1958

The application of certain methods for the determination of the presence of pain in the dog during decompression

Russell Levoy Schelkopf
Iowa State College

THE APPLICATION OF CERTAIN METHODS FOR THE DETERMINATION OF THE PRESENCE OF PAIN IN THE DOG DURING DECOMPRESSION

by

Russell Levoy Schelkopf

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Major Subject: Veterinary Physiology

Approved:

Signature was redacted for privacy.
In Charge of Major Work

Signature was redacted for privacy.
Head of Major Department

Signature was redacted for privacy.
Dean of Graduate College

Iowa State College
1958

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The destruction of animals, whether the object in view be due to the advancing age or the prevention of further suffering caused by disease or accident, is an operation which is repugnant to the operator and essential in the public interest. It is not to be denied that when the time arrives that pets need to be put painlessly out of existence, they are entitled to receive in this last humane service the same high standard of care and attention which they generally receive during life. The views on which is the most humane method of euthanasia are extremely varied.

Decompression is a method of euthanasia which simulates high altitude conditions and produces a decrease in oxygen tension and a state of anoxia. Cerebral anoxemia results in unconsciousness and death of the animal. The decompression of small animals as a method of euthanasia has found extensive use in certain areas of the United States. The Humane Society of Los Angeles, Calif., destroys approximately fifty dogs a day by decompression. This method of euthanasia is now in use in New York City, N. Y.; Chicago, Ill.; San Francisco, Calif.; Brentwood, Mo.; Fort Wayne, Ind.; Bakersfield, Calif.; Los Angeles, Calif.; Tacoma, Wash.; Denver, Colo.; Palo Alta, Calif.; Santa Rosa, Calif.; and Pomona, Calif. Many other cities are contemplating its use. Workers using the Euthanair, decompression system of euthanasia, feel that it has the

advantages of being cleaner, safer, not dangerous to the personnel, more humane than other methods of euthanasia, and requires less skill to operate.

The originators[1] of high altitude euthanasia for small animals installed a decompression apparatus (Euthanair) in the Veterinary Physiology and Pharmacology Department at Iowa State College in the spring of 1955 for purposes of experimental research. Since several humane societies use this method of euthanasia, it would seem of widespread interest to know if pain is experienced during decompression. To accurately obtain this information it is essential to determine the pain reaction threshold in an experimental animal. The pain reaction threshold is defined as the least amount of a quantitatively measurable stimulus necessary to evoke a pain reaction. A literature survey reveals a paucity of research on pain reaction thresholds in the animal and nearly its complete absence with the canine as the experimental subject.

The purpose of this preliminary investigation was to determine if pain is perceived during decompression. Various methods of determining pain reaction thresholds in the dog were investigated. A surgical experiment was designed to completely alleviate the sensation of pain by the animal except from

---

[1]Euthanair Engineering and Sales Company, 5156 Southridge Avenue, Los Angeles 43, California.

those structures supplied by certain cranial nerves. The amount of anxiety and apprehension during decompression was observed before and after the surgical operation. The effect of morphine on the pain reaction thresholds was recorded. Observations on the excitement and anxiety observed during decompression were recorded before and after morphine administration to the dog. Movies were taken during decompression of the experimental animals for detailed study.

LITERATURE CITED

Research by Woollard *et al.* (82) in 1940 revealed that pain is a specific sensory experience mediated through nerve structures which are separate from those which mediate other sensations such as touch, pressure, heat, and cold. Painful impulses are received at ramifying naked nerve terminals scattered throughout the skin, subcutaneous structures and viscera which are specific for that sensation (67, 70, 82). Investigators (21, 74) have found that painful impulses are carried through myelinated and nonmyelinated fibers of variable sizes either directly to the posterior root ganglia in somatic nerves or indirectly in sympathetic trunks.

In 1941 Wolf and Hardy (77) found that nerves which subserve pain continue to conduct the sensation as long as the stimulus is applied. Thus, for painful stimuli, no true adaptation occurs as it does for touch. These workers mention that there may be apparent adaptation when, during prolonged stimulation, the local situation in the painful part is altered so that the mechanism for pain is interrupted. Wolff and Wolf (81) point out that the intensity of two pains existing separately at the same time is no greater than that of the more intense of the two. The existence of one pain actually raises the threshold for perception of another.

The methods which have been employed in algesimetric studies have been classified by Goetzl *et al.* (23) in 1943

as mechanical, thermal, chemical and electrical, depending upon the nature of the stimulus. Valuable work has been done with mechanical, chemical and electrical methods for evoking pain, but these techniques do not combine the flexibility and precision equal to that of the thermal methods (28).

Thermal Stimulation as a Method for Studying Pain Threshold

Thermal methods of evoking pain are among the oldest and were first reported by Goldscheider (24) in 1884. One of the early attempts to measure pain threshold by the application of a hot object to the skin was the method of Elo and Nikula (18) in 1910. A thermometer was used, the bulb of which was flattened to a surface of about 0.5 $cm.^2$. Just above this flattened end the bulb was covered with insulating wire connected with resistances and a source of electrical energy. Any desired temperature could be obtained and easily read from the thermometer itself. The temperature at which pain was elicited was called the pain threshold.

The adaptation to pain from radiant heat was studied by Stone and Dallenbach (66) in 1934. They shaved the skin on the dorsal surface of the forearm and stimulated this area with thermal radiation. The intensity of the stimulus was not measured because these authors were not primarily concerned with measurements of pain threshold.

In 1936 Oppel and Hardy (50), who demonstrated that the radiation technique could be applied quantitatively to the study of temperature sense, adapted this method to measuring the intensity of the thermal stimulus required to elicit a painful sensation in the skin. This new method for measuring pain threshold was first described by Hardy, Wolff and Goodell (29) in 1940. These investigators revealed a quantitative method for measuring pain thresholds in the skin by thermal radiation and this method has the general advantage of measuring a physical quantity which is directly proportional to the changes occurring in the skin. Further advantages of the method were the simplicity of the technique, rapidity of measurement, and that any part of the skin surface could be studied and the size of the stimulated area could be varied at will.

The authors were used as subjects and it was found that intense pain in any part of the body, raised the pain threshold in the skin of other parts as much as 35 per cent. The intensity of radiation which produced blistering in 3 seconds was observed to be twice that necessary for the bare perception of pain. The pain thresholds measured did not vary consistently with the time of day, with the general effectiveness, or the emotional state of the three subjects tested. Individual threshold measurements for the three authors were 0.229, 0.231 and 0.233 gm. cal/sec./cm.^{2} [1] and all measurements

[1] Gram calories per second per square centimeter.

were found to be within ± 12 per cent of their respective average values. The standard deviation for a single measurement was calculated to be ± 2 per cent. The apparatus for measuring the pain threshold was described in detail.

