, anthropometry, and surgical instrumentation of a subject is done here. All tools, materials, and instrumentation equipment necessary to prepare the subject are accounted for (or constructed) and laid out in advance. Included in the setup are surgical instruments, an anthropometer, gauze and toweling, clothing for the cadaver, pressurization equipment, accelerometer mounting hardware, and modified Foley catheters.

Radiology Lab - The table is positioned and a sufficient supply of film is loaded into the cassettes, such that all work done in the radiology lab can be completed as necessary in the test sequence. A subject will be X-rayed three times. First, when it is received to check for skeletal integrity. Second, after instrumentation to check that everything is positioned properly and pressurization fluid is flowing correctly. Finally, the orthogonal X-rays are taken when the test sequence is finished.

Impact Lab - All test facilities, recording equipment, and transducers must be assembled, wired, and tested. In addition, a portable cart containing surgical instruments for instrumenting the subject with transducers must be prepared and brought in. Below is a brief description of the preparation required in the impact lab.

Materials - Impact padding (Styrofoam and Ensolite) and support materials for the subject (balsa wood, foam, rope, etc.) are assembled near the impact pendulum, and the support seat necessary for the head impacts is installed on the pendulum frame. Cameras, power supplies, and strobes are set up; the cameras are loaded and positioned on tripods.

Electronics - The input/output voltage characteristics of all analog tape channels and amplifiers are checked by calibration with a known test signal. The signal from each channel or amplifier is then played back (through either the brush chart recorder or a digital voltmeter) and the playback signal is compared with the input signal.

All transducers are labeled and wired through a patch panel into the instrumentation room. From there, the signals are sent through amplifiers if necessary and wired to their designated channels on one of the analog tape recorders. Amplifiers are set for the proper gain and transducer excitation voltage is set on each. Instrumentation room wiring cannot be completed until the timer box and the devices it controls are wired and set for the proper delay and run times. Final wiring is completed in the instrumentation room and the pendulum is prepared for a trial test.

Trial Test - To insure that all mechanical and electronic equipment is functioning and wired correctly, several trial tests of the equipment are performed on the day before the test, allowing sufficient time to locate and correct system defects. Accelerometers, amplifiers, umbilical cables, and recorders are tested by suspending a rubber cylinder weighing approximately 20 pounds in front of the impactor piston with all the accelerometers taped to it. A preliminary check of the accelerometers is made to insure proper balancing and noise levels. The pendulum is then manually released into the impactor piston and the signals from all accelerometers are recorded on the analog tape machines. All channels are played back immediately on the brush recorder. The piston accelerometer is also tested in this manner. Pressure transducers are tested by sending the signal directly to the brush chart recorder and tested individually, as impact to the rubber cylinder does not produce sufficient output from these transducers. The timer box, rope cutters, strobes, and velocity probe are tested individually. Triaxial clusters of accelerometers and pressure transducers are then labeled for their specific point of attachment and placed in protective sleeves.

TEST SYNOPSIS

Subjects are obtained from from the Anatomy Department and transported to UMTRI by Biomechanics Department personnel. Upon arrival they are weighed and pertinent information is logged in. Initial sanitary preparation is completed and pretest X-rays are taken of the head, thorax, pelvis, and femurs. If the skeletal structure is intact and no metallic implants are found, the subject is taken to the anatomy lab for surgical preparation. Following the procedure outlined in the protocol the cadaver is placed on its back and anthropometric measurements are taken. Any anatomical abnormalities are recorded and special note taken if they will alter the usual instrumentation techniques. While the subject is on its back, rib and sternum accelerometer mounts are attached and both pulmonary and cardiovascular pressurization apparatus is installed. Flow of pressurizing fluid in the vascular system is checked and a calibration for correct volume of air is made of the lungs. When all mounting acrylic is dry, the subject is rolled over onto its stomach to allow for the installation of head, pelvis, and spine accelerometer mounting hardware as well as cerebrospinal pressurization apparatus.

When these tasks have been completed the path of cerebrospinal fluid flow is pressurized with a solution of radioopaque sodium iodide and a radiograph of the head is taken. In addition to a visual flow check, this procedure is necessary to insure complete pressurization of the ventricles.

Following completion of all mounting and pressurization procedures the cadaver is dressed in a vinyl sweatsuit to prevent excessive leakage onto the outer set of long underwear. Support harnesses are attached and the cadaver is stored in the cooler overnight.

On the morning of the test, the subject is transferred to the impact laboratory and all transducers necessary for the head impacts are rigidly attached to the mounts. A final check of electronic equipment is made with the instrumentation installed to insure that all accelerometers, pressure transducers, and amplifiers are functioning properly and that all wiring connectors are secure. The cadaver is positioned and foam padding is placed such that no injuries will occur due to the subject hitting a hard object on reaction to impact. Setup photos are taken and a final checklist is run through. After all other initial conditions have been met, a final zero of the transducers is made and the pressurization equipment is connected to the cadaver. Impact must be coordinated precisely with the time that pressurization occurs. When the current pressure has been achieved the first impact sequence is triggered.

Running the second head impact in the series involves repositioning of the cadaver, resetting the pressurization equipment, and re-zeroing the transducers. While this is occurring, all signals recorded on analog tape from the test are played back on the brush recorder. Thus, amplifier gains may be changed if a certain signal has an unexpected value and/or equipment that may have failed during the test may be located and repaired or replaced.

Following the second head impact and a replay of the data, the subject is positioned for the series of thorax taps. This involves the mounting of a different seat on the pendulum frame, such that the point where the impactor contacts the thorax is the specified distance above the seat plate. The epidural pressure transducers are removed, freeing data channels for more thorax accelerometer data. In addition, the carotid artery pressure transducer is moved to the descending aorta and a trachea pressure transducer is installed.

The subject is first positioned for a frontal thorax tap. Setup photos are taken, a final checklist is run through, the subject is pressurized, and the impact sequence is triggered.

Two more thorax taps are done following the above procedure. They consist of an oblique tap to the left side of the subject (45° P-A into R-L) and a left-side lateral tap, both with the subject's arms at his sides. The data is checked, and appropriate recalibration of the instrumentation is made to prepare for the lateral thorax impact to the left side. Initial conditions, positioning, and pressurization are the same as for the tap of this configuration.

At the completion of this test, the head accelerometers are attached to the pelvis accelerometer plate, pressurizing apparatus is removed, and the cadaver is positioned for a right-side lateral pelvis impact. Impactor surface padding is changed and the impact is performed, completing the testing sequence.

All instrumentation is removed from the subject, which is stored in the cooler overnight. The autopsy is performed the following day.

METHODS OF ANALYSIS

The analysis procedures used in this test series have been developed at UMTRI over a number of years. The procedures are outlined below and examples given in Appendix B.

MECHANICAL IMPEDANCE

For a mechanical system excited by a sinusoidal force input of a given frequency, it is desired to determine the velocity (that is of the same frequency) of a remote point in the system. The quantity relating the force and resulting velocity of the same frequency is called mechanical transfer impedance (Z). By generating values of Z over a range of frequencies, a transfer function for the system may be described. Mechanical impedance techniques can facilitate the understanding of kinematic response to blunt impact of a system. Force and acceleration transducer time-histories are monitored during the impact event and a

Fast-Fourier Transformation is performed on the digitized signals. From this data a transfer function of the form

$$Z(i\omega) = \frac{\omega F(f(t))}{F(a(t))}$$

can be generated, where ω is the given frequency and $F(f(t))$, $F(a(t))$ are the Fourier transforms of the impact force and accelerations, respectively, of the points of interest.

The response of a second-order linear mechanical system to blunt impact may also be described in terms of physical parameters such as springs, masses, and dampers. Based on mechanical impedance analysis of a single impact, a model of the system for that particular impact may be generated in terms of these physical parameters. These models may be generalized to fit a number of similar systems if either sufficient impact data is obtained or sufficient properties about the physical system are known. Such analyses assume that the system(s) under consideration (in this case the human system) may be approximated as second-order linear.

The general equation of motion for a mechanical system containing a spring, mass, and damper may be written in terms of velocity as:

$$m \frac{dv(t)}{dt} + cv(t) + k\int v(t)\, dt = f(t) \qquad (1)$$

where υ = velocity
m = system apparent mass
c = damping ratio
k = spring constant
f = time-dependent forcing function

Alternatively, it may be expressed in terms of force as

$$\frac{1}{k}\frac{d f(t)}{dt} + \frac{1}{c} f(t) + \frac{1}{m}\int f(t)\, dt = \upsilon(t) \tag{2}$$

These equations are analogous in the general sense to those which may be written for an electrical RLC circuit, with respect to Kirchoff's current law as

$$\ell \frac{d i(t)}{dt} + R\, i(t) + \frac{1}{c}\int i(t)\, dt = e(t) \tag{3}$$

and with respect to Kirchoff's voltage law as

$$c \frac{de(t)}{dt} + \frac{1}{R} e(t) + \frac{1}{\ell}\int e(t)\, dt = i(t) \tag{4}$$

where i = current
c = capacitance
R = resistance
ℓ = inductance
$e(t)$ = time dependent voltage imput

The systems may be compared as follows:

Mechanical System Quantity	Electrical System Analog
Velocity	Current
Force	Voltage
Mass	Inductor
Damper	Resistor
Spring	Capacitor

The method of Fourier Transformation for solving the differential equations describing the electrical system may therefore be applied, in most cases, to the analogous mechanical system. The method involves transforming the differential equation of motion into the complex frequency domain to obtain an algebraic equation which may be solved much more easily. This method assumes that the system is time invariant, linear, and that the principle of superposition may be applied. In addition it is assumed that the initial conditions of the system are all zero and that the magnitude of the response at any given frequency is a result of an excitation of the same frequency. Letting the variable x denote the displacement of the system mass from rest, eq (1) can be written as

$$m\ddot{x} + c\dot{x} + kx = f(t) \qquad (5)$$

Fourier Transformations to the frequency domain of $x(t)$ and its time derivatives are as follows:

$$F[x(t)] = X(\omega)$$
$$F[\dot{x}(t)] = \omega X(\omega) \qquad (6)$$
$$F[\ddot{x}(t)] = \omega^2 X(\omega)$$

Performing this operation on eq. (5) results in

$$F(m\ddot{x} + c\dot{x} + kx) = F(f(t)) \qquad (7)$$

and since the operation is linear and m, c, and k constant,

$$m F(\ddot{x}) + c F(\dot{x}) + k F(x) = F(f(t)) \tag{8}$$

Therefore by the relationships (6),

$$m\omega^2 X + c\omega X + k X = F(\omega)$$

$$(m\omega^2 + c\omega + k) X(\omega) = F(\omega) \tag{9}$$

$$(m\omega + c + \frac{k}{\omega}) X(\omega) = \frac{F(\omega)}{\omega}$$

From the form of eq. (9), it is apparent that a quantity increasing linearly with the frequency ω is behaving as a mass; a quantity constant with ω is behaving as a damper; and a quantity decreasing linearly with ω is behaving as a spring. The mechanical impedance Z of a system is defined as the (complex) ratio of the Fourier transform of the force to the Fourier transform of the velocity:

$$Z(i\omega) = \frac{F(f(t))}{F(v(t))}$$

Where the magnitude of the complex-valued quantity Z is increasing linearly with frequency ω, the system is behaving as a mass (Figure 18a); where Z is constant with

ω , the system is behaving as a damper (Figure 18b) ; and where Z decreases linearly with ω, the system is behaving as a spring (Figure 18c). This is apparent from the form of eq. (9). Figures (18d), (18e), and (18f) show the impedance response of various combinations of these elements. For example, in Figure 18f, with a low frequency input the system responds as a rigid body with a characteristic mass. However, when the frequency content of the input signal increases, energy is dissipated in the damper and the mass is not displaced. The mechanical impedance plots of the response of the human cadavers to impact may be analyzed in this manner.

FRAME FIELDS

One method for analyzing the motion of a material body is to analyze the motion of a point on that body.

A vector field is a function which assigns a uniquely defined vector to each point along the path generated by the moving point. Similarly, any collection of three mutually orthogonal unit vectors emanating from each point on the path is a frame field. Thus any vector defined on the path (for example, acceleration) may be resolved into three orthogonal components of any well-defined frame field.

In biomechanics research, frame fields which are frequently used are defined based on anatomical reference frames. Other frame fields such as the Principal Direction Triad (2) or Frenet-Serret frame (Appendix C), which contain information about the motion embedded in the frame field,

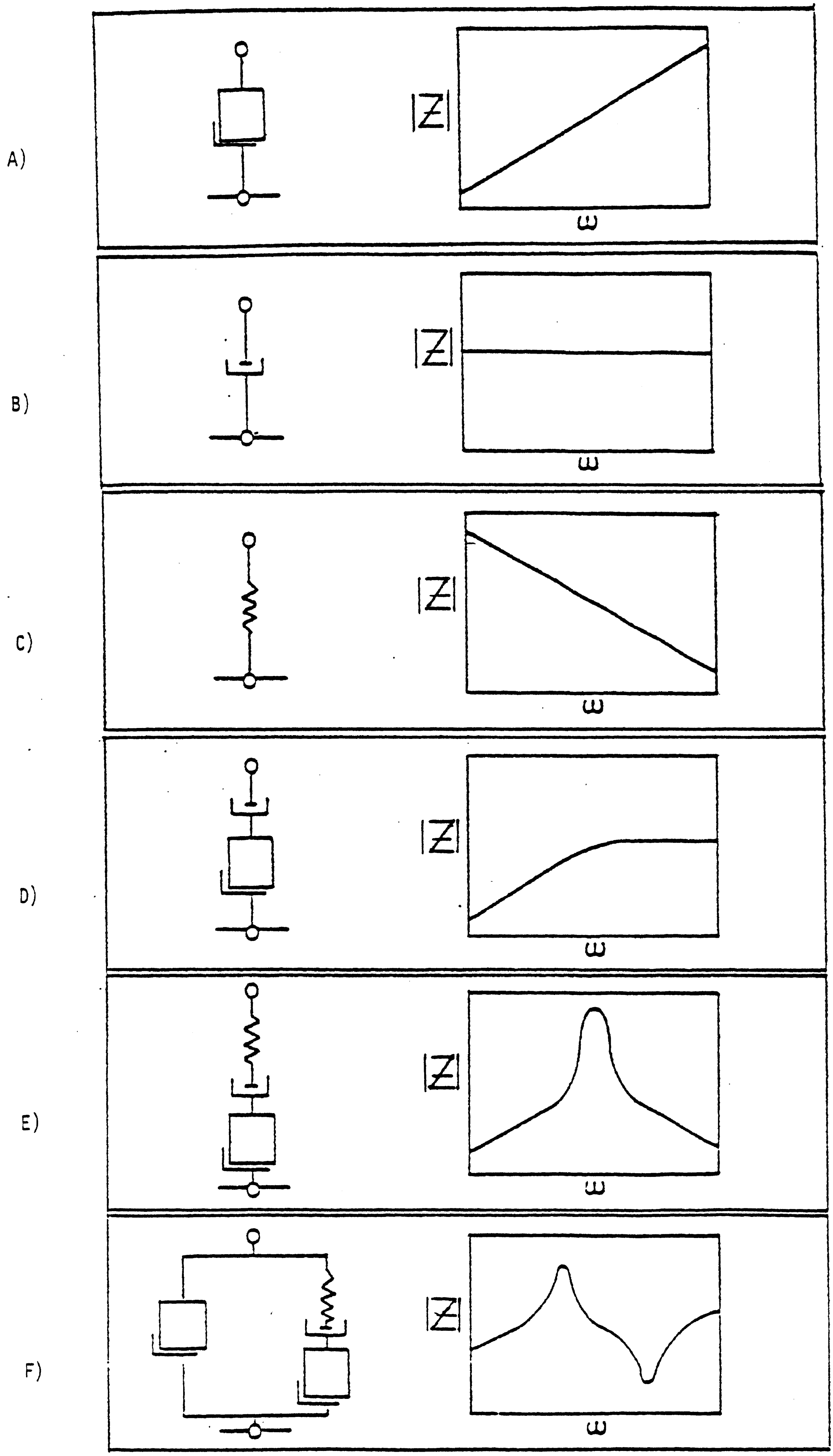


Figure 18: Lumped parameter models and associated impedance magnitude diagrams

have also been used to describe motion resulting from impact.

The Frenet-Serret frame consists of three mutually orthogonal vectors T, N, B. At any point in time a unit vector can be constructed that is co-directional with the velocity vector. This normalized velocity vector defines the tangent direction T. A second unit vector N is constructed by forming a unit vector co-directional with the time derivative of the tangent vector T (the derivative of a unit vector is normal to the vector). To complete the orthogonal frame, a third unit vector B (the unit binormal) can be defined as the cross product T x N. This then defines a frame at each point along the path and resolves the acceleration into two distinct types. The tangent acceleration (Tan(T)) is always the rate of change of speed (absolute velocity) and the normal acceleration (Nor(N)) gives information about the change in direction of the velocity vector. The binormal direction contains no acceleration information.

In the case of a single triaxial accelerometer the use of the Frenet-Serret frame is impractical but it has been found (3) that in many cases during impacts it is possible to find the most significant component of acceleration, therefore the principal direction of motion can be obtained.

PRINCIPAL DIRECTION TRIAD

One method of determining the principal direction of motion and constructing the Principal Direction Triad is to determine the direction of the acceleration vector in the moving frame of the triaxial accelerometer cluster and then prescribe the transformation necessary to obtain a new moving frame that would have one of its axes in the principal direction. A single point in time at which the acceleration is a maximum was chosen to define the directional cosines for transforming from the triax frame to a new frame in such a way that the resultant acceleration vector (AR) and "principal" unit vector (A1) were co-directional. This then can be used to construct a new frame rigidly fixed to the triax but differing from the original one by an initial rotation. After completing the necessary transformation a comparison between the magnitude of the principal direction and the resultant acceleration is performed. In the case of the impacts presented here there was only a slight difference between the two quantities during the most significant part of the impact. However, for responses occurring after impact this was not always the case.

RESULTS

Using the impact pendulum with a 25 kg free-moving impacting mass, a total of twenty-five tests were performed on three cadavers. Tables 1, 2, and 3 show initial conditions of test subjects and the type of padding used, as well as the resultant test velocity. Table 4 gives the resultant linear and angular head accelerations and velocities, as well as the HIC values. Tables 5, 6, and 7 give the peak thoracic accelerations. Table 8 gives the peak pelvis accelerations. Peak pressures (epidural, trachea, aorta, carotid) are given in Table 9. An autopsy summary for each test is given in Table 10. Appendix D contains the force time histories of all the tests.

TABLE 1. TEST SERIES 82E00X (CADAVER 1)

Test Number	Impact Configuration	Velocity (ft/sec)	Padding
82E001	Forehead Frontal	5.7	1.25 cm Ensolite
82E002	Forehead Frontal	5.5	1.25 cm Ensolite
82E003	Forehead Impact	6.3	1.25 cm Ensolite
82E004	Sternum Tap	2.1	None
82E005	45° Lft. Thorax Tap	2.0	None
82E006	Lft. Side Thorax Tap	1.9	None
82E007	Lft. Side Thorax Impact	8.4*	10 cm Ensolite
82E008	Rt. Side Pelvis Impact	8.4	2.5 cm Ensolite+ 1.3 cm Styrofoam

*For tests with 10 cm of ensolite padding, a 26.Kg impact mass was used.

TABLE 2. TEST SERIES 82E02X (CADAVER 2)

Test Number	Impact Configuration	Velocity (m/s)	Padding
82E021	Forehead Impact	5.5	2.0 cm Ensolite
82E022	Forehead Impact	5.5	2.0 cm Ensolite
82E023	Sternum Tap	2.0	0.5 cm Ensolite
82E024	45° Lft. Thorax Tap	2.0	0.5 cm Ensolite
82E025	Lft. Thorax Tap Arms Up	2.0	0.5 cm Ensolite
82E026	Lft. Thorax Tap Arms Down	2.0	0.5 cm Ensolite
82E027	Lft. Thorax Impact	8.5*	0.5 cm Ensolite
82E028	Rt. Side Pelvis Impact	8.5	0.5cm Ensolite

*For tests with 10 cm of ensolite padding, a 26.Kg impact mass was used.