D'Amour and Smith (12) in 1941 described a rapid method for determining the pain threshold in the rat. A thermal technique was used and the apparatus used in eliciting pain included a 6 to 8 volt bulb, voltage regulator, transformer, rheostat and stop watch. The rays from the bulb were focused on the tip of the rat's tail which was placed in a grooved board. The response to pain was a sudden, typical twitch of the tail. After a few trials it was found that a stimulus of light intensity which produced a reaction in about 5 seconds was most convenient.

Some 10,000 individual tests were made on several hundred rats. Little individual variation was observed. The method was applied to the assay of the analgesic properties of several drugs. A comparative assay of five opiates gave results in good agreement with clinical observations.

Pain threshold measurements with the thermal technique in the dog were reported by Andrews and Workman (1) in 1941. The standard Hardy-Wolff (29) apparatus having a variable intensity light source and a fixed 3 second exposure apparatus was used. Two adult female dogs were used as the subjects. The hair was clipped closely over the mid-dorsum at the thoraco-

lumbar region and this spot was thoroughly blackened with India ink.

Attempts to record a galvanic skin reflex in the dog were not successful, but the investigators found that there was a characteristic reflex twitch of the musculature of the back whenever a definite level of stimulation was exceeded. The twitch was not confined to the site of stimulation, but included a rather large surrounding area. The analgesic action of 3 opiates was tested. The authors found the intensity of the stimulus required to evoke a response is constant to just about the same degree as in man.

Wolf and Hardy (77) in 1941 found that pain is entirely separate from and independent of the sensation of cold. They report that pain does not show the phenomenon of spatial summation and that the highest bath temperature in which pain can be obtained is 18°C. The blood pressure raising effect is proportional both to the intensity of pain experienced and to the degree of cold. Their work revealed that sympathectomy was found to augment the intensity of pain derived from cold. Evidence is presented which indicates that the elevation of blood pressure which results from immersion of a part in cold water is a measure of the subject's reaction to "cold pain".

The discrimination of differences in intensity of a painful stimulus as a basis of a scale of pain intensity was reported on by Hardy et al. (30) in 1947. They mention that

the effective range of this stimulus is limited by the pain threshold and pain of maximal intensity. The authors found that pain induced in the skin by thermal radiation has a ceiling intensity and this ceiling pain was produced on the forearm in man by a stimulus intensity of 680 millical./sec./cm.^{2} in a 3 second exposure. Twenty-one discriminate intensities of pain were observed between the threshold pain and the ceiling pain. The workers presented a scale of pain intensity, the unit of which is called a "dol". A dol is composed of two perceptible steps in discrimination of stimulus intensity. The investigators used a modified Hardy-Wolff-Goodell pain threshold apparatus as a stimulator.

In 1948 Hardy et al. (25) used a three second exposure of thermal radiation on the skin as a painful stimulus. Measurements were made of the stimulus intensities which evoke painful sensations of various relative magnitudes. The authors performed three series of experiments, in the first of which three experienced observers reported the relative intensities of pain in terms of fractions of an eight-dol pain. In the second series of experiments 70 medical students were similarly studied. In a third series of experiments the effects of fatigue and minor mood changes upon discriminations of relative intensity of pain were studied.

These investigators found that moderate fatigue and day to day variations in mood were not associated with an appreciable change in the ability to estimate pain intensity. The

accuracy of estimating pain intensity is limited by the ability of the individual to discriminate differences in pain intensity. They found this limit is plus or minus one-half dol.

They found that the dol scale provides a numerical scale of sensory steps all of which are equal. It affords a basis for the intercomparison of other methods of estimating pain intensity, providing these estimates have been made in terms of a reproducible pain.

In 1948 Lloyd-Smith and Mendelssohn (44) studied the "tolerance limit" of the human skin to radiant heat by exposing areas of skin measuring 12 x 12 cm. over the epigastrium and interscapular region on human subjects to radiation from a 1000 watt tungsten filament bulb set in a concave mirror. The "tolerance limit" was defined as "the maximal amount of radiant heat that could be tolerated with comfort and without hazard of burn". They devised a skin thermometer of fine copper and constantan wires threaded through a hypodermic needle and soldered together at the tip to form a thermojunction. It was found that at a skin temperature of 44.6°C there is a sharp and well defined transition from a sensation of heat to one of burning or sharp prick. These authors estimated that human skin could tolerate approximately 2.5 gm. cal./cm.^{2}/min.

Another method of evoking pain was devised by Wolf and Hardy (77) whereby they used lowered tissue temperature to

induce pain. The subject's hand was immersed in cold water and threshold aching pain was induced at a temperature of 18°C. In 1951 Boring (4) introduced hot and cold water in the alimentary canal, thereby evoking pain. His studies were not particularly concerned with the measurement of pain threshold.

In 1949 Hardy and Javert (26) reported on the measurement of pain intensity in childbirth by using the dolorimeter (30). Four hundred test readings, resulting in 55 measurements of pain intensity, were made on 13 patients during the first, second and fourth stages of labor without analgesia. The measurements were made by comparison of the labor pains with a pain of standard intensity which was produced by a three second exposure to thermal radiation on the dorsal surface of the right hand. The pain evoked on the hand had been previously standardized into ten and one half units of painfulness between the threshold pain and the most intense pain which can be experienced. The intensity of the pain experienced by the patient could not always be evaluated on the basis of her reaction, nor correlated with her apparent distress.

Haugen and Livingston (34) in 1953 reported on a study of the dolorimeter to determine whether or not it could be used to measure pain in clinical patients. It was concluded that the inexperience of such subjects in the testing method

would introduce new variables that would be difficult to evaluate. They reported that tests above threshold values tend to sensitize the skin. In clinical testing of patients, such sensitization would be difficult to avoid when grading pain intensities. They felt that the dolorimeter may be useful in the hands of experts in evaluating the relative efficacy of analgesic drugs, but they doubted that the "dol" scale will prove of practical value in measuring pain in the clinic.

A statistical analysis was made by Winder (76) of radiant thermal stimulus energies (lamp wattage) required for eliciting the nociceptive contraction of the musculus cutaneous maximus of the guinea pig. The data consisted of three successive readings at 20 minute intervals on 365 animals. The distribution of thresholds among animals was approximately normal without transformation. This finding was more inferentially related to the greater absolute variability among animals than that within animals. Without significant influence on the thresholds were: elapse of as many as 74 days of observation, time of day, shade of skin color, body weight, and/or age within the range studied, and sex.

In 1957, Hardy et al. (27) reported on the responses of the rat to thermal radiation. These authors also presented data on the thermal properties of the rat's skin below the burn level which could be used for test purposes. Two types

of reaction thresholds were reported: the twitching of the skin and a retraction of the entire body. The end points for the reactions were quite clear cut for stimuli between 100 and 250 mc./sec./cm.^{2} [1].

Electrical Methods of Evoking Pain as a Mean for Studying Pain Threshold

As early as 1908 Martin *et al.* (46) studied sensation in humans by the method of faradic stimulation. These investigators observed a diurnal rhythmic variation in the level of the sensory threshold for faradic stimulation. Goetzl and his associates (23) in 1943 point out that electrical stimuli have been used in algesimetric studies in form of galvanic, faradic, high frequency currents or condenser discharges. Such stimuli are measurable in terms of volts or amperes in divisions as small as is practical. They mention that the electrical method of stimulation appears to be highly flexible, and capable of accurate timing and measurement.

Extensive quantitative studies of the pain threshold in rats after the administration of various analgesic agents were reported by Macht and Macht (45) in 1940. These observers applied faradic stimulation from a standardized induction coil to sensitive areas of the scrotum of tame adult male

---

[1] Millicalories per second per square centimeter.

rats, and measured the minimal energy required to elicit a painful squeal. In one of their series of 20 rats the voltage required to elicit threshold pain varied from 100 to 445 volts.

Weitz (71) in 1942 conducted experiments revealing the effect of skin temperature on pain thresholds. He used single break shocks from a Harvard inductorium on the arms and measured the intensity of stimuli in terms of the position of the secondary coil.

A method of ascertaining pain thresholds by applying an electric current through a metal filling in a tooth and noting the voltage at which the subject first experienced a painful sensation was first described by Goetzl et al. (23) in 1943. It was found that a sensation of pain was the only definite sensation that could be produced in a tooth by this stimulus. At each determination, the pain threshold value accepted for the subject was the lowest voltage which produced a painful sensation three times in succession. The authors did not report numerical measurements of pain threshold in their subjects.

This method was also adapted to the study of effects of noxious stimulation in dogs. Two silver amalgam pit fillings were placed in each cuspid tooth in opposite positions so that pincer like electrodes would engage pits in the two fillings. The electrodes had platinum points. The cavities for the fillings were cut as deeply as possible without opening into

the pulp chamber. The first distinctly perceptible twitch of an isolated muscle or group of muscles was regarded as the standard pain threshold response. In a group of 5 dogs observed over a period of 16 weeks the authors reported an average threshold of 1.09 volts with an average deviation of plus or minus 0.14 volts. The workers also describe the apparatus used for measuring the pain threshold.

Thresholds of the tooth were determined in the human by stimulation of the pulp, through a metal filling, with an induced, highly damped sinusoidal current by Sonnenschein and his associates (63) in 1950. The instrument, calibrated from 0 to 4.2 volts in steps of 0.2 volt, delivered impulses at approximately one per second. The intensities of current, measured to the closest 0.05 volt, for the production of two end points were determined. The authors were interested in studying the analgesic effect of tetra-ethyl-ammonium chloride in man.

In 1950 Harris and Brandel (32) analyzed and discussed the results of an experiment using the tooth pulp of the human as the receptive site and 60 cycle induced current as a painful stimulus. Their algesimeter was a modification of one described by Goetzl et al. (23). In their instrument, the primary coil rotated through a fixed path while the secondary was in a fixed position. The current was varied from 0 to 250 microamperes by the inclusion in the circuit of a 250 ohm

potentiometer. The dial of the potentiometer was calibrated in centivolts (0.01 v.). Four control threshold determinations were made at five minute intervals. The authors found that there were very significant differences between the thresholds of subjects and the thresholds of the two teeth in the same head. Also a significant difference was found between the thresholds of teeth on different days. There was no significant difference between the thresholds obtained at five minute intervals on the same tooth.

An effort was made by Harris and Blockus (31) to evaluate quantitatively the reliability and validity of electrical excitation of the human tooth pulp as an algesimetric method. Only filled teeth were studied and uncontrolled current loss was reduced by careful drying of the teeth. The 117 volt house current was stabilized through a 110 volt, constant voltage transformer, then passed through 1600 ohms of fixed resistance to a 200 ohm, 200 watt, linear taper potentiometer. From the potentiometer, current flows through the primary of a 110:5000 volt, neon tube transformer. Each lead from the secondary passes through a 1 megohm carbon resistor to the subject.

Mechanical variations were rigorously controlled and the influence of suggestion was carefully evaluated and found to be significant after oral medication. Evidence of reliability was obtained by finding that no significant differences oc-

curred between the thresholds of experimentally induced pain when measured in 28 teeth, three times in immediate succession; and when 2 teeth were studied in each of 9 men, the changes in threshold which occurred after injection of 65 mgm. of codeine correlated very significantly in 4 of the subjects. The stability of the threshold was studied and found to decline significantly in two hours.

In 1954 Harris and Worley (33) elicited pain in the human tooth by electrical stimulation of the tooth pulp in 15 subjects. The stimulator used was described and the pain threshold varied from 1590 to 1641 mv.

Robertson and his associates (59) in 1947 studied the distribution and mechanism of headache and other pain in the face and head, which resulted from noxious stimulation of the teeth. Using an adaptation of the method of Goetzl et al. (23) as described by Ziskin and Wald (84), they ascertained pain thresholds in the teeth of four subjects. Considerable variation in the pain threshold could be observed from tooth to tooth and at various sites on the same tooth.

A method for effectively stimulating single sensory receptors in human skin, without mechanically deforming the skin was described by Bishop (3) in 1943. He used repetitive electric sparks applied to the skin and adjusted the strength to give threshold prick sensation. Such a stimulus excited touch endings at many points, which sensation could be readily

differentiated from prick. In general, prick had a lower electrical threshold than touch. The author does not report on quantitative measurements of pain thresholds in any units of stimulus.

Mechanical Methods of Inducing Pain as a Method for Studying Pain Threshold

Lacey et al. (41) and Pelner (54) have related the amount of pressure and the pain threshold by the use of mechanical devices for production of pain by pressure. The von Frey hair stimulator adapted for the study of pain has been discussed in detail by Kiesow (39). With sharp bristles attached to the ends of hairs he tested skin areas for pain sensation. He demonstrated that the pain threshold determined with pressure on the skin by fine hair is lower than the touch threshold.

An investigation by Gaensler (20) in 1951 revealed a quantitative method for measuring visceral pain thresholds by hydrostatic distention of the biliary ducts. The painful sensation elicited by external elevation of the intrabiliary pressure was described as sharp or "colicky" by 47 per cent of the patients. The initial pain threshold in different patients varied from 90 to 800 mm. of water. The administration of analgesic substances invariably resulted in an elevation of the visceral pain threshold.

The author reports that differences between visceral pain occurred earlier than for superficial pain. The duration of action was shorter and the intensity of the analgesia was somewhat smaller for visceral pain.

The effect of tissue temperature on the pain threshold as measured with a percussion type of algesimeter was demonstrated in 1947 by Wells (72). A metal rod weighing 12.5 gm. was dropped from varying heights onto the dorsum of a finger held firmly in a groove cut into a large cork stopper. Pain threshold was expressed in terms of the height from which the metal rod had to be dropped to first produce pain. The threshold were observed to be lowered when the finger temperature at 36°C was either increased or decreased.