TABLE 3. TEST SERIES 82E04X (CADAVER 3)

TEST NUMBER	IMPACT CONFIGURATION	VELOCITY (m/s)	PADDING
82E041	Forehead Impact	6.0	2.0 cm Ensolite
82E042	Forehead Impact	6.0	2.0 cm Ensolite
82E043	Sternum Tap	2.0	0.5 cm Ensolite
82E044	45° Lft. Thorax Tap	2.0	0.5 cm Ensolite
82E045	Lft. Thorax Tap Arms Up	2.0	0.5 cm Ensolite
82E046	Lft. Side Thorax Tap	2.0	10.0 cm Ensolite
82E047	Lft. Side Thorax Tap	2.0*	10.0 cm Ensolite
82E048	Lft. Side Thorax Impact	8.5*	10.0 cm Ensolite
82E049	Rt. Side Pelvis Impact	8.5	1.5 cm Ensolite+ 2.5 cm Styrofoam

*For tests with 10 cm of ensolite padding, a 26.Kg impact mass was used.

TABLE 4. RESULTANT HEAD VELOCITIES AND ACCELERATIONS AND HIC VALUES

	Linear Velocity (m/s)	Linear Acceleration (m/s^2)	Angular Velocity (rd/s)	Angular Acceleration (rd/s^2)	HIC
82E001	5.9	6300	63	58000	3490
82E002	5.5	2200	47	14000	514
82E003	6.0	2500	28	13000	847
82E021	5.4	2200	20	9700	572
82E022	5.9	1900	15	12000	736
82E041	6.9	2500	13	9600	977
82E042	7.5	2600	21	9400	980

TABLE 5. 82E00X PEAK THORACIC ACCELERATIONS (g's)

	T1			T12			US			R4R			R4L					
	P-A	R-L	I-S	P-A	R-L	I-S	P-A	R-L	I-S	P-A	R-L	I-S	P-A	R-L	I-S	R8R	R8L	LS
82E001	68	17																
82E002	49	122																
82E003	38	38																
82E004	7.2	4.5	2.4	4.3	2.3		28	10	NA	4.8	10	75	5.7	7.7	4.9	11	10	>20
82E005	2.7	3.8	2.4	1.3	1.0	2.5	3.8	35	NA	2.4	3.2	2.4	6.6	9.8	1.5	4.2	14	9.2
82E006	1.1	0.4	5.2	2.6	0.7	4.4	2.8	6.2	NA	NA	6.0	3.4	4.9	5.1	3.0	5.4	4.0	3.4
82E007	21	21	31	24	18	27	36	24	NA	30	104	44	37	77	26	36	92	19

TABLE 6. 82E02X PEAK THORACIC ACCELERATIONS (g's)

	T1			T12			US			R4R			R4L					
	P-A	R-L	I-S	P-A	R-L	I-S	P-A	R-L	I-S	P-A	R-L	I-S	P-A	R-L	I-S	R8R	R8L	LS
82E021	42	20	80															
82E022	29	24	25															
82E023	4.0	0.6	2.9	2.4	0.6	1.3	8.8	1.8	4.2	2.5	2.8	3.4	2.2	2.7	2.6	4.0	2.7	10
82E024	3.0	1.3	1.7	2.2	1.8	1.0	7.4	3.4	2.6	2.7	2.8	3.0	6.3	2.6	1.4	1.7	2.8	10
82E025	2.3	2.3	1.1	2.6	2.4	1.2	3.7	4.9	2.6	2.1	5.6	1.6	9	8	2.1	3.4	2.8	10
82E016	1.4	2.9	1.0	1.8	1.8	0.8	1.9	6.2	2.2	1.1	4.2	2.1	4.8	14	3.6	3.2	11	5.0
82E027	42	49	40	51	22	29	84	110	90	38	52	30	144	170	68	31	150	113

TABLE 7. 82E04X PEAK THORACIC ACCELERATIONS (g's)

	T1			T12			US			R4R			R4R					
	P-A	R-L	I-S	P-A	R-L	I-S	P-A	R-L	I-S	P-A	R-L	I-S	P-A	R-L	I-S	R8R	R8L	LS
82E041	23	12	43															
82E042	23	14	58															
82E043	2.7	0.7	2.8	1.9	0.4	0.8	11	5.4	8.8	2.6	2.8	3.4	2.9	1.5	1.0	2.5	1.9	12
82E044	1.5	1.6	1.9	1.7	1.2	0.8	6.2	4.3	5.7	2.4	2.8	3.4	4.5	3.4	3.4	2.1	4.5	4.6
82E045	0.7	2.6	1.8	2.6	3.5	1.0	6.2	9.3	11	1.7	3.8	2.2	11	5.4	3.2	11	20	6
82E046	0.6	2.8	1.5	1.5	1.2	0.7	0.2	5.1	3.5	1.5	3.2	1.2	3.3	7.2	4.9	2.3	7.2	2.5
82E047	0.5	1.7	1.1	0.6	0.9	0.6	1.2		1.3	0.7	2.1	0.7	2.1	5.0	2.5	5.4	7.2	2.1

TABLE 8. PEAK PELVIS ACCELERATIONS

Test No.	Peak Force (N)	Impulse (N-s)	Duration (ms)	Peak Linear Acceleration (m/s/s)				Peak Angular Acceleration (rad/s/s)			
				P-A	R-L	I-S	Tan	P-A	R-L	I-S	Res
82E008	14000	190	29	300	840	-340	831	-2270	-6910	-4600	6010
ms=	13			18	11	14	14	14	14	16	11
82E028	13000	190	21	350	710	550	650	3620	10100	8190	10250
ms=	7			6	6	11	6	4	8	5	8
82E049	14000	206	26	127	360	-100	370	2700	-3480	-1990	3750
ms=	14			15	14	14	14	13	13	16	16

TABLE 9. PEAK PRESSURE (psi's)

	EPIDURAL 1	2	3	4	TRACHEA	AORTA	CAROTID
82E001	17	4	13	4			
82E002	11	2	8	8			
82E003	4	18	2	8			
82E004					0.56		
82E005					0.24		
82E006					0.15		
82E007					0.67		
82E021	24	7	9	5			
82E022	25	7	6	7			
82E023						0.8	
82E024						0.6	
82E025						0.4	
82E026						0.4	
82E027						5.0	
82E041	3.5	4.6	8	5.5			11
82E042	8.2	3.5	7.5	5.6			16
82E043							
82E044						0.5	
82E045						0.4	
82E046						0.45	
82E047							
82E048							

TABLE 10. AUTOPSY SUMMARY

82E003 HEAD IMPACT

Basal skull fracture, fracture line propagating from foramen magnum to apex along superior aspect.

Bilateral subarachnoid hematoma of frontal and parietal lobes.

82E007 THORAX IMPACT

R3, R5, R7 on left side crushed, but not fully separated.

Peticeal hemorrhage on pericardium near ascending aorta.

82E008 PELVIS IMPACT

No injuries.

82E022 HEAD IMPACT

Subarachnoid hemorrhage of right parietal lobe.

Rupture of disc between C6 and C7, anterior longitudinal ligament 90% disrupted.

82E027 THORAX IMPACT

4 fractures on R2; 1 fracture on R3 and partial separation on R3; 2 fractures on R4; 2 fractures on R5; 1 fracture on R6.

Complete separation of acromion and clavicle.

82E028 PELVIS IMPACT

Complete longitudinal fracture of acaetabulum, including crushing of superior aspect.

Fracture of ramus of ischium.

82E042 HEAD IMPACT

Subarachnoid hemorrhage of right parietal lobe.

82E048 THORAX IMPACT

Incomplete crushing fractures to R3 and R7 on left side.
Complete fracture of R8 on left side.

82E049 PELVIS IMPACT

No injuries.

REFERENCES

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2. Nusholtz, G.S., Melvin, J.W., and Alem, N.M., "Head Impact Response Comparisons of Human Surrogates," Proceedings of the 23rd Stapp Car Crash Conference, Paper No. 791020, Society of Automotive Engineers, Inc., 1979.

3. Nusholtz, G.S., et al., "Response of the Cervical Spine to Superior-Inferior Head Impacts," Proceedings of the 25th Stapp Car Crash Conference, Paper No. 811005, Society of Automotive Engineers, Inc. 1981.

APPENDIX A: Test Protocol

DEPARTMENT OF TRANSPORTATION

MULTIPLE IMPACT TESTS

_______ Through _______

as performed by

the Biomechanics Department of

the Highway Safety Research Institute

Ann Arbor, Michigan

1982 E Series

TABLE OF CONTENTS

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Head impact, subject in a normal seated position, neck angle approx. 10° forward, impact to forehead, angle of head determined by tangent forehead plane.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 15cm DIA.

Impactor Angle: 50°(5.0m/s)

Padding: 3.5cm Dow Ethafoam

Pre-Impact Travel: 14cm

Post-Impact Travel: 16cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	P-A, S-I
Photosonics 2:		
HyCam:	3000	P-A, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9 AX)	X	Head	X	Trachea	
Up. Sternum (3-AX)		Acromion	X	Ascending Aorta	
Lwr. Sternum (1)		Sternum (2)		Internal Carotid	X
Spine (2 triax)	X	Spine			
Pelvis (9 AX)		Pelvis		Subdural 1:	X
Lwr. Rib R8 (2)				2:	X
Up. Rib R4 (2 triax)				3:	X
				4:	?

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description:
Head impact, same as previous.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 15cm DIA.

Impactor Angle: 50°(5.0m/s)

Padding: 3.5cm Dow Ethafoam

Pre-Impact Travel: 14cm

Post-Impact Travel: 16cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	P-A, S-I
Photosonics 2:		
HyCam:	3000	P-A, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9 AX)	X	Head	X	Trachea	
Up. Sternum (3-AX)		Acromion	X	Ascending Aorta	
Lwr. Sternum (1)		Sternum (2)		Internal Carotid	X
Spine (2 triax)	X	Spine			
Pelvis (9 AX)		Pelvis		Subdural 1:	X
Lwr. Rib R8 (2)				2:	X
Up. Rib R4 (2 triax)				3:	X
				4:	?

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Front tap, mid-sternum, angle of thorax determined by sternum tangent plane, top of impact 54 cm from seat pan.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 21cm. sq.

Impactor Angle: 17°(2m/s)

Padding: .5cm ensolite

Pre-Impact Travel: 8cm

Post-Impact Travel: 22cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	P-A, S-I
Photosonics 2:		
HyCam:	3000	P-A, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	X	Head	X	Trachea	X
Up. Sternum (3-AX)	X	Acromion	X	Ascending Aorta	X
Lwr. Sternum (1)	X	Sternum (2)	X	Internal Carotid	
Spine (2 triax)	X	Spine			
Pelvis (9-AX)		Pelvis		Subdural 1:	
Lwr. Rib R8 (2)	X			2:	
Up. Rib R4 (2 triax)	X			3:	
				4:	

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Left side tap, 45°P-A into R-L, normal seated posture, move arm if necessary, top of impact 54 cm above seat pan.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 21cm. sq.

Impactor Angle: 17°(2m/s)

Padding: .5cm ensolite

Pre-Impact Travel: 8cm

Post-Impact Travel: 22cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	45° P-A into R-L, S-I
Photosonics 2:		
HyCam:	3000	45° P-A into R-L, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	X	Head	X	Trachea	X
Up. Sternum (3-AX)	X	Acromion	X	Ascending Aorta	X
Lwr. Sternum (1)	X	Sternum (2)	X	Internal Carotid	___
Spine (2 triax)	X	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural 1:	___
Lwr. Rib R8 (2)	X			2:	___
Up. Rib R4 (2 triax)	X			3:	___
				4:	___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Left side tap arms up, position arms to minimize interference from scapula as well as centering piston in the R-L/I-S plane, normal seated posture. Top of impact 54 cm above seat pan. (This test may be dropped.)

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 21cm sq.

Impactor Angle: 17°(2m/s)

Padding: .5cm ensolite

Pre-Impact Travel: 8cm

Post-Impact Travel: 22cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	R-L, S-I
Photosonics 2:		
HyCam:	3000	R-L, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	X	Head	X	Trachea	X
Up. Sternum (3-AX)	X	Acromion	X	Ascending Aorta	X
Lwr. Sternum (1)	X	Sternum (2)	X	Internal Carotid	___
Spine (2 triax)	X	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural 1:	___
Lwr. Rib R8 (2)	X			2:	___
Up. Rib R4 (2 triax)	X			3:	___
				4:	___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Left side tap arms down, normal seated posture, in the R-L/I-S plane, top of impact 54 cm above seat pan.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 21cm sq.

Impactor Angle: 17°(2m/s)

Padding: .5cm ensolite

Pre-Impact Travel: 8cm

Post-Impact Travel: 22cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	R-L, S-I
Photosonics 2:		
HyCam:	3000	R-L, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	X	Head	X	Trachea	X
Up. Sternum (3-AX)	X	Acromion	X	Ascending Aorta	X
Lwr. Sternum (1)	X	Sternum (2)	X	Internal Carotid	___
Spine (2 triax)	X	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural 1:	___
Lwr. Rib R8 (2)	X			2:	___
Up. Rib R4 (2 triax)	X			3:	___
				4:	___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Left side impact, same as left side arms down tap.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 21cm sq.

Impactor Angle: 100°(8.8m/s)

Padding: 15cm APR pads

Pre-Impact Travel: 9cm

Post-Impact Travel: 21cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	R-L,S-I
Photosonics 2:		
HyCam:	3000	R-L, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	X	Head	X	Trachea	X
Up. Sternum (3-AX)	X	Acromion	X	Ascending Aorta	X
Lwr. Sternum (1)	X	Sternum (2)	X	Internal Carotid	___
Spine (2 triax)	X	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural 1:	___
Lwr. Rib R8 (2)	X			2:	___
Up. Rib R4 (2 triax)	X			3:	___
				4:	___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.________ (Head, Shoulder, Pelvis)

Test Description: Pelvic impact, right side, 8cm anterior to trochanterion, centered on femur.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 15cm DIA.

Impactor Angle: 100°(8.8m/s)

Padding: .5cm ensolite

Pre-Impact Travel: 12cm

Post-Impact Travel: 18cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	R-L, S-I
Photosonics 2:		
HyCam:	3000	R-L, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	___	Head	___	Trachea	___
Up. Sternum (3-AX)	___	Acromion	___	Ascending Aorta	___
Lwr. Sternum (1)	___	Sternum (2)	___	Internal Carotid	___
Spine (2 triax)	X	Spine	X		
Pelvis (9-AX)	X	Pelvis	X	Subdural 1:	___
Lwr. Rib R8 (2)	___			2:	___
Up. Rib R4 (2 triax)	___			3:	___
				4:	___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description:____

____

____

____

____

Type of Impactor:_______________

Type of Bumper:_________________

Type of Striker:________________

Impactor Angle:_________________

Padding:________________________

Pre-Impact Travel:______________

Post-Impact Travel:_____________

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	__________	____________
Photosonics 2:	__________	____________
HyCam:	__________	____________

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	___	Head	___	Trachea	___
Up. Sternum (3-AX)	___	Acromion	___	Ascending Aorta	___
Lwr. Sternum (1)	___	Sternum (2)	___	Internal Carotid	___
Spine (2 triax)	___	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural	1:___
Lwr. Rib R8 (2)	___				2:___
Up. Rib R4 (2 triax)	___				3:___
					4:___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description:____

____

____

____

____

Type of Impactor:_______________

Type of Bumper:_________________

Type of Striker:________________

Impactor Angle:_________________

Padding:________________________

Pre-Impact Travel:______________

Post-Impact Travel:_____________

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	__________	____________
Photosonics 2:	__________	____________
HyCam:	__________	____________

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	___	Head	___	Trachea	___
Up. Sternum (3-AX)	___	Acromion	___	Ascending Aorta	___
Lwr. Sternum (1)	___	Sternum (2)	___	Internal Carotid	___
Spine (2 triax)	___	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural	1:___
Lwr. Rib R8 (2)	___				2:___
Up. Rib R4 (2 triax)	___				3:___
					4:___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description:____

____

____

____

____

Type of Impactor:_______________

Type of Bumper:_________________

Type of Striker:________________

Impactor Angle:_________________

Padding:________________________

Pre-Impact Travel:______________

Post-Impact Travel:_____________

35mm stills:

___ Black and White

___ Color

CAMERAS	POSITION
Photosonics 1: __________	____________
Photosonics 2: __________	____________
HyCam: __________	____________

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	___	Head	___	Trachea	___
Up. Sternum (3-AX)	___	Acromion	___	Ascending Aorta	___
Lwr. Sternum (1)	___	Sternum (2)	___	Internal Carotid	___
Spine (2 triax)	___	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural	1:___
Lwr. Rib R8 (2)	___				2:___
Up. Rib R4 (2 triax)	___				3:___
					4:___

COMMENTS:

PRE-SURGERY

TASK	TIME	COMMENTS
Pick up cadaver from U of M Anatomy Dept. and transport to HSRI Biomedical lab.		
Weigh cadaver and log cadaver information.		
Store cadaver if necessary.		
Sanitary preparation.		
Pretest X-rays: (KV/MA/T) head A-P (100/10/1) __/__/__ thorax A-P (90/10/1) __/__/__ thorax A-P(2) (90/10/1) __/__/__ pelvis (105/10/1) __/__/__ femur (80/10/1) __/__/__		
Anthropometry.		

ANTHROPOMETRY

Height:__________

Weight:__________

Sex:__________

Age:__________

Stature: left:__________ right:__________

Suprasternale height:__________

Substernale height:__________

Substernale depth:__________

Substernale breadth:__________

Substernale circumference:__________

Vertex to 12th rib:__________

Head to C7:__________

Mastoid to vertex: left:__________ right:__________

Tragon to vertex: left:__________ right:__________

Menton to vertex:__________

Bitragon diameter:__________

Acromion height: left:__________ right:__________

Acromion to tip of finger:__________

Biacromion:__________

Axillary breadth:__________

Axillary depth:__________

Axillary circumference:__________

Head breadth (R-L):__________

Head depth (A-P):__________

Head circumference:__________

Neck circumference:__________

Bitrochanteric breadth:__________

Symphysion depth:__________

Vertex to Symphysion:__________

Bispinous (ASIS) diameter:__________

Biiliocristale breadth:__________

ASIS to Symphysion:__________

Anatomical Anomalies / Clinical Observations

1. Head: a. Brain b. Skull

2. Neck:

3. Thorax: a. Ribs b. Heart c. Lungs d. Diaphragm

4. Pelvis:

5. Femur

6. Abdomen

RIB AND STERNUM MOUNTS

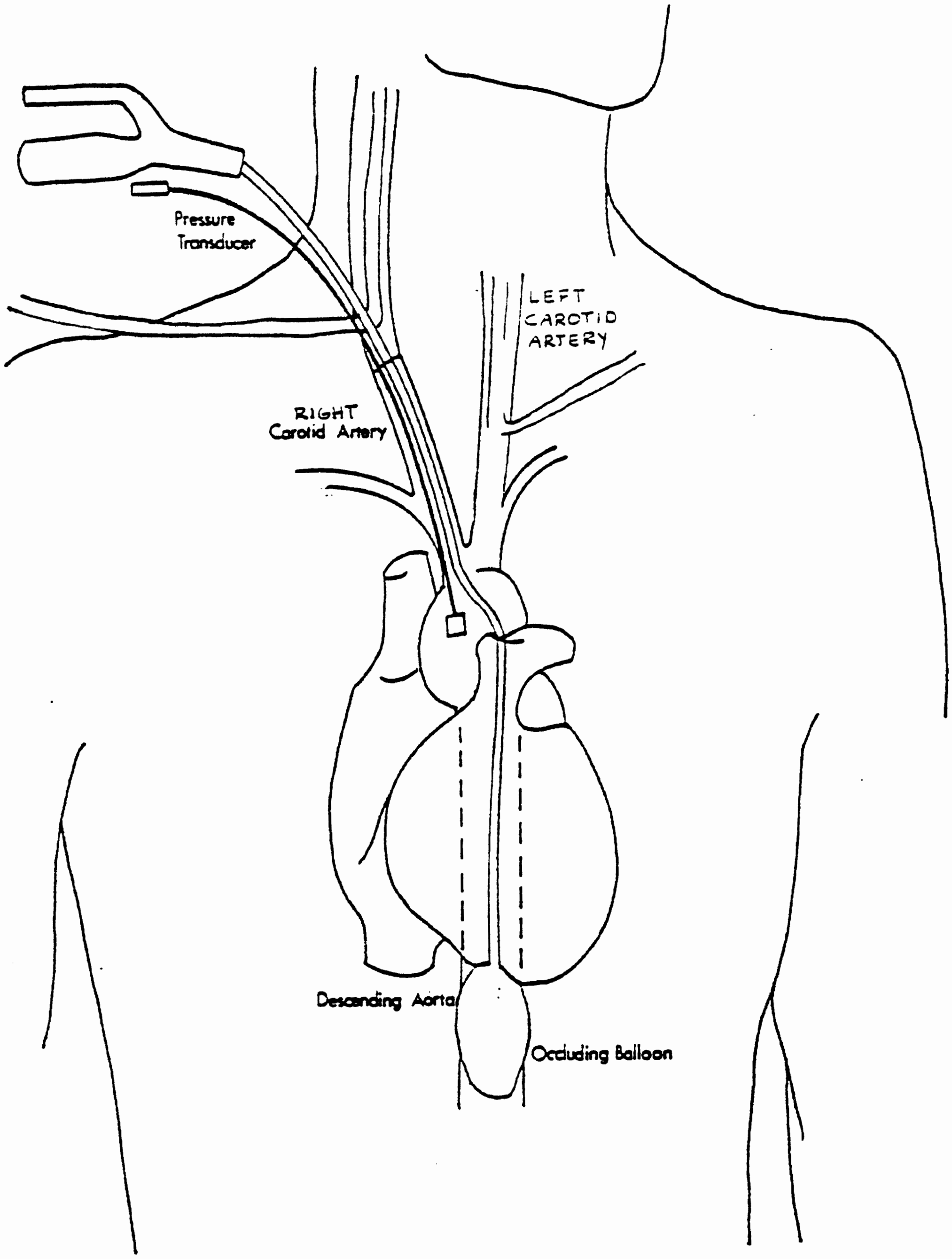
TASK	TIME	COMMENTS
Locate right and left R4 by palpation.		
Make incisions over ribs near flat region. Surface must be normal to the R-L vector.		
Loop two pieces of wire (1/2" apart) around each rib.		
Locate R8 by counting down from R4 and up from R12.		
Make incision over rib near flat region. Surface must be normal to the R-L vector.		
Make incisions over suprasternale and substernale.		
Secure mounts to rib by anchoring with pins and wire.		
Screw lag bolt into each acromion.		