Chapman et al. (9) describes a method of inducing pain in the esophagus, bile duct and gastrointestinal tract by mechanical distension. The apparatus consisted of a rubber balloon about 3 cm. long attached by a stomach tube to a U-shaped water manometer. The balloon was introduced through the nose and secured in a position from 5 to 10 cm. above the cardiac end of the esophagus. Air is passed into the balloon by a syringe at a rate of rise of water pressure of 2 cm. per second.

A report by Chapman and Jones (10) revealed the conduction of visceral sensory threshold measurements on 29 normal subjects. Values ranged from a level of 15 cm. of water

pressure for the most sensitive subject, to 89 cm. for the least sensitive.

In 1934 Libman (43) in attempting a rough estimate of pain sensitivity grouped individuals according to their reports of pain experienced, as having 0, 1 plus and 3 plus pain sensitivity. The test consisted of pressing the thumb against the tip of the mastoid bone and the index finger against the styloid process. A "dolorimeter" was devised by Gluzek (22) in 1944 to measure pain threshold on the flat surface of the middle third of the tibia. With the subject's leg placed on a leg rest, a plunger surrounded by a metal sleeve ending in a rubber ring was rested lightly against the tibia and fixed in position by adjusting a screw. Air is pumped through a gauge into the sleeve cylinder, which forced the plunger against the tibia. Pain threshold is estimated as the amount of air pressure which first elicited pain by this force.

Chemical Stimulation as a Method for Studying Pain Threshold

A literature review reveals that little of a quantitative nature has been done using injurious chemicals to evoke pain. In regard to what has been done Goetzl et al. (23) points out that the substance to be tested is applied to the intact or injured skin or mucous membrane and the time which elapses between the application and the occurrence of a response is measured. Such measurements of the intensity of the stimulus have proved to be insufficiently refined. The intensity of chem-

ical stimuli can hardly be varied by satisfactorily small measurable differences. Chemical stimuli do not reach the peak of their intensity instantaneously and cannot be of constant intensity for the duration of stimulation because of continuous chemical interaction between the irritant and the tissues. The authors mention that it is yet uncertain whether any chemicals are capable of stimulating selectively pain receptive organs. Chemical irritants do cause tissue changes and the intensity of stimulation cannot be reproduced on different occasions.

Palmer (51) mentions that the application of a chemical to a peptic ulcer will evoke pain, but no attempt was made to measure the pain threshold. Revici and Ravich (58) in 1949 conducted studies of the pain from gastric ulcers as affected by the concentration of acid in the stomach. McAuliffe and associates (47) found that cotton tampons, soaked with adrenaline solution and inserted along the turbinates for the purpose of shrinking tissues in order to gain access to the sinuses, induced local and referred pain.

Rosenthal (60) reported on the application of corrosive mixtures onto and into the skin to elicit pain. Research by Simons et al. (62) reveals that pain can be elicited by intramuscular injection of hypertonic saline. There is no quantitative chemical method available at present for the study of pain threshold or pain intensity (28).

The Effect of Analgesic Agents upon Pain

Hardy et al. (28) point out that pain of low intensity can be controlled by the analgesics of mildest action, such as the coal tar derivatives. Pain of moderate intensity, and short duration, can be eliminated by the opiates. Pain of high intensity necessitates for its control the elimination of the noxious stimulation or complete unconsciousness.

The application of the radiant heat technique to the human integument has found wide application in evaluating analgesic drugs (40, 45, 55, 78, 79, 80). Work by Wolff et al. (78) reveals that the minimum effective quantity of morphine sulfate was 0.5 mgm. The saturation quantity, or the smallest amount with which the highest threshold raising effect was attained, was approximately 30 mgm. The saturation level for morphine sulfate was 100 per cent above the control threshold. The maximum threshold raising effect for quantities of morphine sulfate in 0.5 mgm. to 15 mgm. was reached at approximately the same time; that is, about 90 minutes after administration. Other opiates tested took approximately the same time.

Investigators (1, 14, 15, 45) report on the effects of analgesic agents upon the reaction of an animal to noxious stimulation. Research with dogs by Andrews and Workman (1) reveals that 0.008 gm. of morphine raises the pain reaction threshold approximately 15 per cent above the controls.

Kuhn and Bromiley (40) using the dolorimeter on the human subject report that the effect of morphine upon the pain thresholds is variable. Their data indicate that in some individuals the pain thresholds may not be affected, whereas in others it rises above the level of tissue damage stimulus intensity.

Oberst (49) reports that in addition to the rise in pain threshold, the administration of morphine results in relaxation, freedom from anxiety, lethargy, apathy, and difficulty in meditation in the human subject. He points out that an outstanding feature was the freedom from anxiety and feeling of contentment. The pain threshold raising action was not closely related in time to these psychological changes, the latter effects outlasting the threshold raising action by many hours. The administration of 30 mg. of morphine sulfate produced a state of nausea, loss of initiative, vomiting, sweating, weakness and unsteadiness of gait.

Euthanasia by Decompression

A survey of the literature reveals the absence of any work on determining whether pain is perceived during decompression. Various workers have studied physiological changes in the dog during decompression. Kemph and his associates (36) recorded in 1952 the subcutaneous pressure when dogs were decompressed to 25 or 30 mm. of Hg. They found that the sub-

cutaneous pressure rises to an average of 34 mm. of Hg. differential pressure 60 seconds after decompression.

Kemph and Hitchcock (38) also reporting in 1952 measured changes in the blood and circulation of dogs following explosive decompression to low barometric pressures. These investigators obtained data on the oxygen content and percentage saturation of hemoglobin in the arterial blood of dogs 30 seconds after explosive decompression. Their work indicates a gradual decrease at ambient pressures between 400 mm. of Hg. and 50 mm. of Hg., followed by a marked increase below 50 mm. of Hg. The carbon dioxide content of arterial blood tends to decrease slightly at ambient pressures less than 200 mm. of Hg. and markedly at ambient pressures less than 100 mm. of Hg. It does not show the marked increase shown by the oxygen curve at ambient pressures less than 50 mm. of Hg. The authors reported that the circulation was blocked probably due to intravascular gas bubble formation and usually occurred within 30 seconds after explosive decompression to barometric pressures less than 50 mm. of Hg. The exact location of initial gas bubble formation was unknown, but the data presented indicated that gas bubbles first form centrally in the heart and pulmonary vessels or at the bifurcations of arteries.

Whitehorn (75) in 1948 exposed veins and arteries, and made observations on animals that were exposed to barometric

pressures of 30 mm. of Hg. He reported that exposed veins revealed massive intravascular bubbles which were absent in the arteries. Work by Armstrong (2) reveals that post mortem examinations of animals destroyed by explosive decompression showed that death was principally due to anoxia. There was considerable evidence of nitrogen and water vapor bubble formation throughout the tissue. Burch et al. (7) found that explosive decompression of dogs followed by exposure to an ambient pressure of 30 mm. of Hg. results in vaporthorax which causes distention of the thoracic cage and partial collapse of the lungs. Gas is also formed inside the heart in less than two minutes following explosive decompression.

Kemph and his associates (37) also discussed the cause of death when dogs were decompressed to 30 mm. of Hg. He points out that rarely, if ever, will an animal die when decompressed if anoxia is prevented from occurring.

In 1950 Burch and Hitchcock (6) reported that only two of twelve dogs survived when decompressed for two minutes. No vapor was found present in the heart of the two dogs that survived. They felt that death was due possibly to vaporization blocking the coronary arteries.

Edelmann and Hitchcock (16) mention that when dogs are exposed to an ambient pressure of 30 mm. of Hg., oxygen is unable to reach the blood, and animals could not have remained conscious for more than 10 seconds due to cerebral anoxia.

Surgical Measures for the Relief of Pain

In 1889 Edinger (17) described a tract in man taking origin from cells in or about the posterior horn, crossing the midline and ascending in the anterior or anterolateral column of the spinal cord. This author was able to follow this column as high as the interolivary lamina, where it seemed to mingle with fibers of the medial lemniscus. Previous investigators had shown that fibers of the posterior root entered the posterior columns and ascended to the nuclei of the posterior columns in the medulla. Edinger noted that such a pathway could not explain the anesthesia which he found on the contralateral side of experimental animals after hemisection of the spinal cord. He did not, however, recognize that there was not anesthesia, but only analgesia.

It was not until 1905 that Spiller (64) showed definitely that the fibers carrying pain and temperature reside in the anterolateral columns. The author attended a patient suffering from generalized tuberculosis in whom there developed complete loss of appreciation of pain and temperature in the lower extremities with no diminution in the appreciation of tactile impulses. At autopsy, tubercles were observed in both anterolateral columns of the spinal cord in the lower thoracic region. It was then concluded that the fibers conveying pain and temperature sensibilities traverse the anterolateral columns.

Several authors have studied the spinothalamic tract in lower animals: Quensel and Kohnstamm (57) in rabbits, Mott (48) and Clark (11) in the monkey, and Walker (69) in the monkey and chimpanzee. Walker (68) in 1940 also studied and described the spinothalamic tract in man from the apical and pericornual cells of the posterior horn across the anterior commissure to the anterolateral columns and thalamus.

The surgical operation for anterolateral chordotomy was proposed by Spiller (65) in 1912 and first performed by Martin for the relief of intractable pain of primary or metastatic malignant disease. The level at which the chordotomy is performed will depend upon the segmental areas involved in the pain producing lesion. It is made at least two segments higher than the area to be made analgesic.

In the discussion on relief of intractable pain by Elsberg (19) in 1941, it is mentioned that in general the loss of pain sensibility will be greater during the first few days after the operation than subsequently. If a unilateral section of the anterolateral tract is done for pain on one side of the body, the tract of the opposite side must be divided. This author points out that after bilateral section of the anterolateral tracts, the loss of pain and temperature sensibility involves all tissues below the segment through which the section was made including the viscera. Temporary retension of urine occurs regularly after bilateral chordotomy.

In males, the ability to have sexual intercourse and orgasm is lost.

Peet et al. (53) in 1933 reported on a surgical technique of bilateral cervical chordotomy for relief of pain in chronic infectious arthritis in man. The author mentions that a bilateral chordotomy in the upper cervical segments should not be performed because of the danger of respiratory paralysis. He points out that the phrenic nerves arise chiefly from cells in the fourth cervical segment. The exact location of the tracts descending to these cell bodies is unknown. He felt that, theoretically, edema following section of the anterolateral tracts might involve these descending fibers or the phrenic cells in the anterior horns as well as the tracts of the intercostal muscles, resulting in respiratory failure.

These authors report on one clinical case where a bilateral cervical chordotomy was done at the third and eighth cervical area. Pain and temperature sensibility were lost approximately from the neck caudad.

In 1934 Putman (56) suggested a new operative method of treatment for pain in the upper limbs of man. By means of a spinal instrument which was inserted between the posterior columns, the commissure was divided from the upper cervical to the upper dorsal region. After the operation, there was a loss of pain and temperature sensibility over the chest and both upper limbs.

The first surgical section in man of the lemniscus lateralis at the brain stem for the treatment of diffuse rebellious pain was presented by Dogliotti (13) in 1938. The operation consisted of the interruption of the secondary afferent path of pain (spinothalamic tract) at the highest level, that is, at the brain stem, immediately upon the pons. The author describes the surgical technique and of the four patients operated upon, one died in thirty-six hours and the other three all had uneventful postoperative recoveries. The preoperative pains disappeared immediately in the two patients with a complete secondary hemianalgesia, and were greatly reduced in the other patient.

Schwartz (61) reports a human case in which section of the spinothalamic tract in the medulla was performed for relief of high intractible pain. The operative technique is described. On the basis of sensory changes which resulted, it was concluded that a topical arrangement of fibers is present in the spinothalamic tract, with fibers from the lower dermatomes occupying a dorsolateral position and those from the upper segments lying ventromedially. Further work by White (73) reported in 1941 reveals further observations on the spinothalamic tractotomy in the medulla oblongata. He feels that the land marks for sectioning the spinothalamic tract are just as clear cut in the medulla as the spinal cord,

and the risk of injury to the pyramidal tract is less than in the well standardized spinal procedure.

In the discussion of the possibility of differential section of the spinothalamic tract of man, Hyndman and Epps (35) in 1939 questioned the accepted location of the spinothalamic tract as well as the accepted disposition of the fibers. They reported six cases in which the operation was done with the patient under local anesthesia only. Sections were made in the cord according to various patterns, and cutaneous sensibility was tested at the operating table. These authors found that the spinothalamic tract mediating the sensation of pain and temperature extends from a point about midway from the dentate ligament to the anterior roots to a point about midway from the anterior roots to the anterior median fissure. Their studies indicate that fibers representing the lower segments are situated posteriorly in the tract and fibers representing successive segments upward dispose themselves more anterior.

Bruce and Schafer (5) conducted experiments on monkeys in which the ventrolateral region of the spinal cord was destroyed. They not only found sensation entirely normal, but could not demonstrate any sign of ataxia, though paralysis did occur. On the other hand, Lewandowsky (42) states, that section of Gower's Tract in dogs does produce a certain degree of analgesia.

Cadwalader (8) in 1912 reported on the cutting of the spinothalamic tract in two dogs. The depth of incision was not given, but, after death, the segment in which the incision had been made was mounted in celloidin and cut in serial sections in order to ascertain the exact limits of the area destroyed. Sections were also made from each segment of the cord and parts of the medulla and pons, so that the course of degeneration could be followed.