PRESSURIZATION

TASK	TIME	COMMENTS
Locate right carotid and cut lengthwise.		
Locate right vertebral artery and ligate.		
Loop six pieces of string around carotid artery.		
Insert fabricated Foley catheter (#18 or #20) into descending aorta.		
Insert Kulite shield into ascending aorta.		
Insert Kulite shield into carotid artery.		
Insert arterial pressurization catheters into carotid artery.		
Using syringe, squirt acrylic into artery. Tie and sew.		
Locate left carotid, cut, loop strings.		
Locate left vertebral artery and ligate.		

PRESSURIZATION (CONT'D)

TASK	TIME	COMMENTS
Insert arterial pressurization catheters (#10, #12, or #14) into carotid artery.		
Acrylic, tie and sew.		
Locate trachea and cut lengthwise.		
Loop two Tie Wraps around trachea.		
Insert polyethelyne tube snugly, tie and sew.		
Calibrate lungs.		
Pulmonary pressure relief valve calibration.		
Vascular flow check.		
Sternal geometry if necessary.		



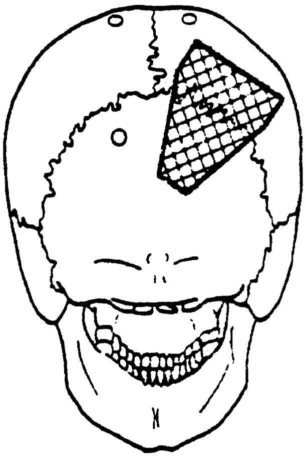
Pressure
Transducer
LEFT
CAROTID
ARTERY
RIGHT
Carotid Artery
Descending Aorta
Occluding Balloon

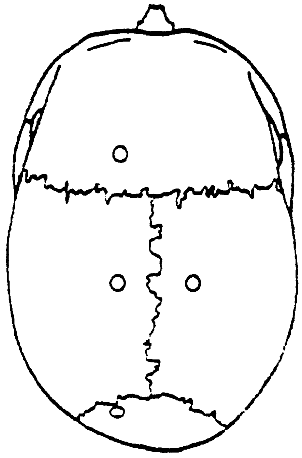
HEAD 9-AX MOUNT

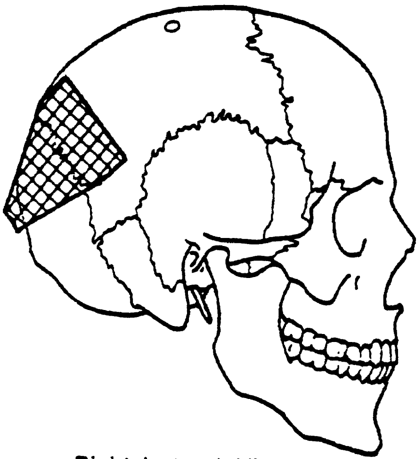
TASK	TIME	COMMENTS
With cadaver facing down, remove a 2x2" area of scalp spanning the right parietal and occipital bones.		
Drill three holes in a triangular pattern, approximately the size of the 9-ax plate.		
Insert three screws.		
Attach four feet to the 9-ax plate such that three of the feet can be positioned near the screws on the exposed forehead.		
Place acrylic around screws.		
Place plate on top of acrylic base, making sure the acrylic goes through the center holes in the plate.		
Insert a strain relief bolt in the acrylic base of the head platform. Make sure bolt does not contact plate.		

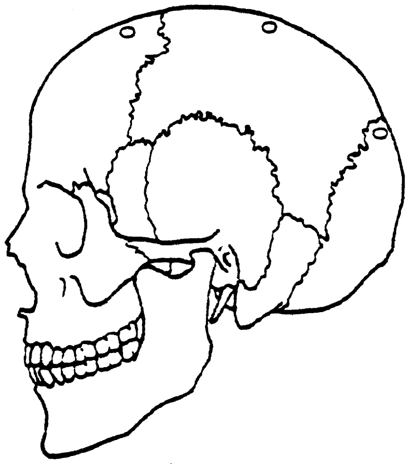
HEAD TRANSDUCERS

TASK	TIME	COMMENTS
Holes for transducers go on frontal,parietal, and occipital bones. Make sure no Xducers will contact the impacting surface. Also, the holes should not be drilled into suture.		
To drill holes, remove a 1/4" dia. circle of scalp.		
Drill through skull with a #7 drill. Be sure not to drill through the dura.		
Perforate the dura without cutting brain.		
Tap hole with a No.7 tap.		
Pinhead screws are attached 2cm from each transducer. Acrylic is applied to each area, carefully molding around the transducers.		
Note positions of head transducers on the figure.		


Posterior View

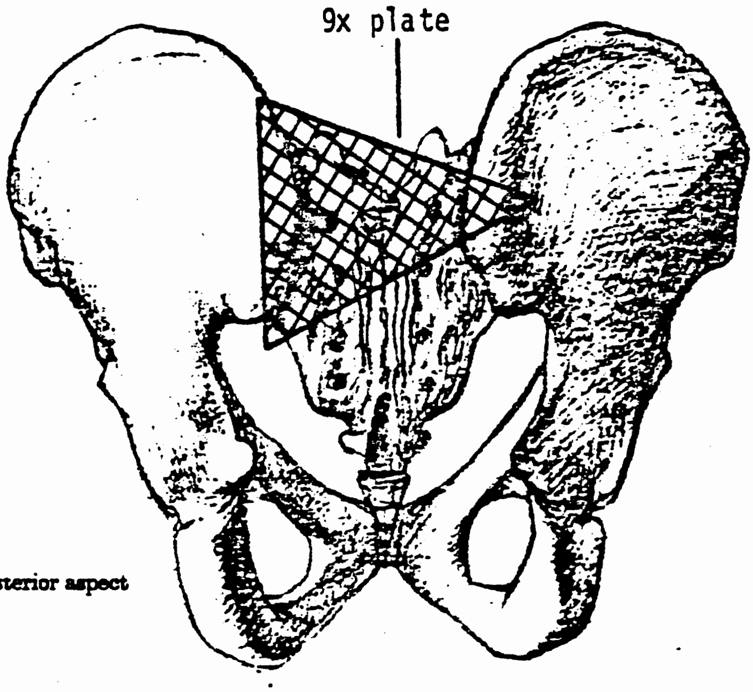

Superior View


Right Lateral View


Left Lateral View

PELVIS MOUNT

TASK	TIME	COMMENTS
Locate the posterior-superior iliac spines.		
Screw two lag bolts into each spine such that the large 9-ax plate spans the bolts.		
Attach four feet to the plate such that the feet are near the lag bolts.		
Place acrylic around screws and feet.		
Imbed feet and posterior surface into acrylic.		
Test plate to see that it is secure.		



Posterior aspect

SPINAL MOUNTS

TASK	TIME	COMMENTS
Spinal mounts go on T1 and T12.		
Make incisions over T1 and T12. Clear muscle and tissue away from process, but do not cut between processes.		
Drill a small hole 1/4" deep in each process.		
Screw mounts on with wood screws (be sure screws are in process).		
Place stabilizing and mooring probic devices on each side of the laminae. Secure with Tie Wraps.		
Mold acrylic around (and under) mounts and mooring devices and allow to dry.		
Make sure accelerometers are anatomically oriented.		
Spinal geometry if necessary.		

CEREBROSPINAL PRESSURIZATION

TASK	TIME	COMMENTS
Locate L2 by palpation and counting from T12.		
Core a small hole in the lamina.		
Insert Foley catheter (#14 or #16) such that balloon is in mid-thorax.		
Insert small screws in lamina and process.		
Seal off hole with acrylic.		
Check for structural integrity of vertebra.		
Cerebral-spinal flow check.		
Check pressurization.		

PREPARATION

TASK	TIME	COMMENTS
Dress cadaver.		
Place head and body harnesses on cadaver.		
Store cadaver if necessary.		
Transport cadaver to sled lab, being careful not to damage mounts.		
Place head, sternum, and rib transducers on cadaver. Stuff and sew.		
Set up pressurization equipment (pulmonary, cerebro-spinal, vascular head and vascular thorax).		

ELECTRONICS CHECK AND PRETEST TRIAL RUN

Electronics Check

- ___ check accelerometers (excitation and zero)
- ___ check wiring and cables
- ___ mount accelerometers in triax clusters
- ___ check amplifiers
- ___ calibrate tape with impedance-matching amp
- ___ recorder
- ___ complete wiring
- ___ check pendulum accelerometer
- ___ check velocity, strobe, gate, timer, rope cutters
- ___ run trial test
- ___ load cell mounted on pendulum day before test
- ___ load Photosonics and HyCam cameras with Kodak 16mm 7242-#FB-430 color film

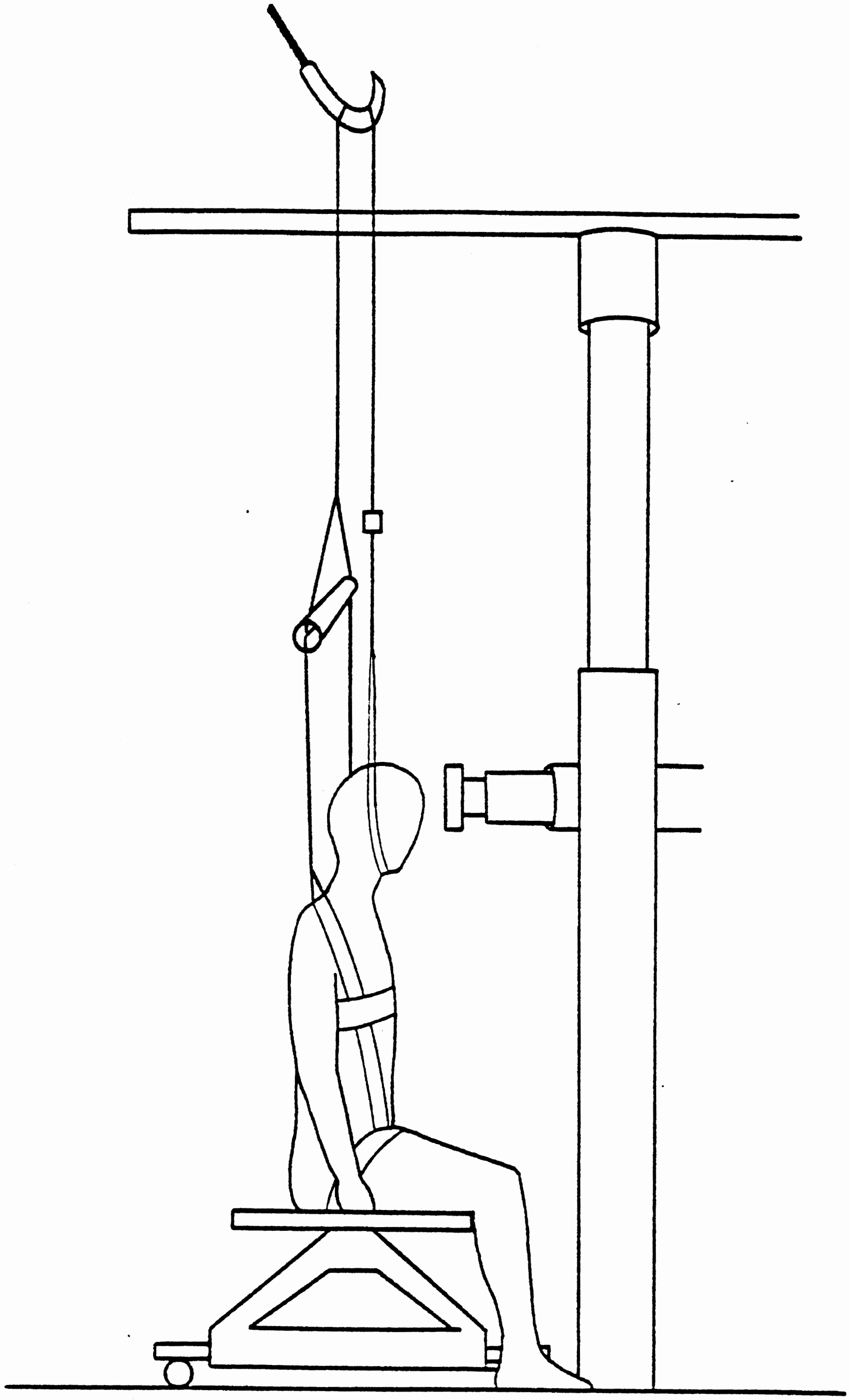
Pretest Trial Run

1. ___ Suspend rubber tube five inches from pendulum with fiber tape.
2. ___ Tape all accelerometers to seat with paper tape.
3. ___ Attach the contact switches to the load cell and shock absorber with paper tape.
4. ___ Run trial test.
5. ___ Record all signals, gate, and strobe.
6. ___ Put a one-volt signal on a junk tape and check to see if one volt is played back. Use signal generator or impedance-matching amp with the scope to calibrate output.

HEAD IMPACT 1

Test No.__________

TASK	TIME	COMMENTS
Head impact 1.		
Attach ball targets and phototargets.		
Change padding on impactor head surface.		
Set up head catch and spinal backup.		
Final positioning (see figure).		
Measure and record head and neck angles		
Setup photos.		
Final checklist.		
Start pressurization of vascular and cerebrospinal systems.		
Finish pressurizatons.		
Run test.		



HEAD IMPACT 1

Timer Box Setup

EQUIPMENT __________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0011	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1390	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0009	8	0050

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

____ zero piston accelerometer

____ head and neck angles

HEAD IMPACT 2

Test No._________

TASK	TIME	COMMENTS
Reposition as for tap.		
Check spinal brace and head catch.		
Final positioning		
Measure and record head and neck angles		
Setup photos.		
Start pressurization of vascular and cerebrospinal systems.		
Final checklist.		
Finish pressurization.		
Run test.		

HEAD IMPACT 2

Timer Box Setup

EQUIPMENT __________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0008	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1290	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0009	8	0050

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

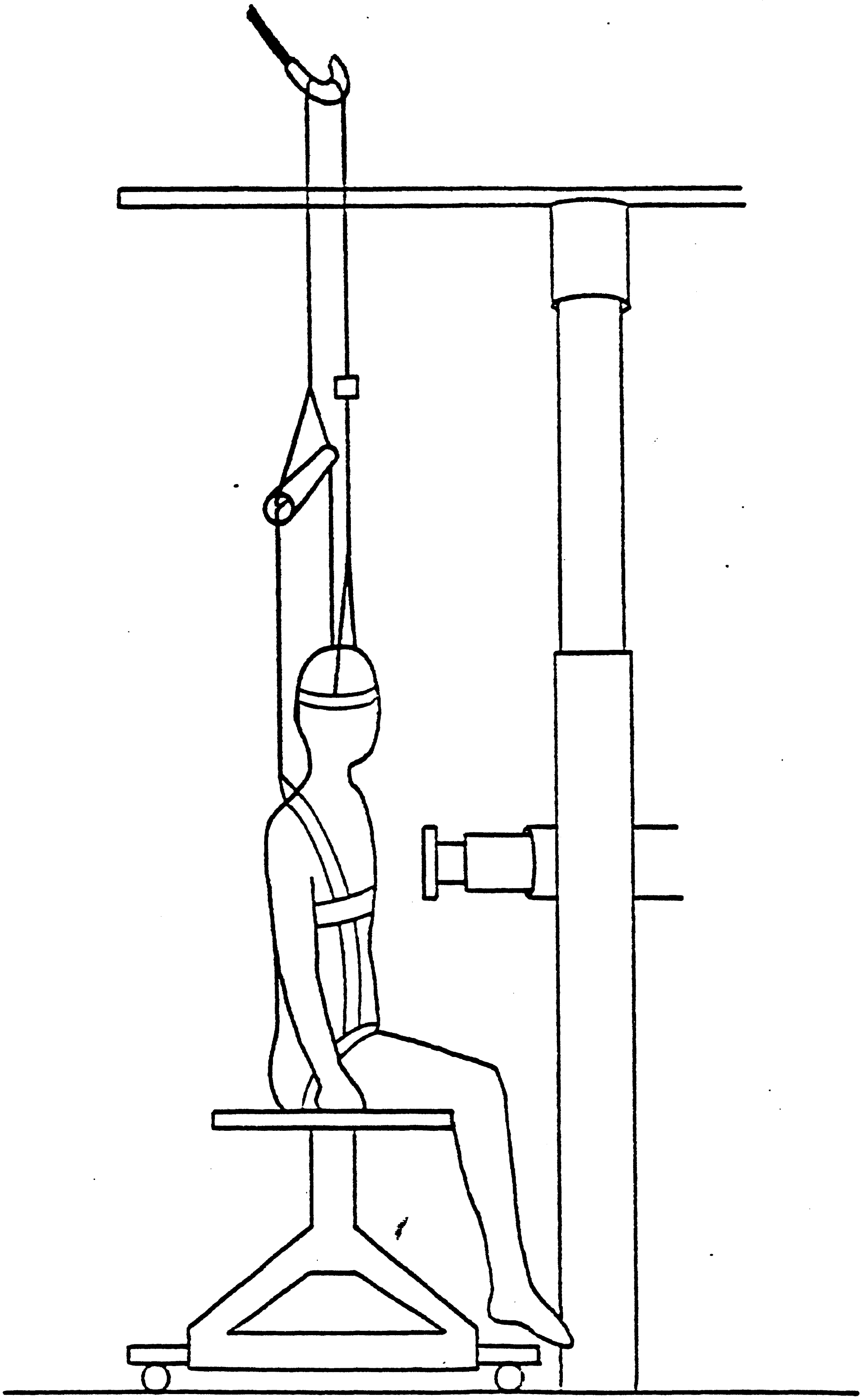
____ zero piston accelerometer

____ head and neck angles

THORAX FRONT TAP

Test No.__________

TASK	TIME	COMMENTS
Place seat in position and square on pendulum.		
String up rope cutters.		
Position subject as per figure with body and head harnesses. Protect any mounts that may be hit with gauze and padding.		
Subject should be in normal sitting position with back inclined approx. 10° forwards.		
Attach ball targets and phototargets.		
Place one of the pressure transducers that was in the head in the trachea, and place the Kulite in the descending aorta.		
Final positioning and setup photos (see fig)		
Final checklist.		
Start pressurization of vascular and respiratory systems.		
Finish pressurization.		
Run test.		



THORAX FRONT TAP

Timer Box Setup

EQUIPMENT __________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0021	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1400	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0012	8	0150

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

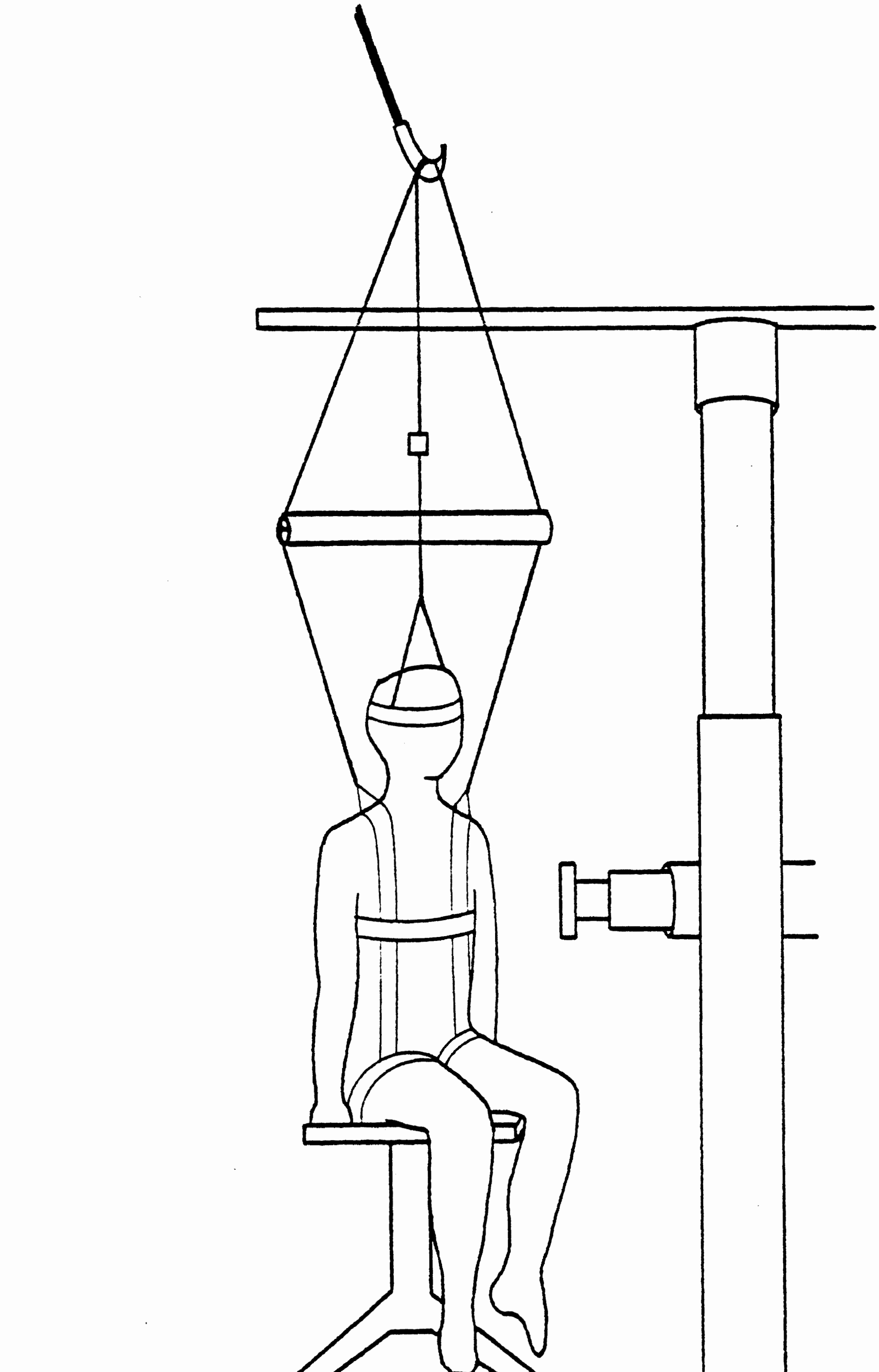
____ zero piston accelerometer

____ head and neck angles

45° THORAX TAP

Test No.__________

TASK	TIME	COMMENTS
Place seat in position.		
String up rope cutters.		
Position subject as per figure with body and head harnesses. Protect any mounts that may be hit with gauze and padding.		
Subject should be in normal sitting position with back inclined approx. 10° forwards.		
Attach ball targets and phototargets.		
Final positioning and setup photos (see fig)		
Final checklist.		
Start pressurization of vascular and respiratory systems.		
Finish pressurization.		
Run test.		



45° THORAX TAP

Timer Box Setup

EQUIPMENT __________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0021	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1400	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0012	8	0150

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

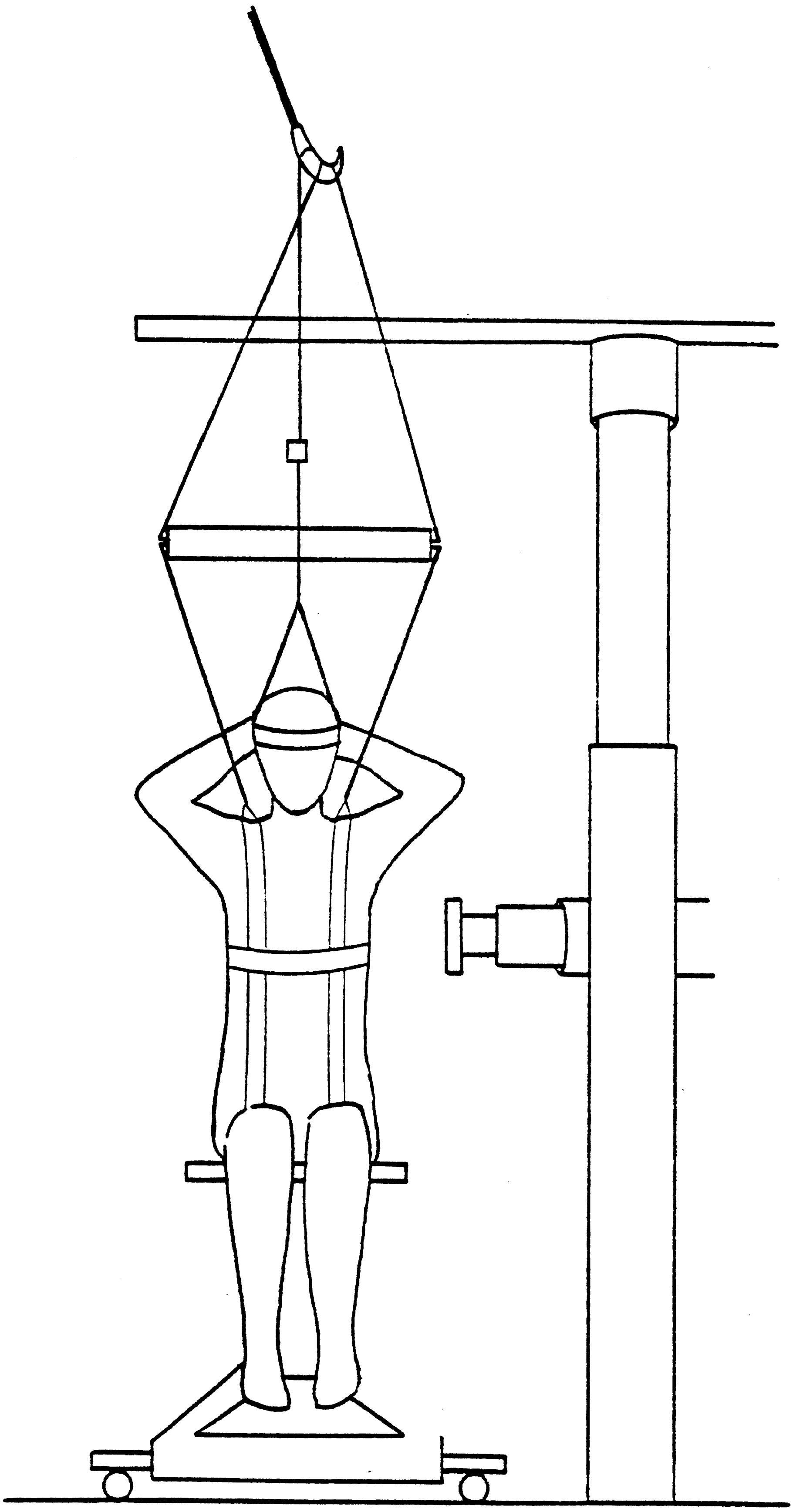
____ zero piston accelerometer

____ head and neck angles

OPTIONAL ARMS-UP THORAX TAP

Test No.__________

TASK	TIME	COMMENTS
Place seat in position.		
String up rope cutters.		
Position subject as per figure with body and head harnesses. Protect any mounts that may be hit with gauze and padding.		
Subject should be in normal sitting position with back inclined approx. 10° forwards.		
Attach ball targets and phototargets.		
Final positioning and setup photos see drawings and figures by ***PAULA LUX***		
Final checklist.		
Start pressurization of vascular and respiratory systems.		
Finish pressurization.		
Run test.		



OPTIONAL ARMS-UP THORAX TAP

Timer Box Setup

EQUIPMENT ________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0021	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1400	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0012	8	0150

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

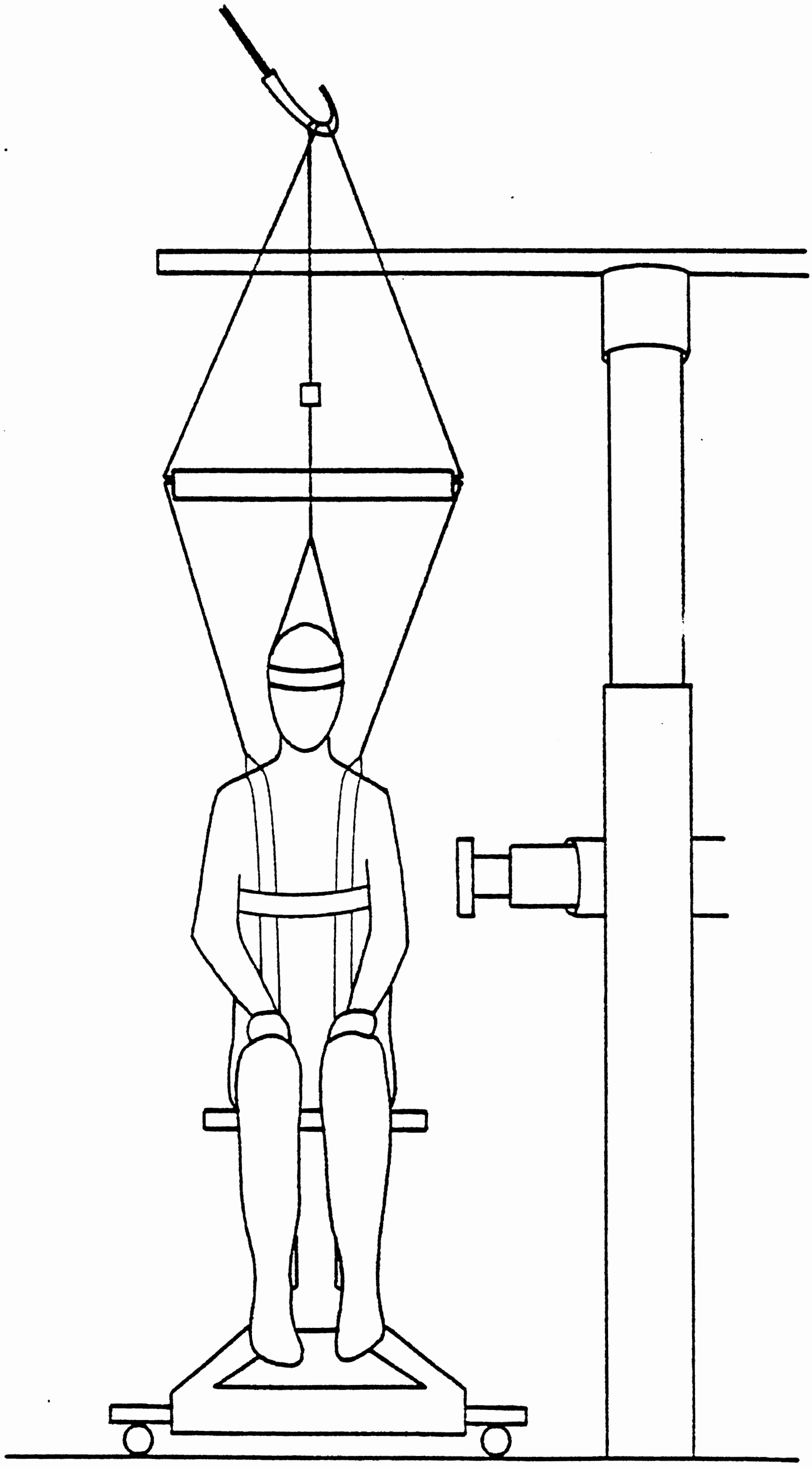
____ zero piston accelerometer

____ head and neck angles

ARMS-DOWN THORAX TAP

Test No.__________

TASK	TIME	COMMENTS
Place seat in position.		
String up rope cutters.		
Position subject as per figure with body and head harnesses. Protect any mounts that may be hit with gauze and padding.		
Subject should be in normal sitting position with back inclined approx. 10° forwards.		
Attach ball targets and phototargets.		
Final positioning and setup photos (see fig)		
Final checklist.		
Start pressurization of vascular and respiratory systems.		
Finish pressurization.		
Run test.		



82E081 Thorax taps - 60

ARMS-DOWN THORAX TAP

Timer Box Setup

EQUIPMENT __________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0021	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1400	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0012	8	0150

November 30, 1982 (rev. January 29, 1982)

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

____ zero piston accelerometer

____ head and neck angles

THORAX IMPACT

Test No.__________

TASK	TIME	COMMENTS
Reposition for shoulder (arms down) impact.		
Set up catch net.		
Slacken body harness.		
Start pressurization of vascular and respiratory systems.		
Final checklist.		
Finish pressurization.		
Run test		

ARMS-DOWN THORAX IMPACT

Timer Box Setup

EQUIPMENT __________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0006	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1220	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0002	7	0050
Piston Acceleration Corridor	0006	8	0050

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

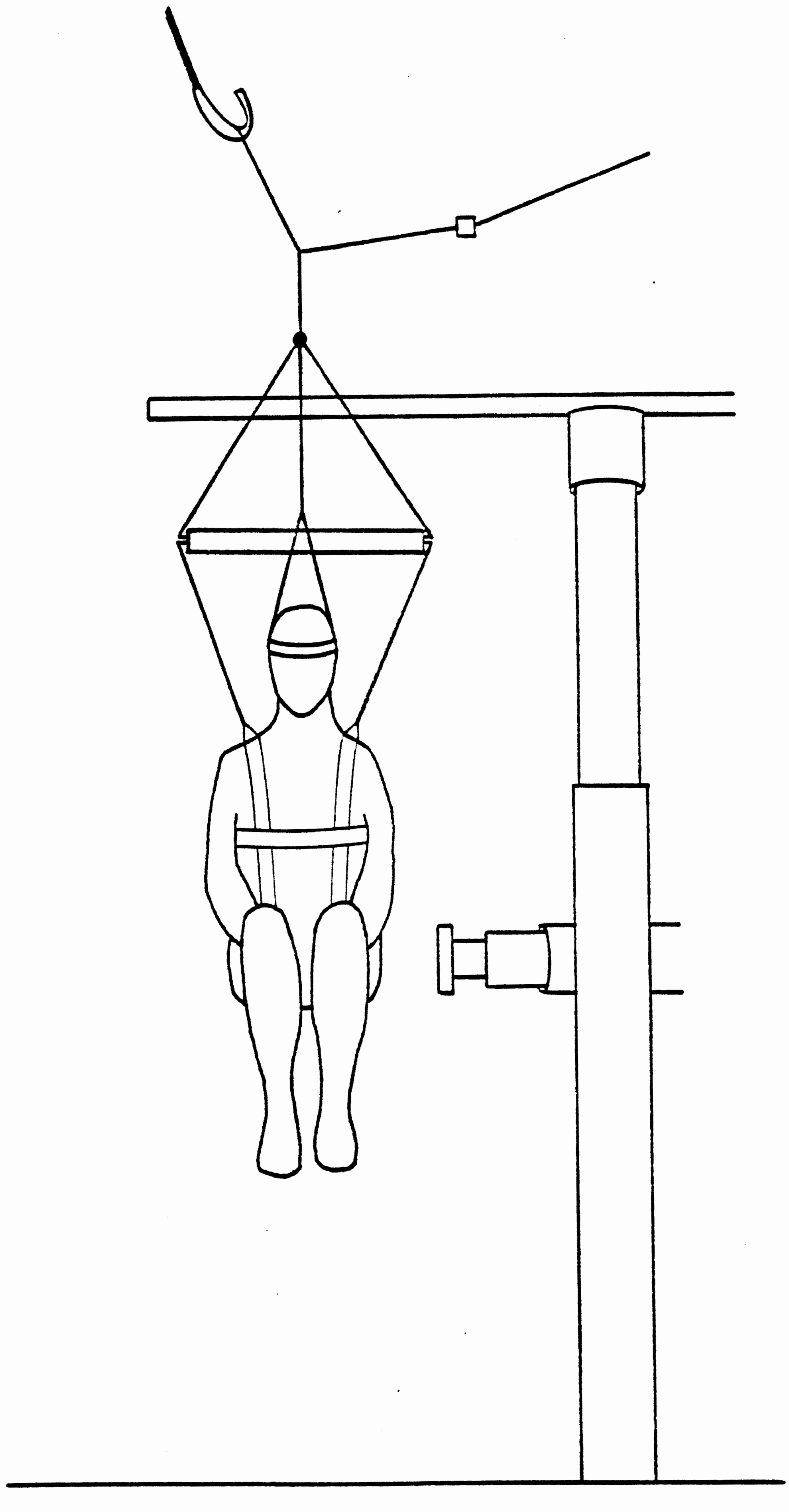
____ zero piston accelerometer

____ head and neck angles

PELVIS IMPACT

Test No.__________

TASK	TIME	COMMENTS
Install pelvic and spinal accelerometers. Stuff and sew. Pad pelvic plate.		
Attach ball targets and phototargets.		
Change padding on impact head surface.		
Final positioning, setup photos (see fig)		
Final checklist.		
Run test.		



PELVIS IMPACT

Timer Box Setup

EQUIPMENT ________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0006	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1220	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0002	7	0050
Piston Acceleration Corridor	0006	8	0050

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

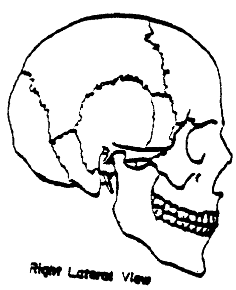
____ zero piston accelerometer

____ head and neck angles

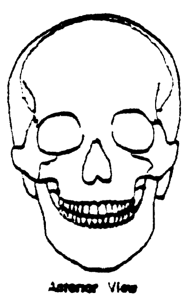
POST TEST PROCEDURE

TASK	TIME	COMMENTS
Remove all targets and triax clusters.		
Store cadaver if necessary.		
Transport cadaver to anatomy lab.		
Remove all instrumentation, except for 9AX head plate.		
Remove head and transport it to X-Ray Room for post test radiographs.		