Microscopic examination showed that the anterior and lateral portion of the white column of the cord had been destroyed on both sides. A line drawn through the posterior limits of this area would just bisect the central canal. Anteriorly it extended to a point which corresponded to the position of the most medially situated anterior root fibers. The ventral and dorsal cerebellar tracts were degenerated as far as the pons.

In both dogs motor paralysis was noted immediately following the operations, but it disappeared rapidly and was replaced by very marked ataxia. They concluded that the dogs did have a definite, though incomplete, loss of cutaneous sensation for pain and for extreme heat.

EXPERIMENTAL PROCEDURE

A total of forty-four mongrel dogs of various ages, weights and sexes were used in these preliminary experiments. They were fed a diet which consisted of a dry commercial dog feed containing a minimum of twenty-five per cent protein and a canned dog food containing meat. Water was fed ad libitum.

Intestinal parasites were controlled by oral administration of an anthelmintic[1] and daily cleaning of the cages. Fleas and lice were controlled with an insecticide[2]. There was no evidence of excessive parasitism or nutritional deficiency during the conduction of pain reaction threshold tests.

The experimental animals were housed in metal cages 36 inches deep, 36 inches high and 30 inches wide. They contain removable floors and trays to facilitate cleaning.

Determination of the Pain Reaction Threshold by the Thermal Technique

An experiment was designed to determine the pain reaction threshold in 15 dogs with the Hardy-Wolff-Goodell Dolorimeter. This apparatus allows for the quantitative measurement of the

---

[1]One capsule per 10 pounds of body weight. Each capsule contains 1 gram of 2,2'-dihydroxy-5,5'-dichlorodiphenyl methane and 1.2 grams of methyl benzene. The trade name of this product is "Vermiplex" and it is marketed by Allied Laboratories, Inc., Indianapolis, Ind.

[2]One per cent cadmium sulfide and an adequate quantity of detergent. The trade name of this product is "Derisol" and it is marketed by Allied Laboratories, Inc., Indianapolis, Ind.

pain reaction threshold by exposing 3.5 cm.^{2} of skin surface for a definite length of time to thermal radiation. An exposure interval of three seconds was used in these experiments.

The Hardy-Wolff-Goodell apparatus consists of a control box and projector (Figure 1). The control box is connected to a 60 cycle power line by means of a power cable. The lowest limit of voltage on which the equipment will operate is 105 volts while the upper limit is 125 volts. A binding post is provided for connecting the instrument to a suitable earth ground. The instrument is turned on by means of a power switch which controls all the power for the control box.

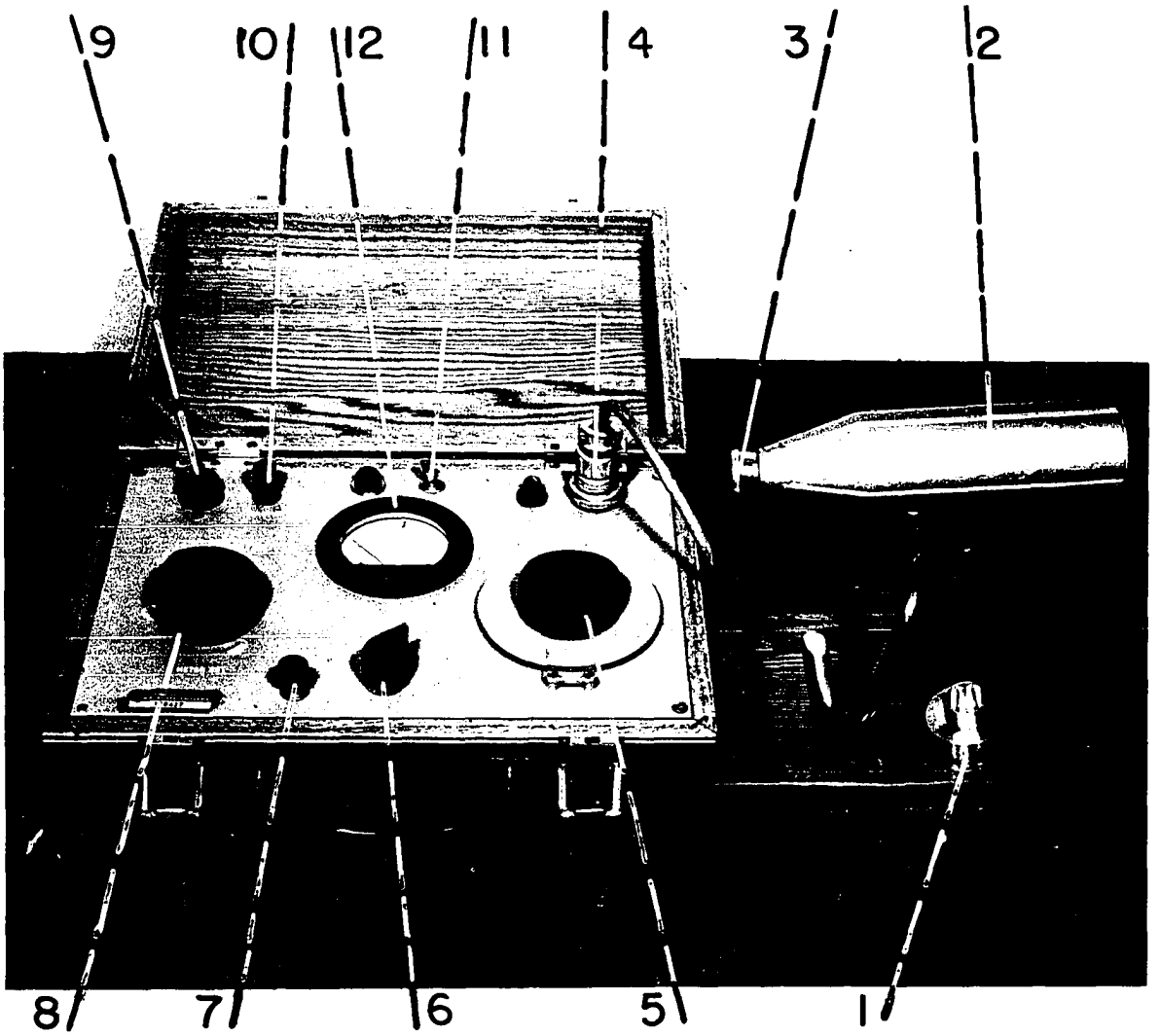
The dolorimeter control box is provided with a variable transformer and a voltmeter to compensate for variations in power line voltage. The voltmeter scale is provided with a single line at mid-scale and the pointer of the meter is to be maintained as accurately as possible at this center line.

The amount of heat in millicalories/cm.^{2}/sec. which is delivered to the area in the plane of the fibre bezel ring of the projector is controlled by means of the heat setting dial. In order not to overheat the projector or shorten the life of the lamp, the dial was not set at values above 200 millicalories except when measurements were being made.