Z-X (Profile)



Z-Y (Frontal)



X-RAYS (X-RAY ROOM)

Reference Point	Z-X Distance from Table	Z-Y Distance from Table
R. Eye		
L. Eye		
R. Ear		
L. Ear		
Q1		
Q2		
Q3		
CG		

	KVP	MA	SEC	LABEL	
Z-X	/	/	/		(100/10/1)
Z-Y	/	/	/		(100/10/1)

AUTOPSY

TASK	TIME	COMMENTS
After completion of radiographs, transport head to Anatomy Room for commencement of Autopsy.		
Autopsy		
SAVE RIBS RIGHT SIDE 4, 5, 6		

Observed Injuries

1. Head: a. Brain b. Kull

2. Neck:

3. Thorax: a. Ribs b. Heart c. Lungs d. Diaphragm

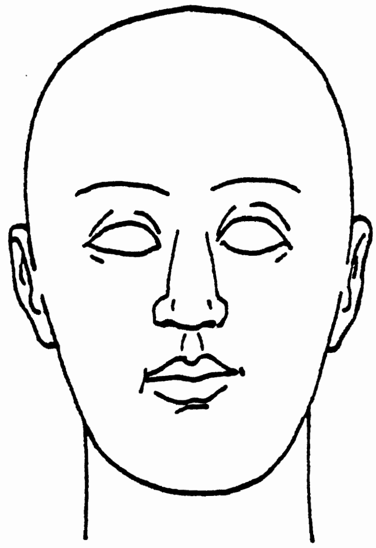
4. Pelvis:

5. Femur

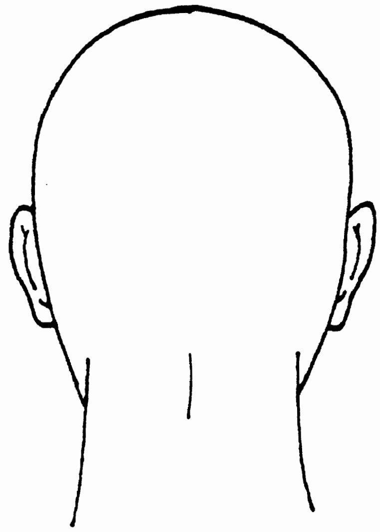
6. Abdomen

COMMENTS:

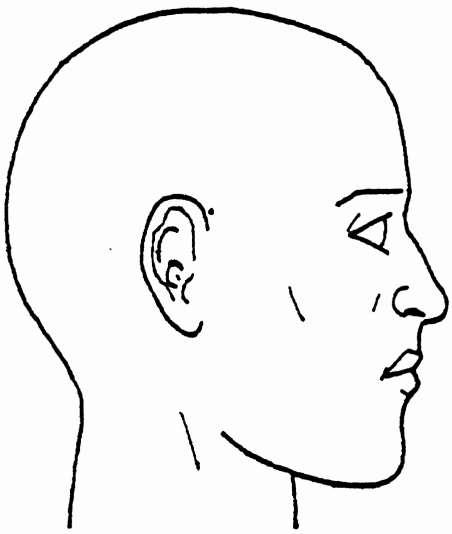
TEST NO. ____________



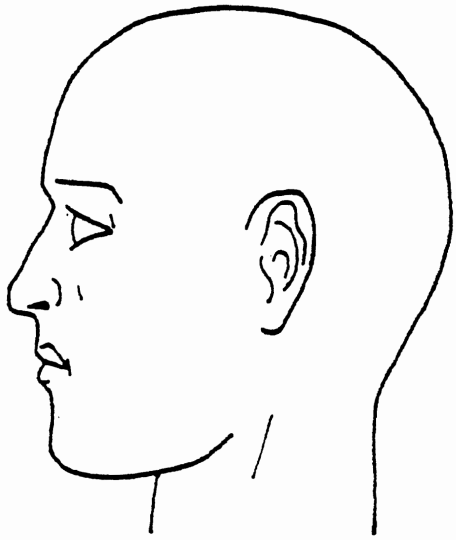
Anterior View



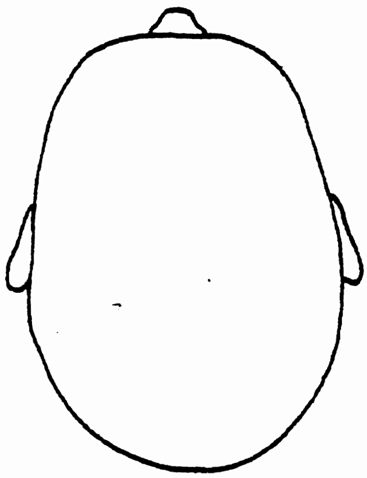
Posterior View



Right Lateral View

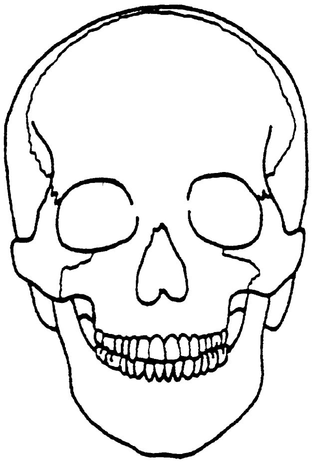


Left Lateral View

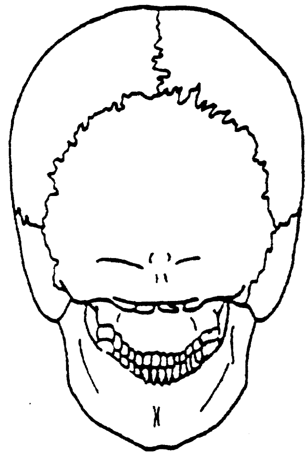


Superior View

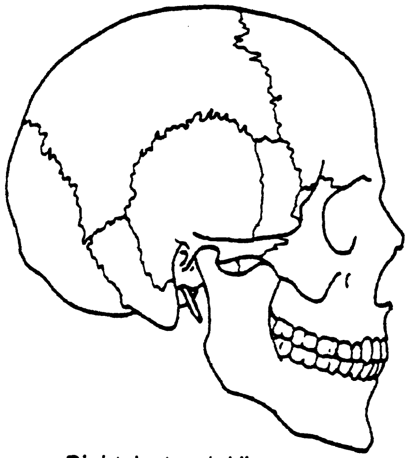
TEST NO. ____________



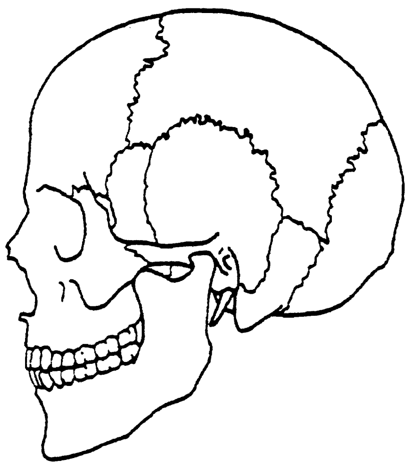
Anterior View



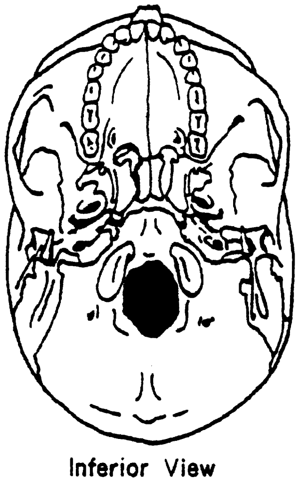
Posterior View



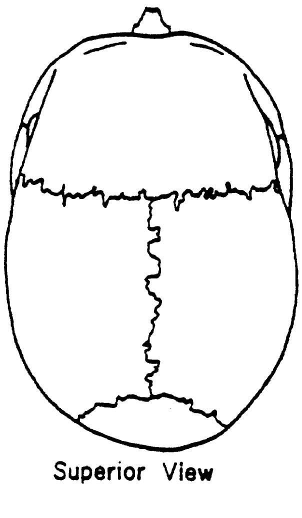
Right Lateral View



Left Lateral View



Inferior View



Superior View

TEST NO. ___________

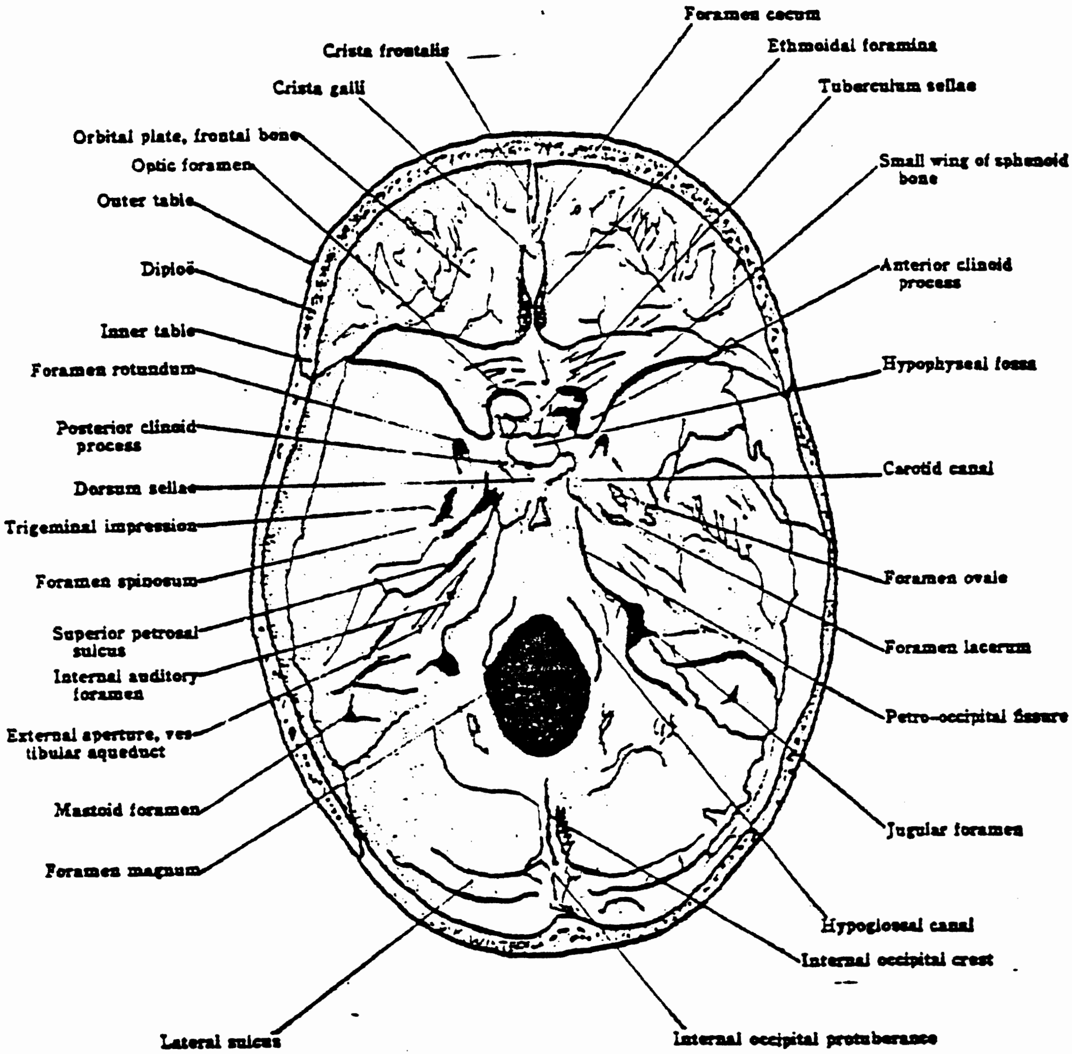
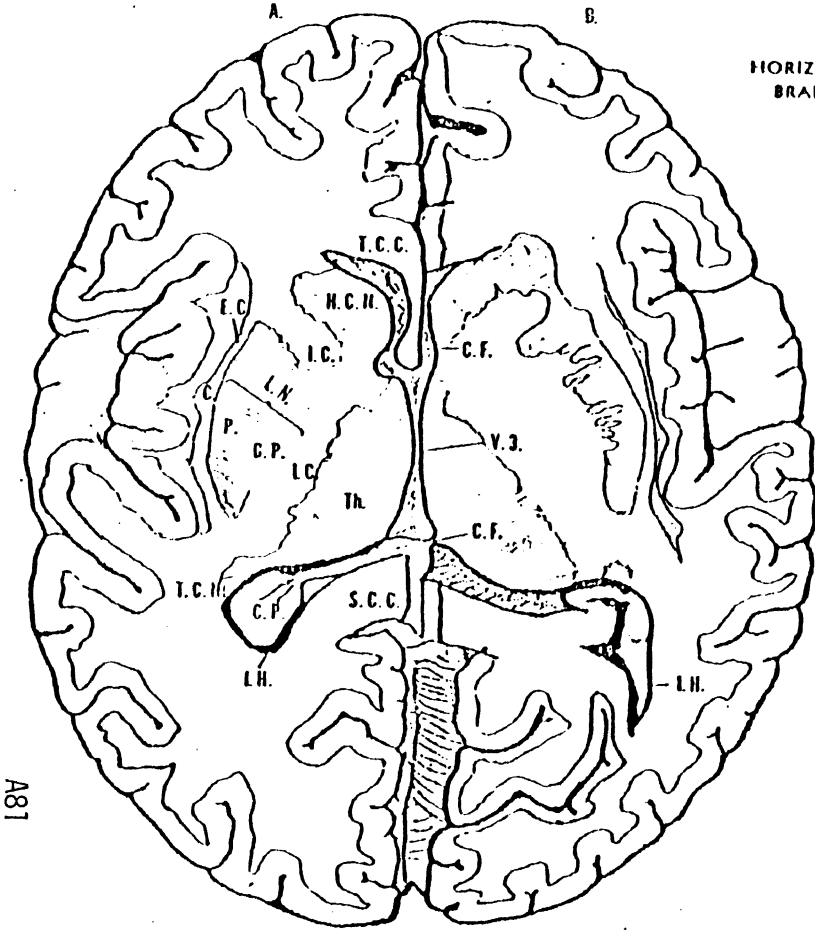


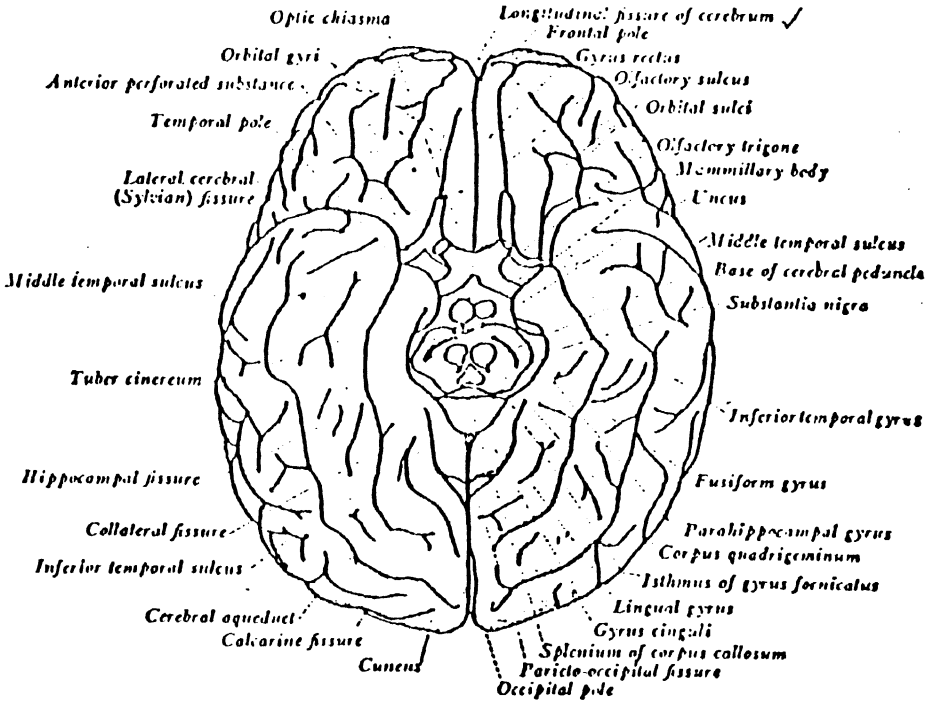
FIG. 109.—THE SKULL, INTERNAL ASPECT OF THE BASE.

TEST NO. ____________

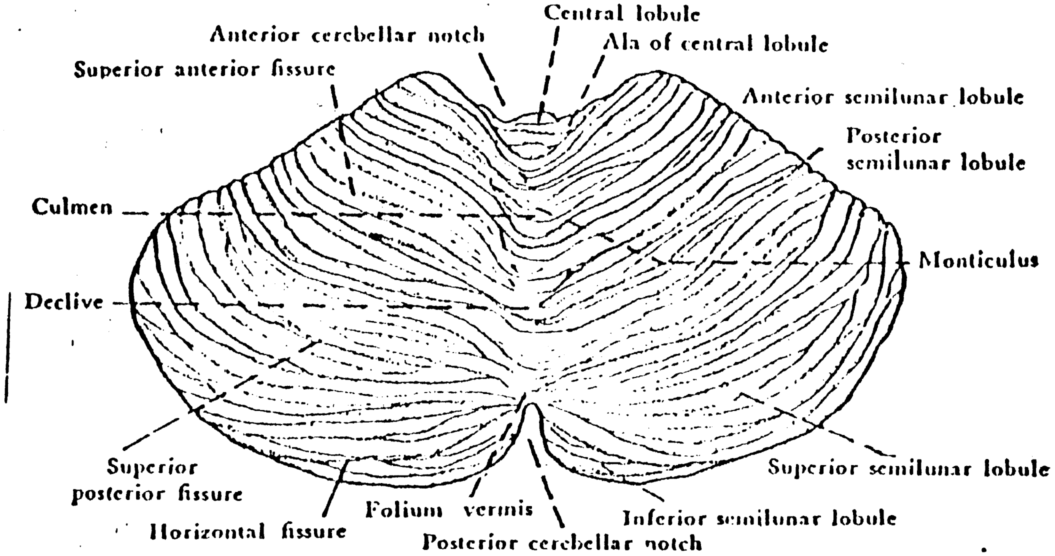


HORIZONTAL SECTIONS OF BRAIN AT TWO LEVELS

C. — Claustrum
C.F. — Crus of Fornix
C.P. — Choroid Plexus
E.C. — External Capsule
G.P. — Globus Pallidus
H.C.N. — Head of Caudate Nucleus
I.C. — Internal Capsule
I.H. — Inferior Horn of Lateral Ventricle
L.N. — Lenticular Nucleus
P. — Putamen
S.C.C. — Splenium of Corpus Callosum
T.C.C. — Trunk of Corpus Callosum
T.C.N. — Tail of Caudate Nucleus
Th. — Thalamus
V.3. — 3rd Ventricle

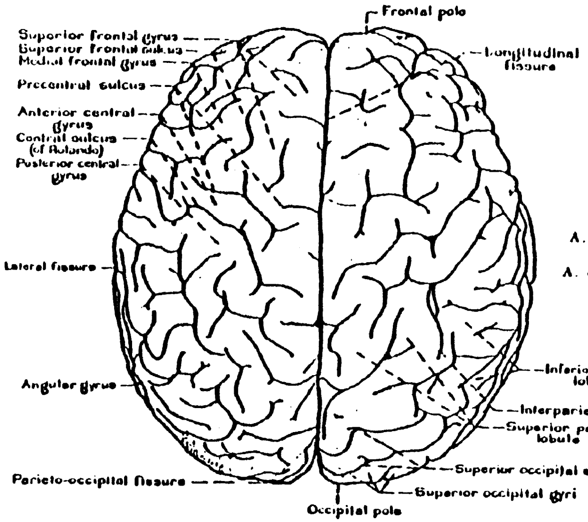


Basal aspect of the human cerebral hemisphere. (Sobotta-McMurrich.)

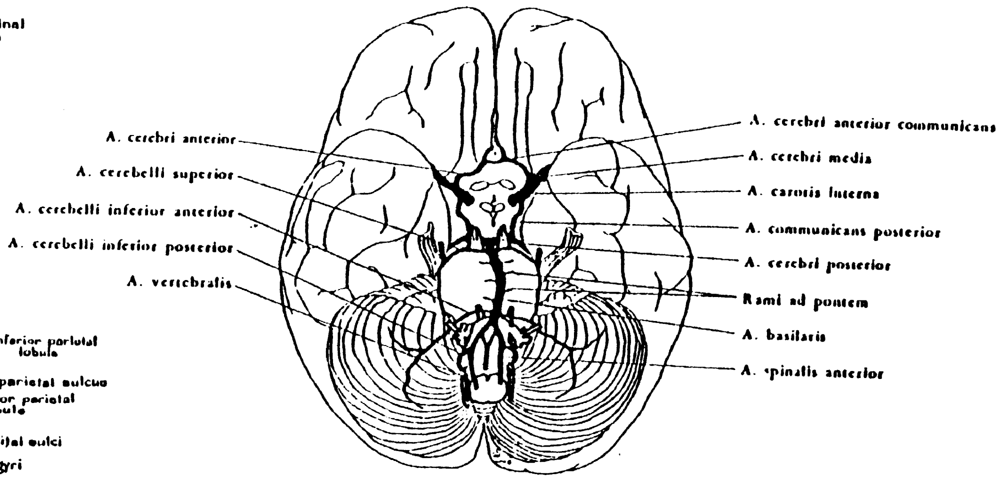


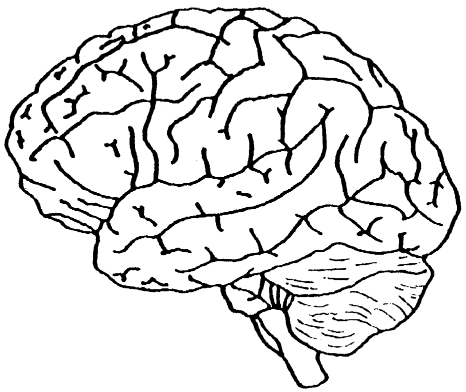
–Upper Surface of Cerebellum.