The time selector switch is provided with three positions, labeled "3 seconds", "Manual" and "Calibrate". With the time selector switch on the "3 seconds" position, the

Figure 1. Hardy-Wolff-Goodell Dolorimeter

1. Model ET2 Thermopile Serial ET2-33
2. Model ES2 Projector
3. Bezel ring with fibre washer
4. Connector for cable to projector
5. Heat setting dial
6. Time selector switch
7. Exposure button
8. Meter setting knob
9. 105-120 volt, 60 cycle a.c. power
10. Ground terminal
11. Power switch
12. Meter


9
10
12
11
4
3
2
8
7
6
5
1

lamp will operate for a 3 second period whenever the button on the projector is held down. The lamp can also be actuated by means of the exposure button on the control panel. For heat exposures greater or less than three seconds, the time selector switch may be placed on the "Manual" position whereupon the lamp will be controlled directly by the button on the projector or the exposure button on the control panel. The "Calibrate" position of the time selector switch turns the lamp on without operation of the exposure buttons. The purpose of this position is to assist in calibration of the instrument.

A binding post is provided for connecting the instrument to a suitable earth ground. This is a safety precaution which guards against accidental shock to the subject or operator in the event that a component failure causes any part of the case of the control box to become connected to the power line. The ground connection is not carried through to the projector, since all electrical connections in the projector are within the insulated "phenolic" handle.

The dolorimeter was calibrated frequently with a Rubicon Potentiometer and a Model ET2 Thermopile to insure its accuracy. The calibration technique outlined by Hardy et al. (30) was followed. A constant of 9.9 was used to calculate the intensity of radiation.

The surface of the skin to be tested was clipped with a No. 10 clipper blade and thoroughly blackened with India ink and sufficient time allowed for the ink to dry. This insured a high degree of absorption of the radiation, independent of the degree of natural pigmentation of the skin. This also eliminated all effects which could arise from any possible penetration of the rays below the skin surface. The stimulus could thus be considered purely thermal (30).

The experimental animals were restrained by tying their legs together and to a one inch board platform with one quarter inch rope. It was essential to restrain the dogs in this manner several times previous to obtaining the pain reaction thresholds. The threshold tests were obtained only when the animal was in a quiescent state.

Various areas of the body were tested for pain reaction thresholds. The smallest intensity of radiation on the shoulder which caused a lateral movement of the head, was denoted as a pain reaction threshold (Figures 2 and 3). It was also found that there was a characteristic reflex twitch of the loin musculature whenever a definite level of stimulation was exceeded. The smallest intensity of radiation on the loin causing this musculature twitch was also recorded as a pain reaction threshold.

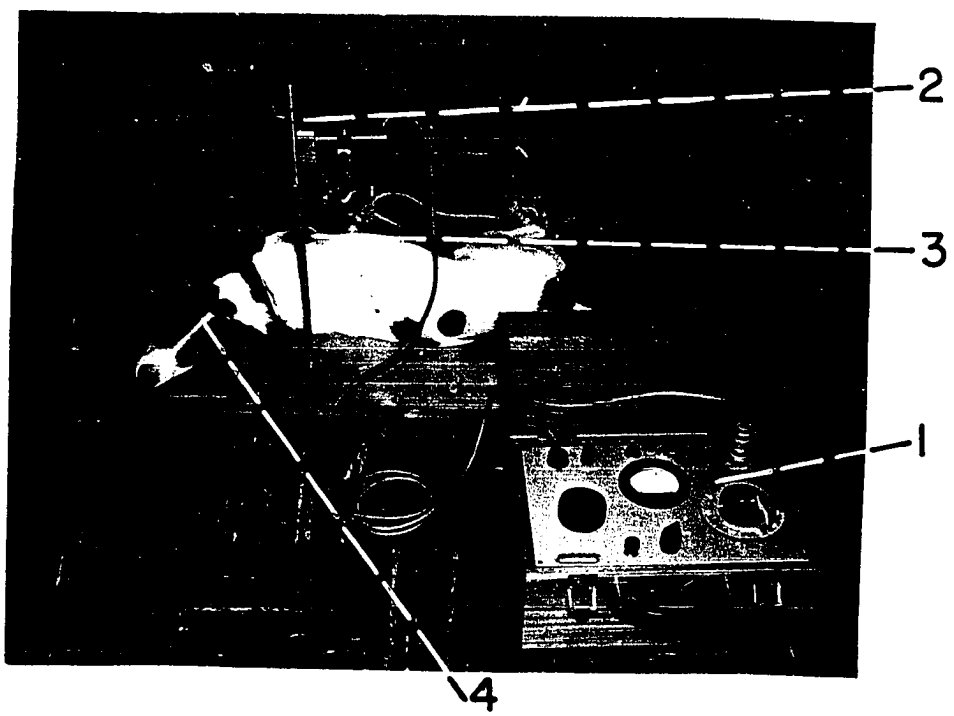
The thermal stimuli were applied no oftener than every 60 seconds. It was essential to keep the bezel ring of the

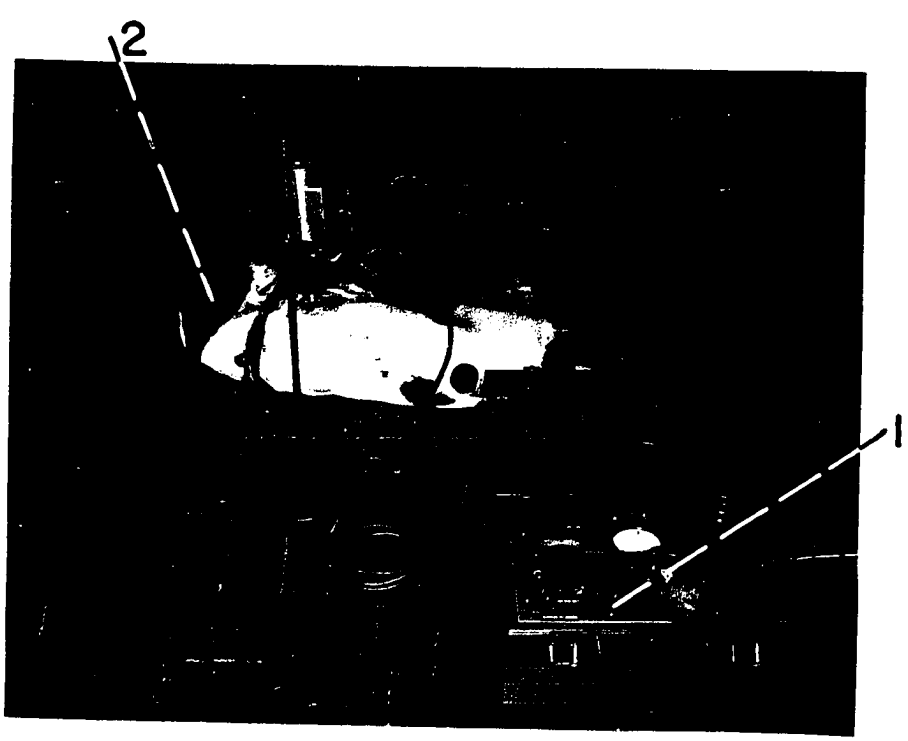
Figure 2. Animal restrained with projector applied to the shoulder

1. Model ER2 Control box
2. Model ES2 Projector
3. Integument blackened with India ink
4. Head in relaxed position

Figure 3. The lateral movement of the head denoting a pain reaction

1. Exposure button pressed
2. Lateral turning of the head to the area when the thermal stimulus was applied


2
3
1
4


2
1

projector assembly from touching the dog, but close enough not to allow the escape of thermal radiation. It was also necessary not to let the experimental animal observe the operator press the exposure button on the control panel or a conditioned reflex was soon developed.