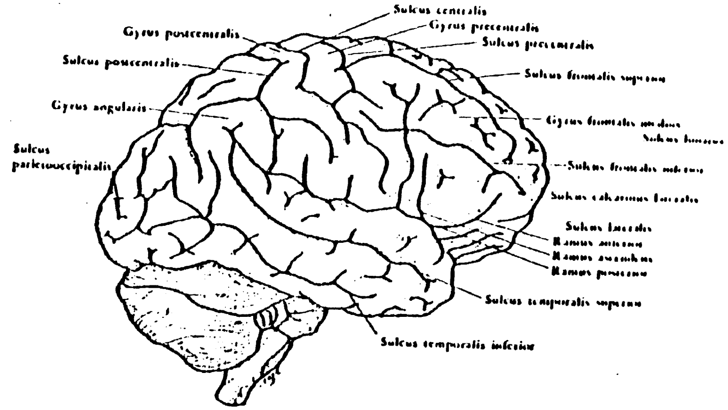
TEST NO. ____________



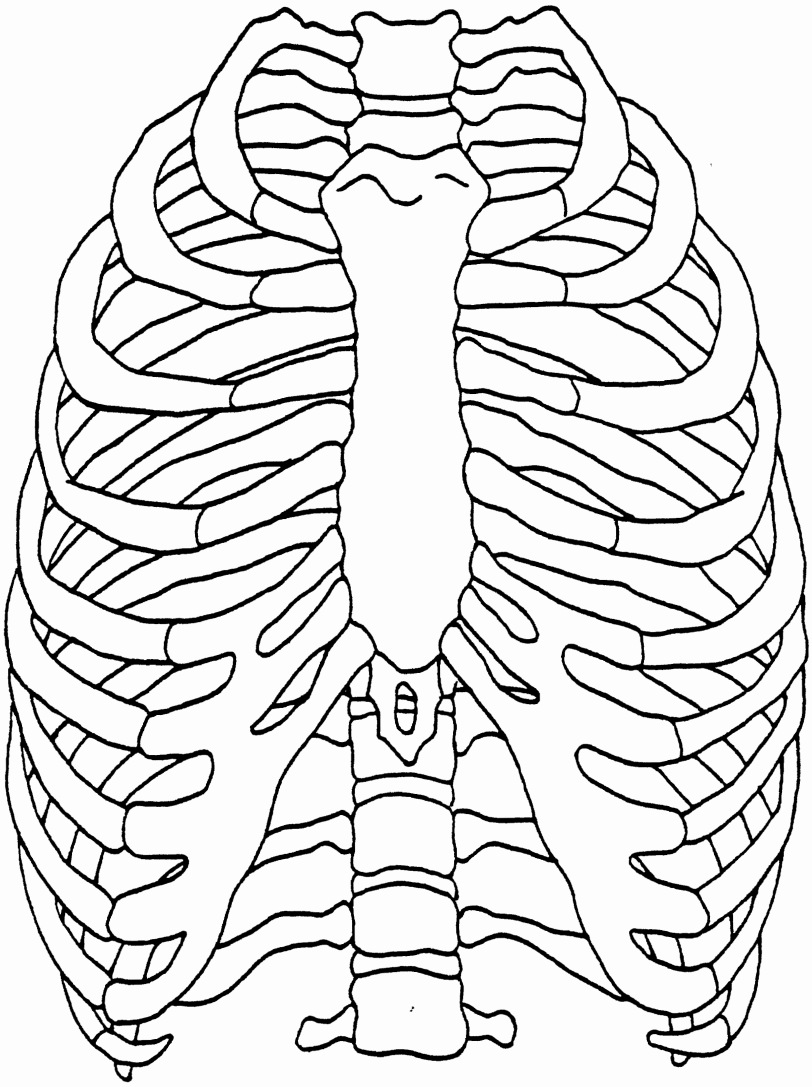
— Cerebral Hemispheres Viewed from Above.





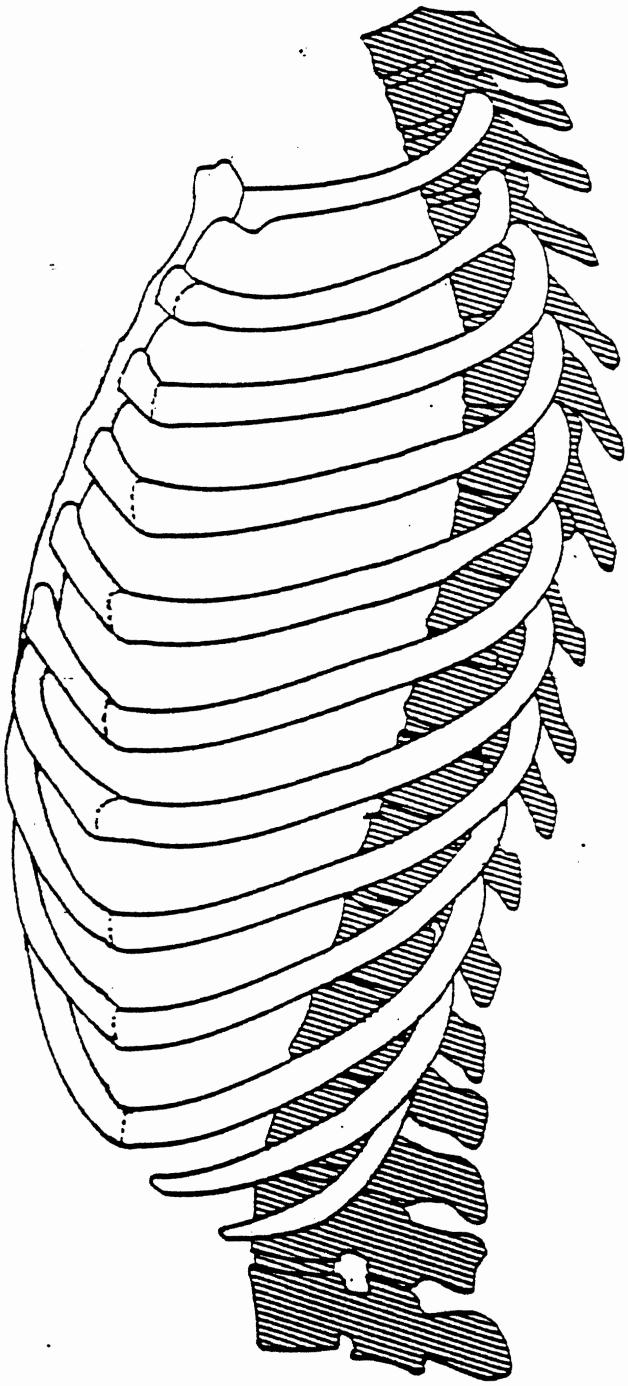


TEST NO. ________________

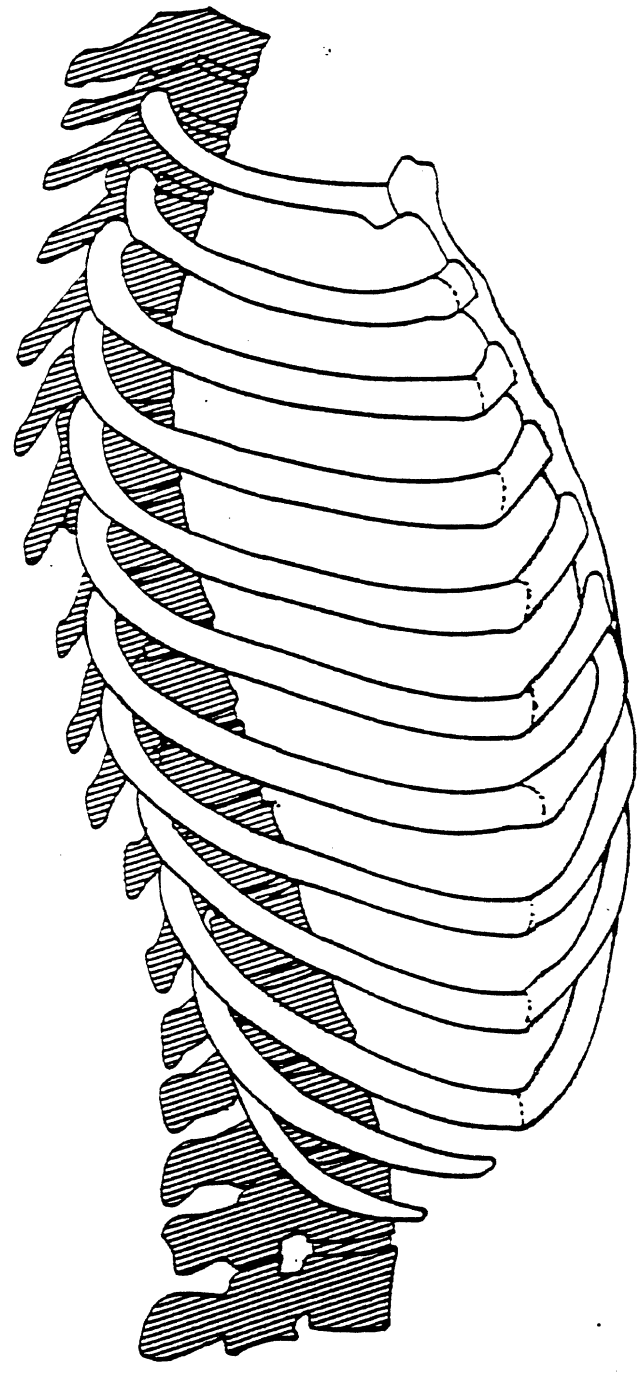


ANTERIOR THORAX

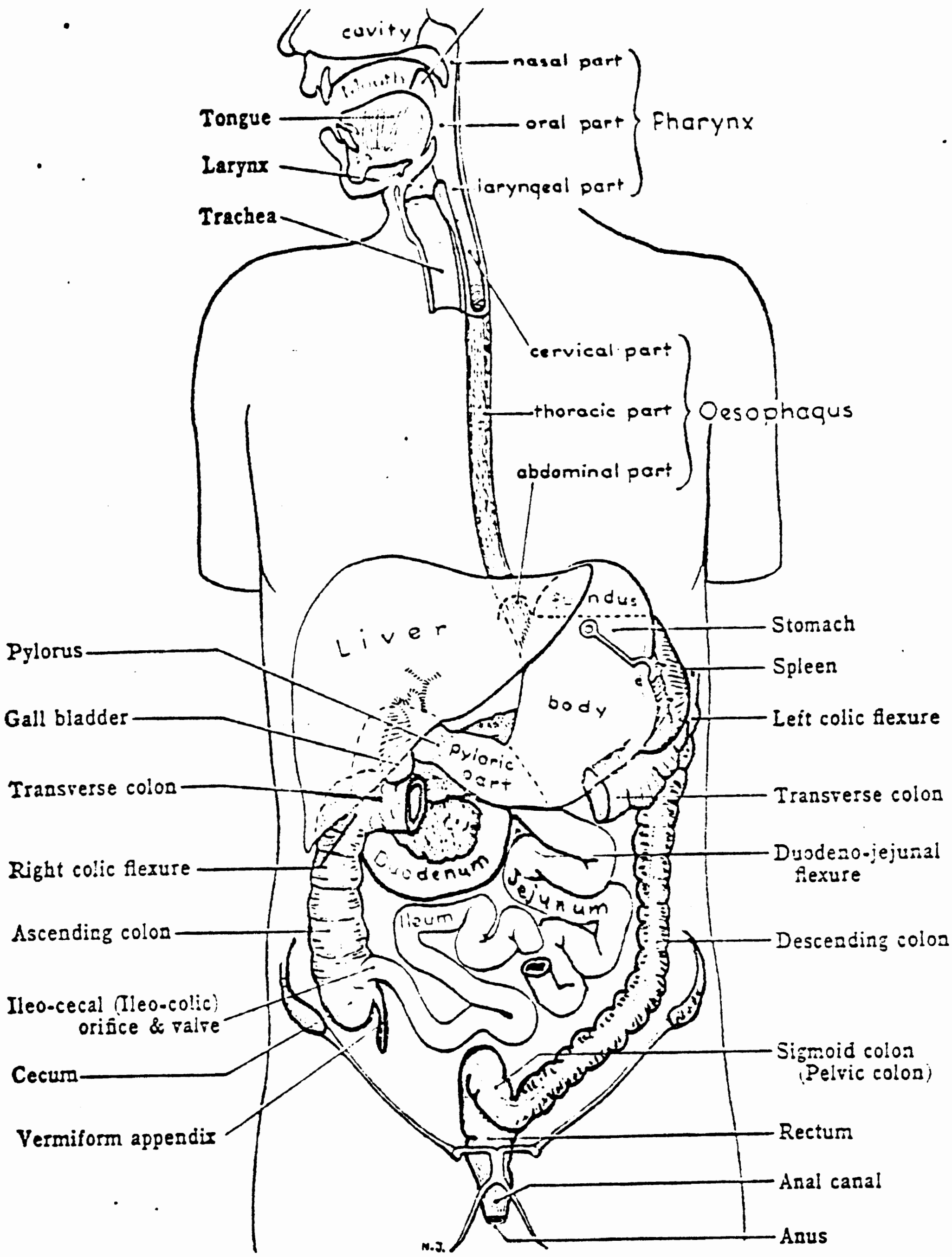
Test No.__________



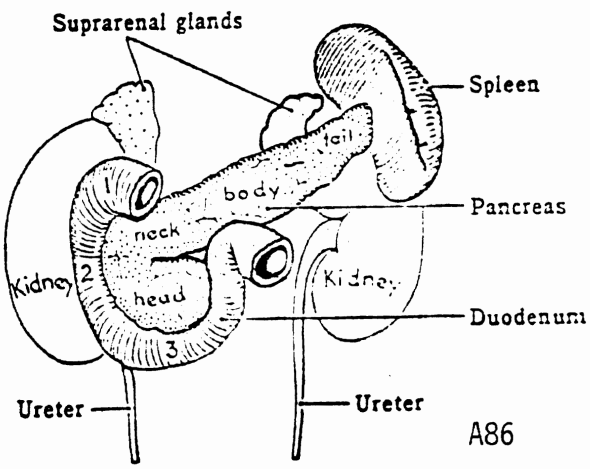
Test No.____________



TEST NO. ________________

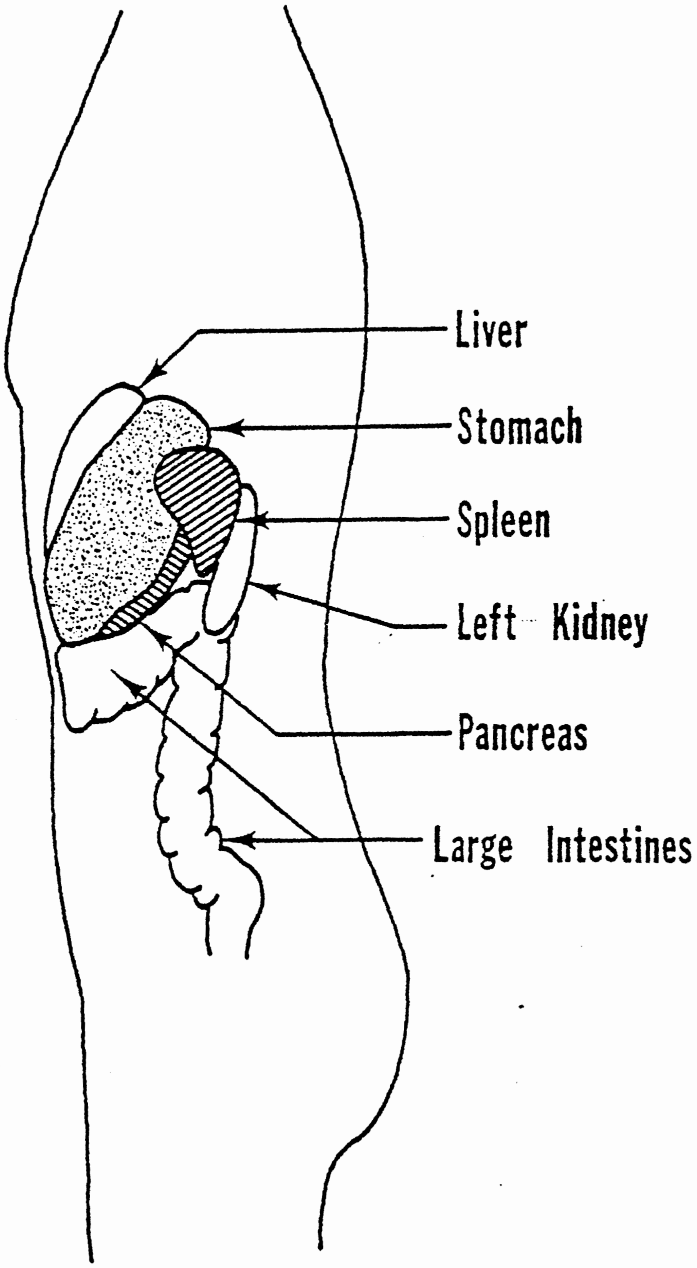


cavity
Mouth
nasal part
Tongue
oral part
Pharynx
Larynx
laryngeal part
Trachea
cervical part
thoracic part
Oesophagus
abdominal part
fundus
Liver
Stomach
Pylorus
Spleen
body
Gall bladder
Left colic flexure
pyloric part
Transverse colon
Transverse colon
Right colic flexure
Duodenum
Duodeno-jejunal flexure
Jejunum
Ascending colon
Ileum
Descending colon
Ileo-cecal (Ileo-colic) orifice & valve
Cecum
Sigmoid colon (Pelvic colon)
Vermiform appendix
Rectum
Anal canal
Anus



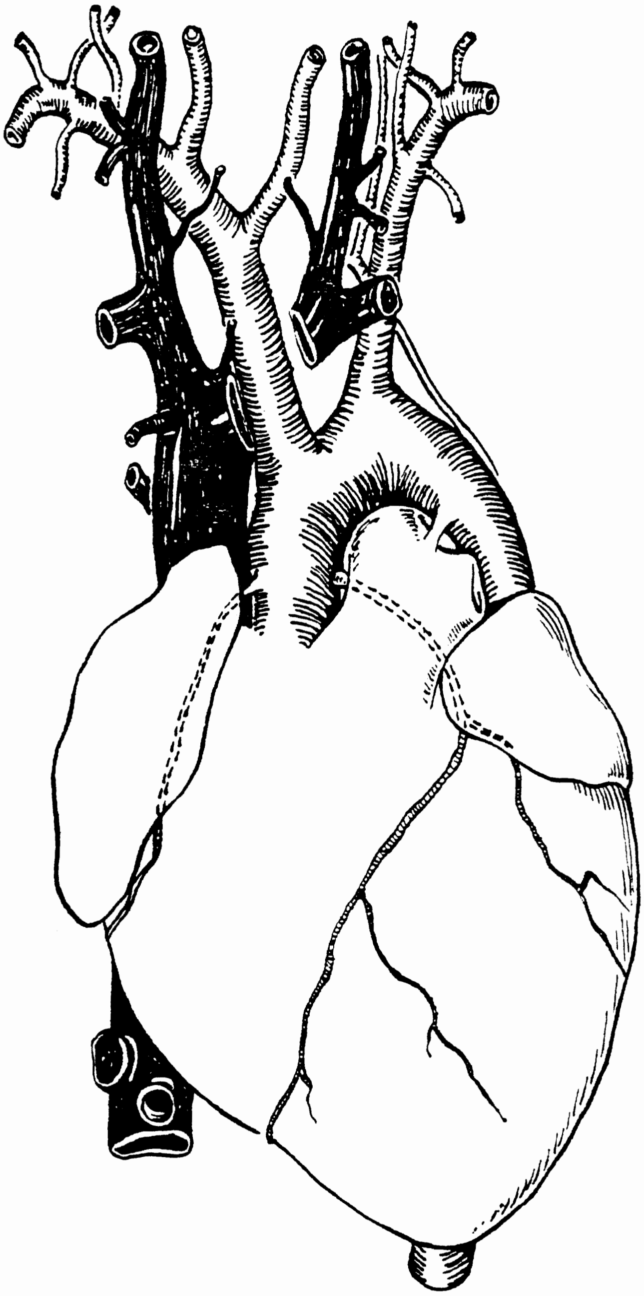
Suprarenal glands
Spleen
tail
body
Pancreas
neck
Kidney
2
head
Kidney
Duodenum
3
Ureter
Ureter

Test No.___________



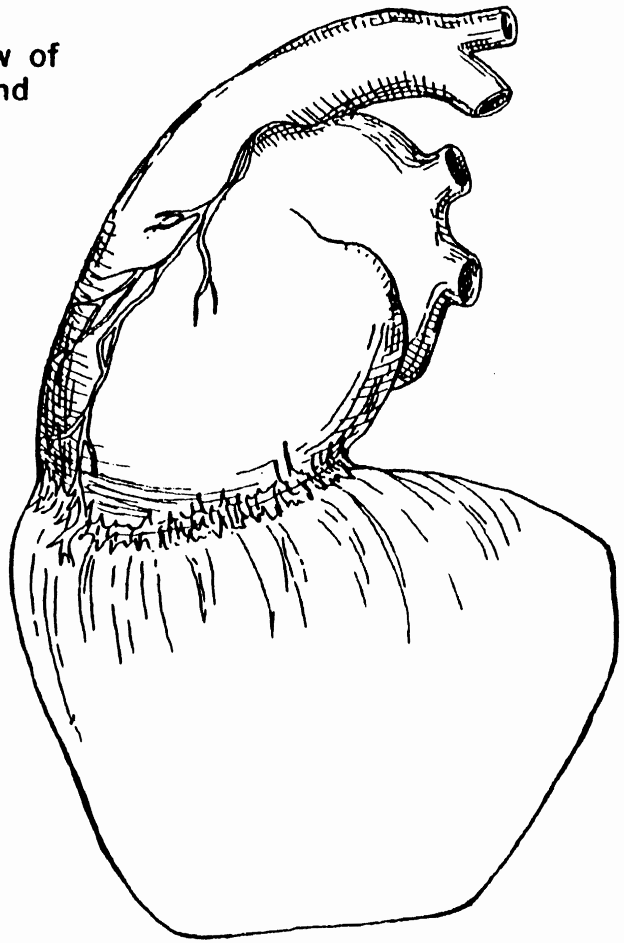
LEFT SIDE

TEST NO. ____________

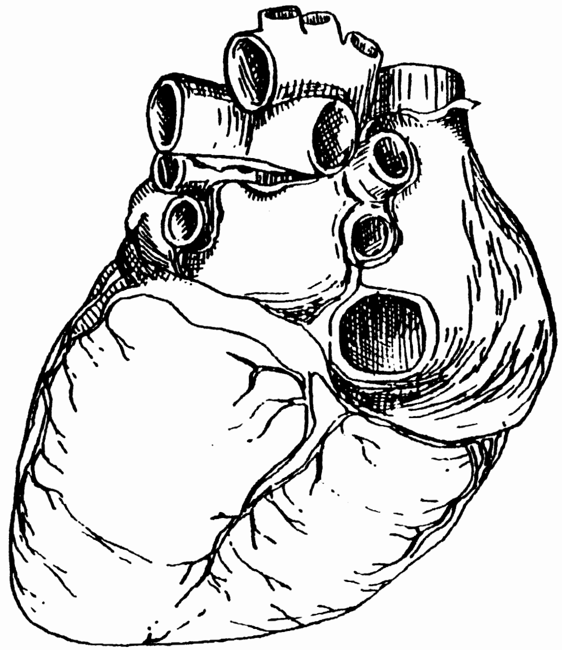


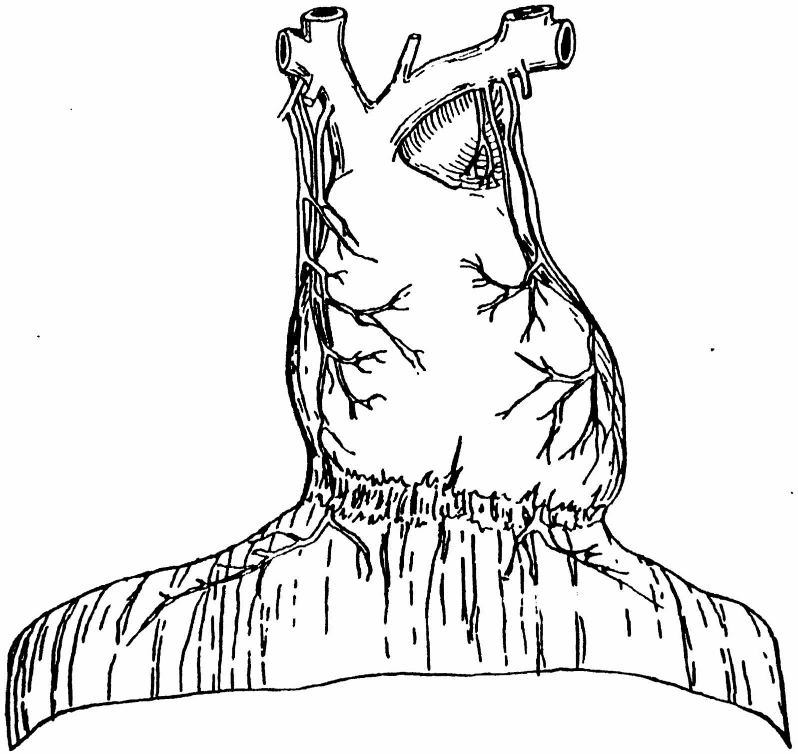
TEST NO. ______________

Left Side View of Pericardium and Diaphragm



Diaphragmatic View of Heart



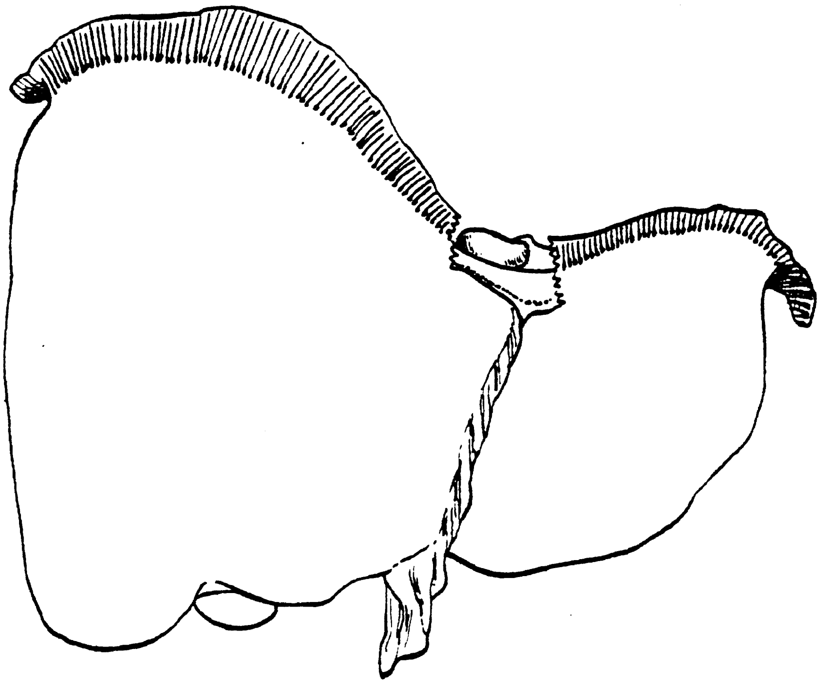


Anterior View of Pericardium and Diaphragm

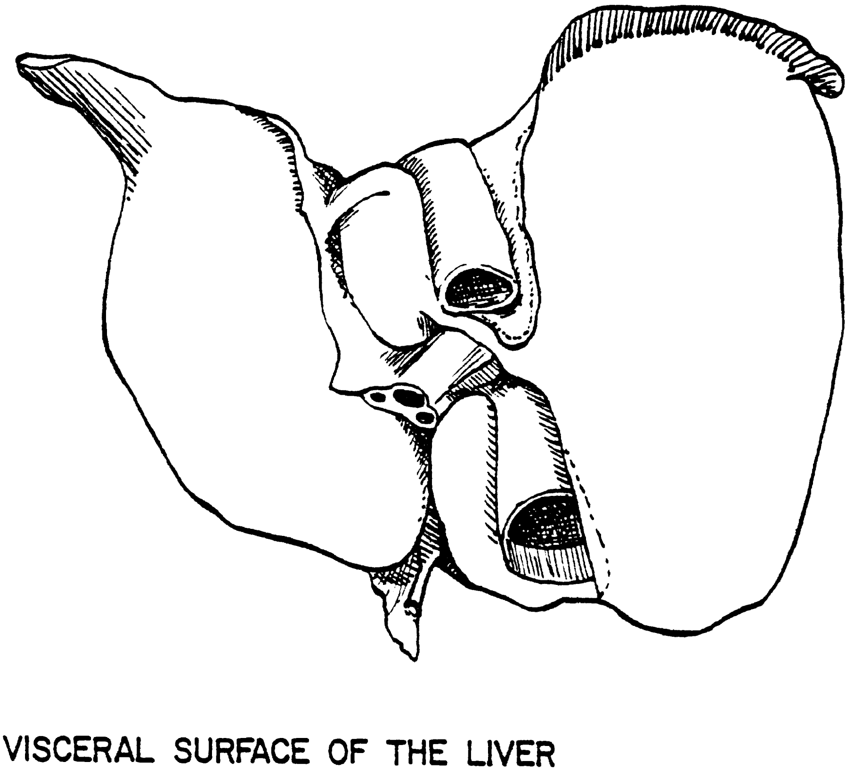
A89

LIVER IMPACT AUTOPSY SUMMARY

ST NO. ________________



SUPERIOR SURFACE OF THE LIVER

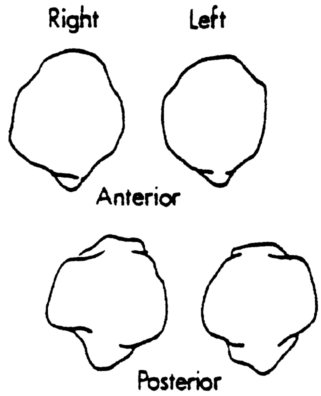


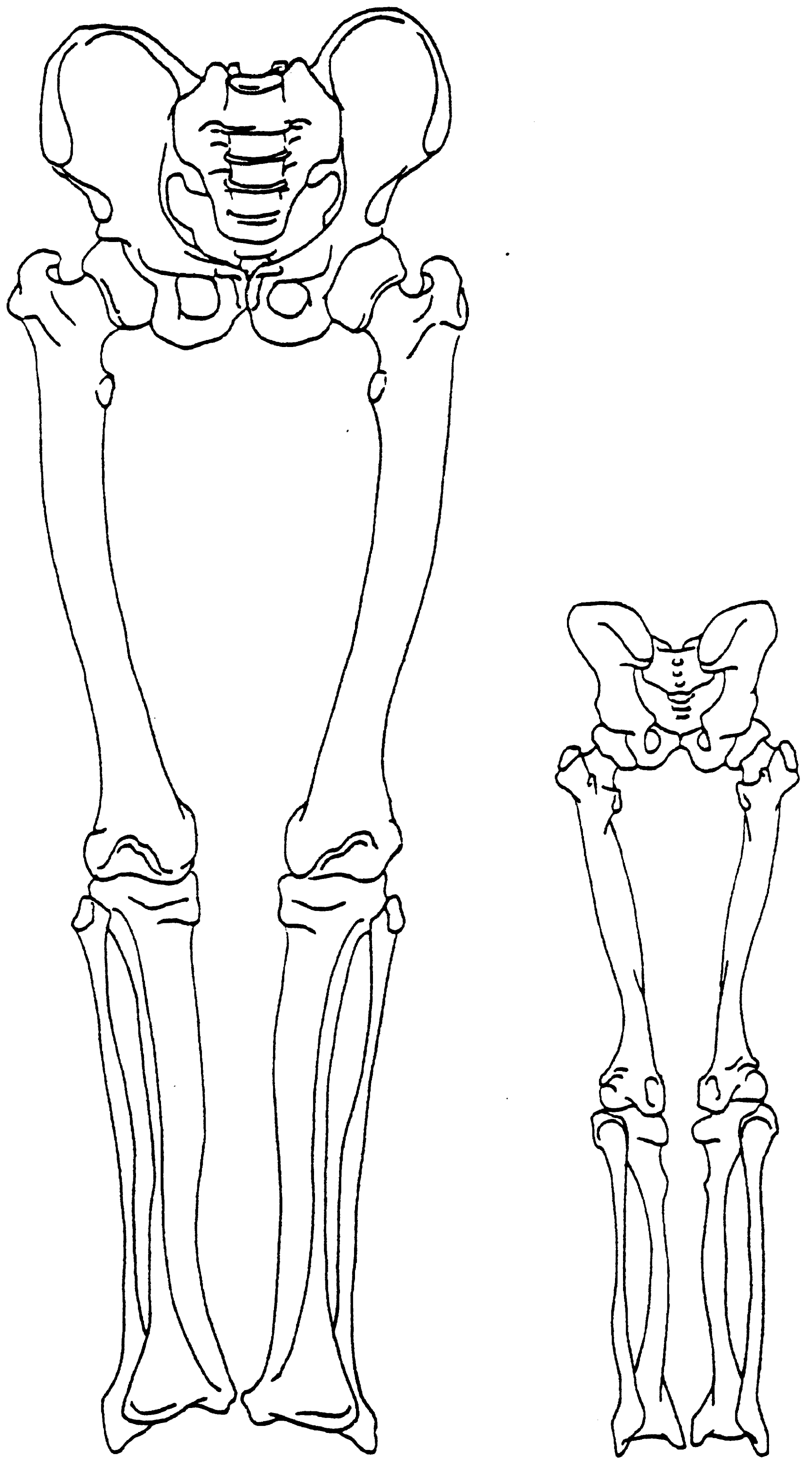
VISCERAL SURFACE OF THE LIVER

TEST NO. ____________________

DATE ________________________

PATELLA

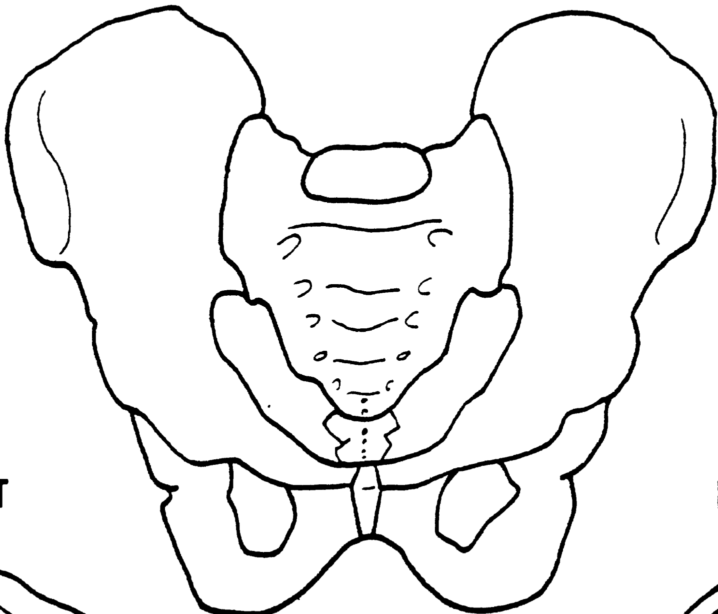




Anterior Posterior

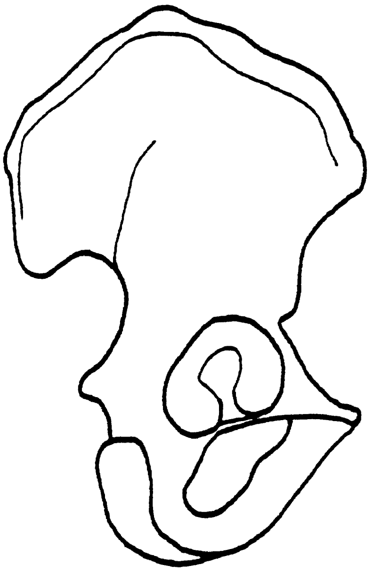
LOWER EXTREMITIES

TEST NO. ____________________

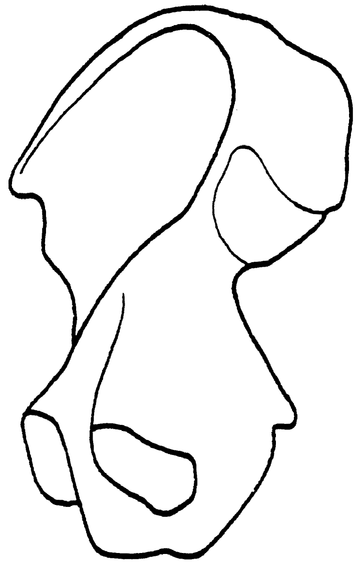


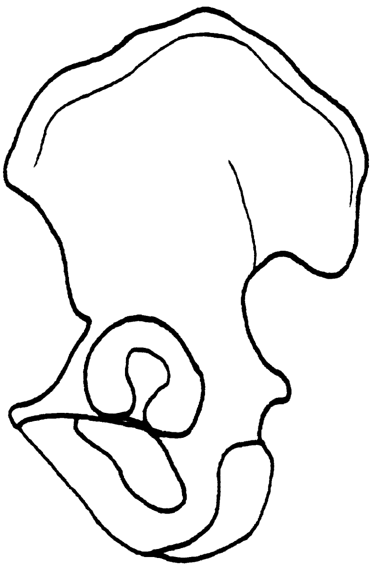
OUTER ASPECT

INNER ASPECT

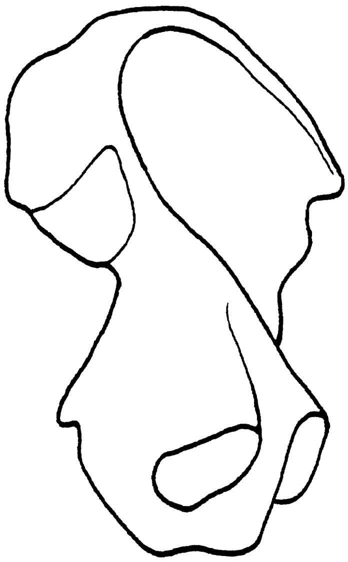


RIGHT ILIUM

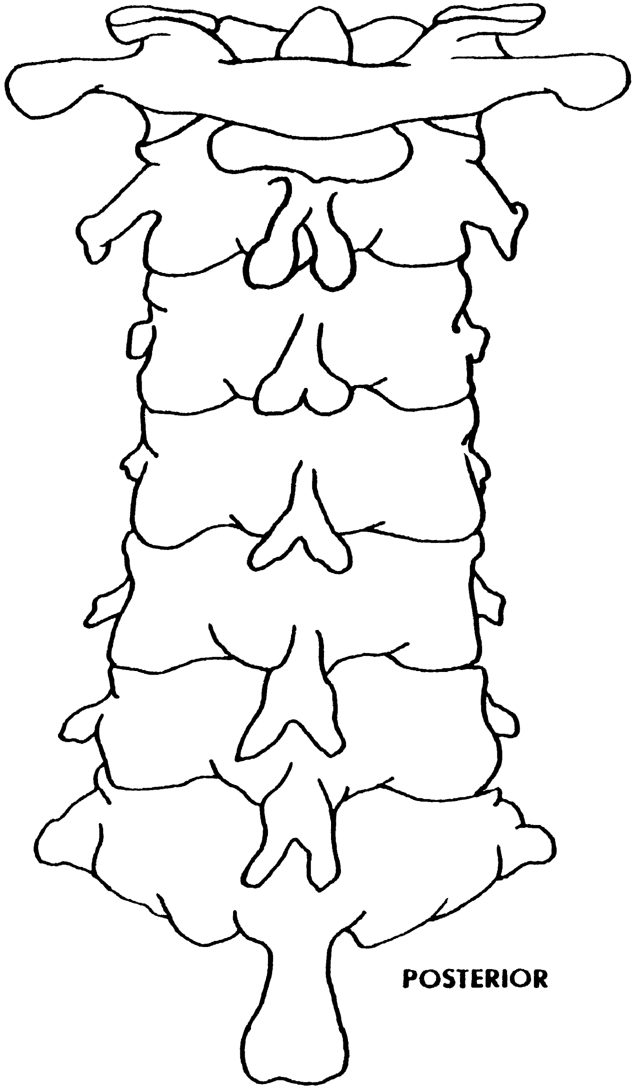




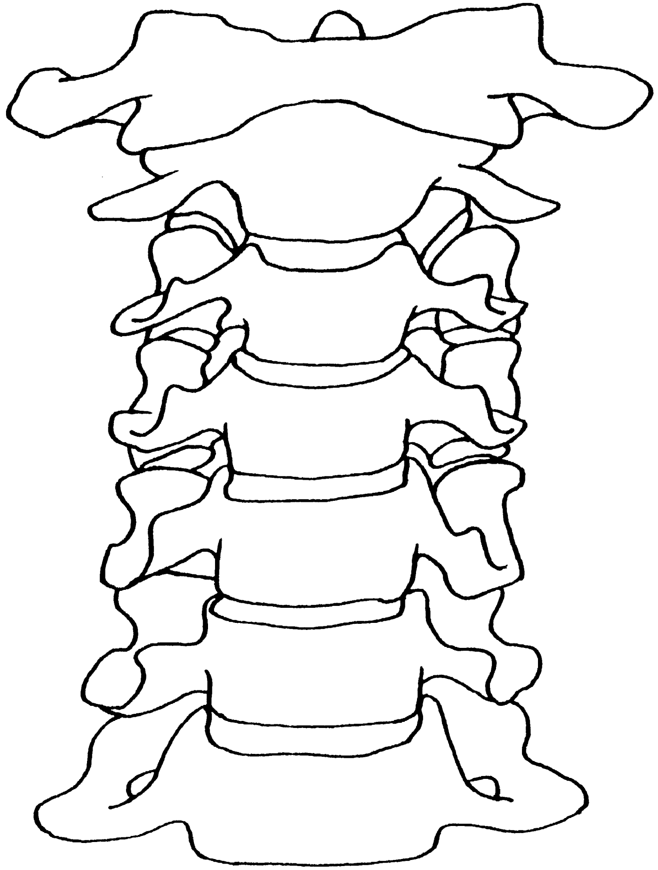
LEFT ILIUM



TEST NO. ____________________



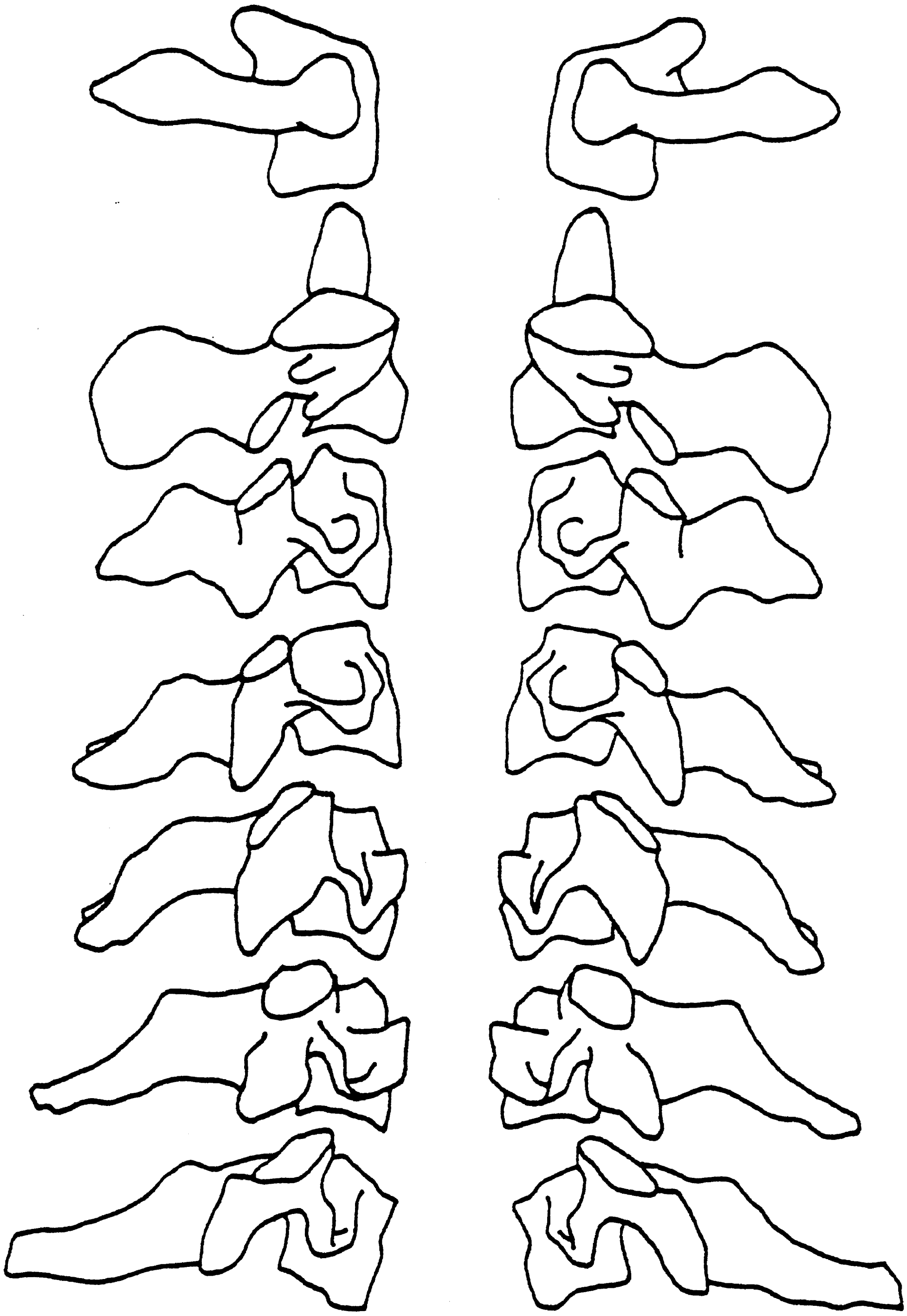
POSTERIOR



ANTERIOR

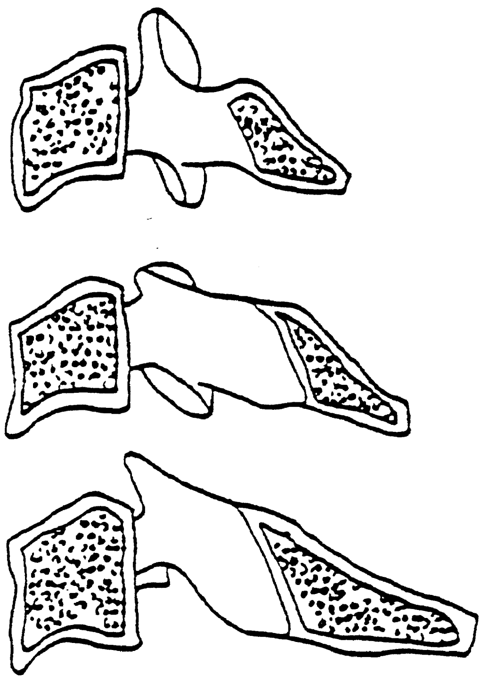
CERVICAL VERTEBRAE

TEST NO. ______________



Right Profile Left Profile

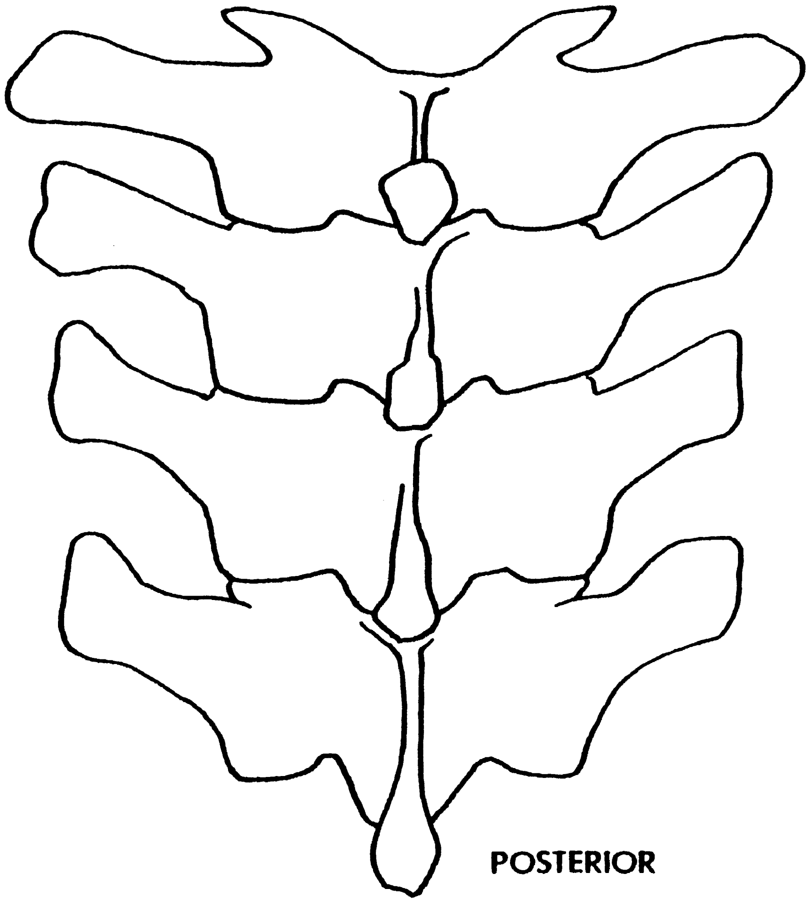
TEST NO. ___________



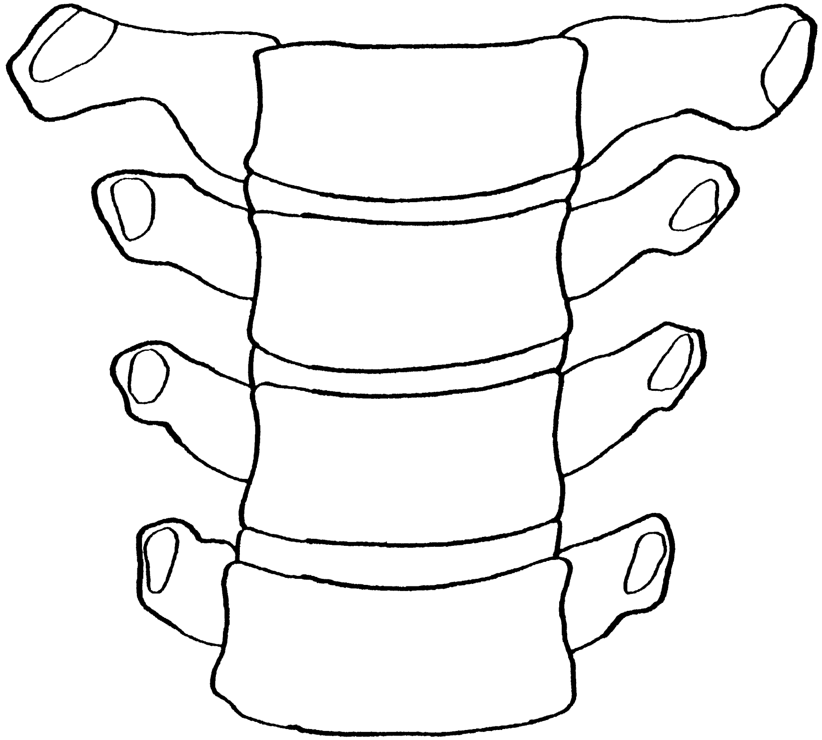
Cross Section

TEST NO. ____________________

THORACIC VERTEBRAE (T1 - T4)



POSTERIOR

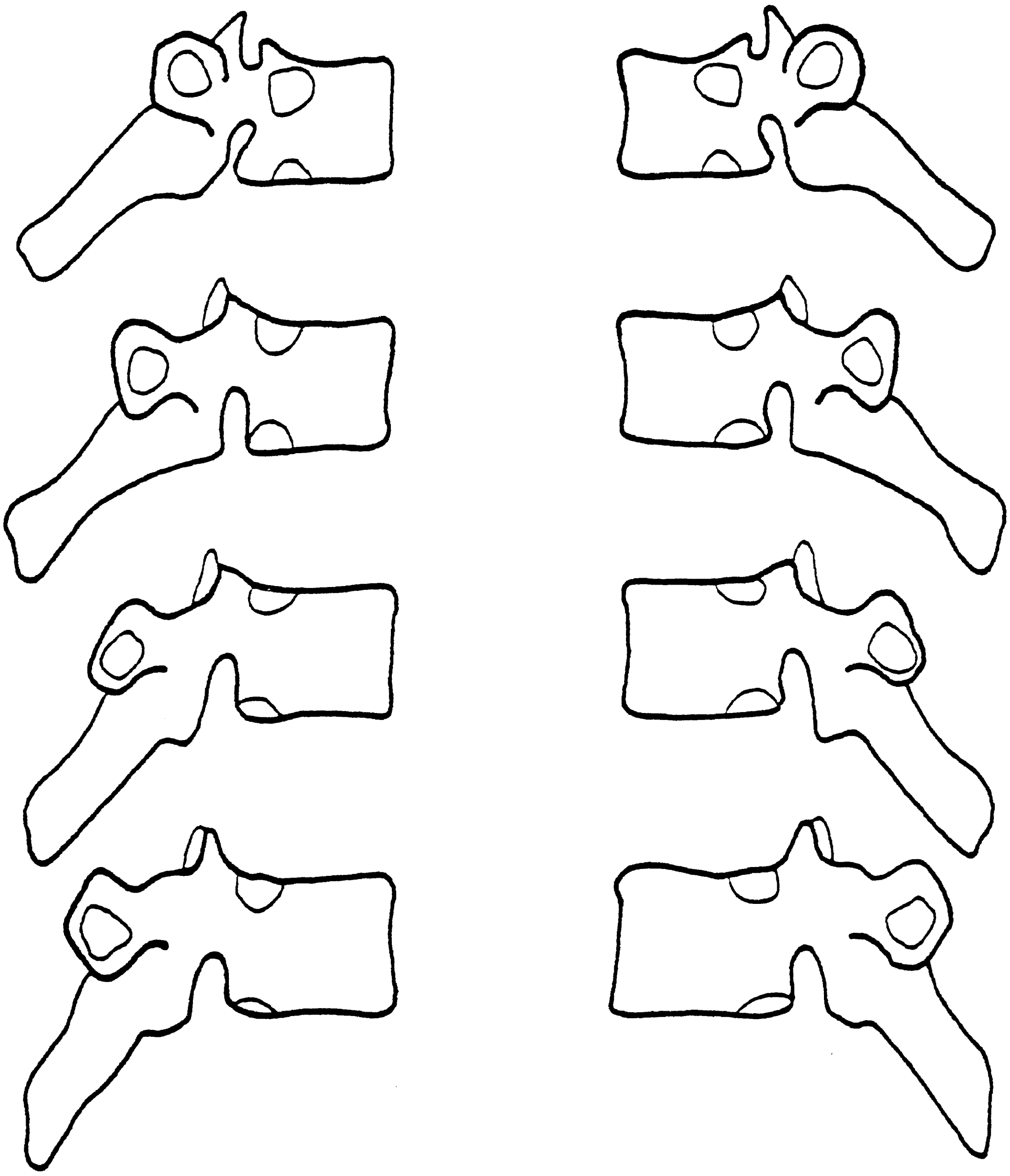


ANTERIOR

A96

TEST NO. ________________

THORACIC VERTEBRAE (T1 - T4)



RIGHT PROFILE

LEFT PROFILE

APPENDICES

MEASUREMENT

___ Anthropometer

___ Metric measuring tape

PAPER AND PLASTICS

___ Visqueen on autopsy table

___ Blue pads on table

___ Gauze

TAPES AND STRINGS

___ Silver tape

___ Masking tape

___ Adhesive tape

___ Fiber tape

___ Flat waxed string

SCALPELS

___ 2 large (#8) handles

___ 2 medium (#4) handles

___ 2 small (#3) handles

___ 2 #60 blades

___ 5 #22 blades

___ 5 #15 blades

___ 2 #12 blades

FORCEPS

___ 2 hooked

___ 2 large plain

___ 2 small plain

HEMOSTATS

___ needle

___ small straight

___ small curved

___ large straight

___ large curved

SCISSORS

___ 2 small

___ 2 medium

___ 2 large

SPREADERS

___ 2 large

___ 2 medium

NEEDLES

___ 2 double curved

___ 8 Trocar with stainless steel lockwire

___ 2 5cc sringes

CLOTHING

___ Tampons

___ Thermoknit longjohns and top

___ Cotton socks

___ Blue vinyl pants and top

___ Head and body harnesses

PRESSURIZATION

___ Modified Foley (#18 or #20) balloon catheters

___ Kulite shield

___ Tracheal tube

___ Right and left carotid pressurization catheters (Foley #10-14)

___ Cerebral spinal catheter (Foley #14-16)

___ Respiratory pressure tank

___ Manometer

___ Fluid pressure tank

___ 7% saline solution with India ink

BOLTS AND SCREWS

___ 6 self-tapping lag bolts

___ 3 lengths of wood screws

___ 1-72 screws

___ 10-32 tap

___ Strain relief bolt

___ Wood and metal self-tapping screw boxes

MOUNTS

___ Spine(2)

___ Rib (2, triax)

___ Rib (2, uniax, R-L)

___ Nine-accelerometer plates (large, small, and 8 feet)

___ Sternum

___ Substernale

___ Suprasternale (triax)

___ Dental acrylic

___ Bone wax

TOOLS

___ Electric hair clippers

___ Electric drill

___ Drill bits (No. 7, approx. 1/16", etc.)

___ large and small screwdrivers

___ nut driver (for lag bolts)

___ wire twisters

___ bone shears

___ Executive Slinky object space calibrated and nearly functional

MATERIALS

___ balsa wood

___ rags

___ foam (at least 2 sheets of 3x4 ft 6")

___ Ensolite

___ Styrofoam

___ Dow Ethafoam

___ Overhead support bar

ROPE CUTTERS

___ head, 1/8"

___ pendulum (with spring, 3/16")

___ nylon strings (10 24" 3/16"; 10 18" 1/8")

___ shock absorber and styrofoam bumper

WEIGHTS

___ steel blocks on pendulum

MISCELLANEOUS

___ calculator

___ bone wax

___ Pressurization equipment (pulmonary, thoracic arterial, head arterial, cerebral spinal)

___ Timer box

___ Strobes

___ Head impact back brace and foam padding

TAPES

___ adhesive

___ fiber

___ silver

___ masking

___ black

___ double stick

PAPER AND PLASTIC

___ blue pads

___ gauze

___ gloves

___ plastic garbage bags

SCALPELS

___ 1 medium (#4) handle

___ 1 small (#3) handle

___ 2 #22 blades

___ 2 #15 blades

___ 1 #12 blade

SURGICAL TOOLS

___ 2 forceps

___ 2 hemostats

___ large scissors

___ 2 double curved needles

STRING

___ flat waxed string

___ black thread

TOOLS

- ___ small (1-72) screwdriver
- ___ large screwdriver
- ___ nut driver
- ___ ball driver (6-32, 0-80)
- ___ 1-72 screws
- ___ 2-56 screws
- ___ 0-80 screws
- ___ wiretwisters

MISCELLANEOUS

- ___ ball targets
- ___ paper targets
- ___ bone wax
- ___ vaseline
- ___ Q-tips
- ___ tubing connectors
- ___ tie wraps
- ___ lockwire
- ___ 50cc syringe
- ___ pulmonary pressurization relief valves

AUTOPSY SETUP

PAPER AND PLASTICS

___ Visqueen on autopsy table

___ blue pads

___ gauze

TAPE

___ silver tape

___ masking tape

___ fiber tape

SCALPELS

___ 2 large (#8) handles

___ 2 medium (#4) handles

___ 2 small (#3) handles

___ 2 #60 blades

___ 5 #22 blades

___ 5 #15 blades

___ 2 #12 blades

FORCEPS

___ 2 hooked

___ 2 large plain

___ 2 small plain

HEMOSTATS

___ needle

___ small straight

___ small curved

___ large straight

___ large curved

SCISSORS

___ 2 small

___ 2 medium

___ 2 large

SPREADERS

___ 3 medium

___ 3 large

MISCELLANEOUS

___ Stryker saw and blade

___ bone shears

___ wedge

___ rib cutters

TIMER BOX SETUP

EQUIPMENT __________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0012-y	1	0150
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	2200-x*	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	1 + Z	8	0050-0150

* x obtained from elliptic integral of the first kind. For 100° .87 sec, 20 ° .70 sec. y=angle/20 Z=210/angle

PENDULUM WEIRDNESS

Average	60.84	61.00	61.26	61.56
Standard Deviation	±.28	±.37	±.05	±.23
Period	3.042	3.050	3.063	3.078
(MGL/I)‡2	2.065	2.060	2.051	2.041
t/2pi	.484	.485	.487	.489