Determination of the Pain Reaction Threshold by the Thermal Technique during Decompression

Ten experimental animals were decompressed within the Euthanair. This apparatus consists of a metal tank and a motor of 5 H.P. to draw a vacuum. The tank is 33 inches in diameter and 40 inches long. The door is fitted with a rubber seal to insure a tight vacuum. The door also contains a small glass window to allow the operator to observe the animal during decompression. The chamber has a small outlet to a Crosby manometer calibrated from 1 to 30 in inches of mercury. It is observed from Table 1 that the Euthanair is capable of decompressing an animal down to 429.6 mm. of Hg. in 11 seconds or 74.0 mm. of Hg. in 70 seconds. The chamber has a decompression capacity of 29.5 mm. of Hg. in 120 seconds.

A metal plate was constructed and fitted into the wall of the tank to allow for the passage of electrical leads into the chamber. The control box of the dolorimeter was operated outside of the chamber while the projector was held by a clamp

Table 1. Time required for decompression of the experimental animal with the Euthanair

Millimeters of mercury	Time required for decompression (seconds)
734.4	0
582.0	5
429.6	11
277.2	21
124.8	47
74.0	70
48.6	90
29.5	120

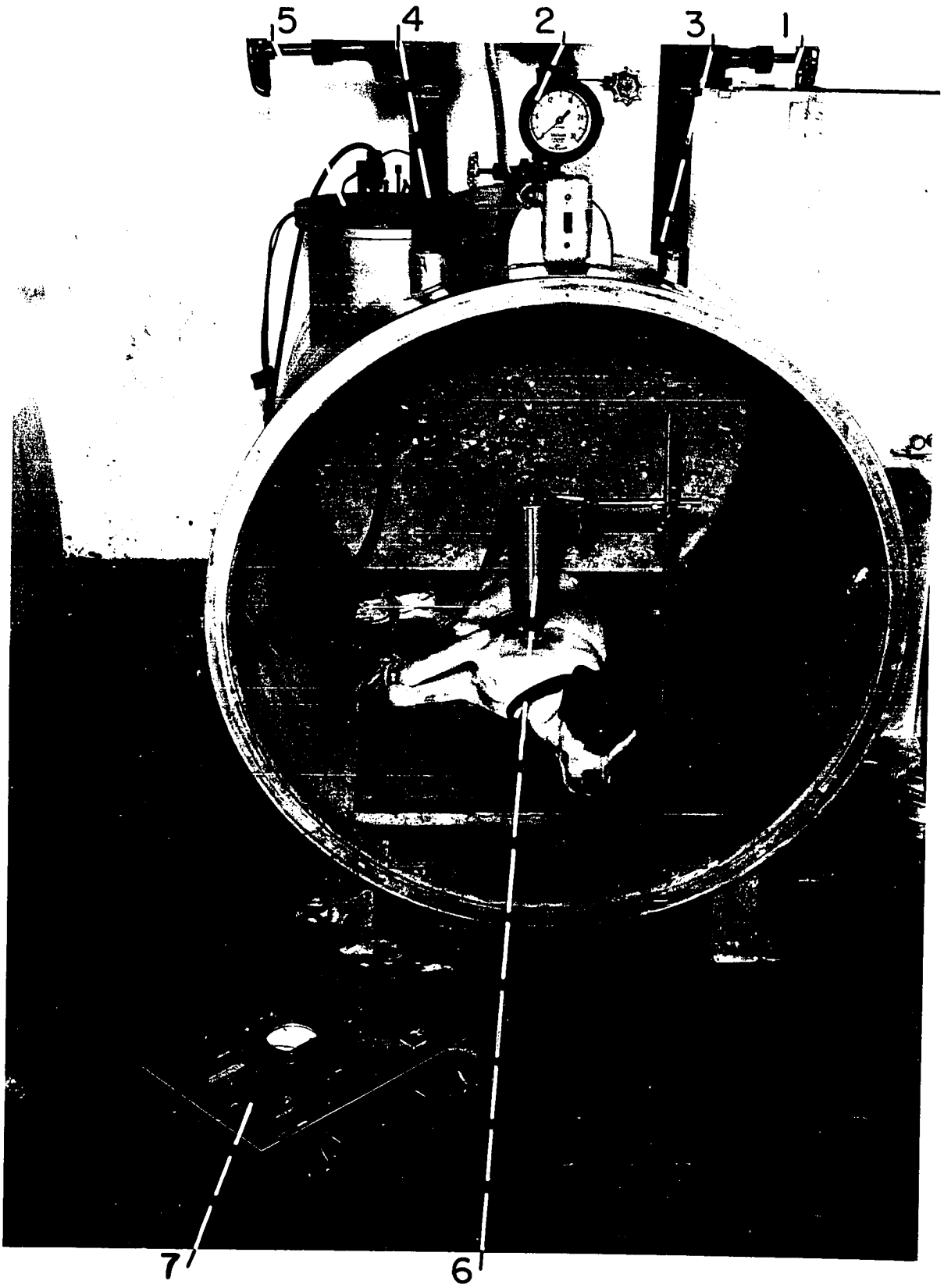
on a three-eighths inch rod mounted onto the platform in the chamber (Figure 4).

The pain reaction thresholds were obtained at 734.4 (average barometric pressure at Iowa State College[1]), 582.0, 429.6, 277.2 and 124.8 mm. of Hg. The lowest decompression level varied slightly as it was obtained just prior to unconsciousness of the animal. Both types of pain reaction thresholds were recorded; that is, the smallest intensity of radiation on the shoulder and loin which caused a lateral deflection of the head and a twitch of the musculature of the second to fourth lumbar area, respectively.

[1]Obtained from the Physics Department, Iowa State College.

Figure 4. The experimental animal in the Euthanair with the projector applied to the skin of the shoulder

1. Euthanair chamber
2. Crosby mercury manometer
3. Recompression pipe leading to outside
4. Vacuum pipe leading to the motor
5. Detachable plate containing the electrical leads
6. Projector
7. Control box


5
4
2
3
1
7
6

Determination of the Pain Reaction Threshold by Electrical Stimulation of the Canine Tooth

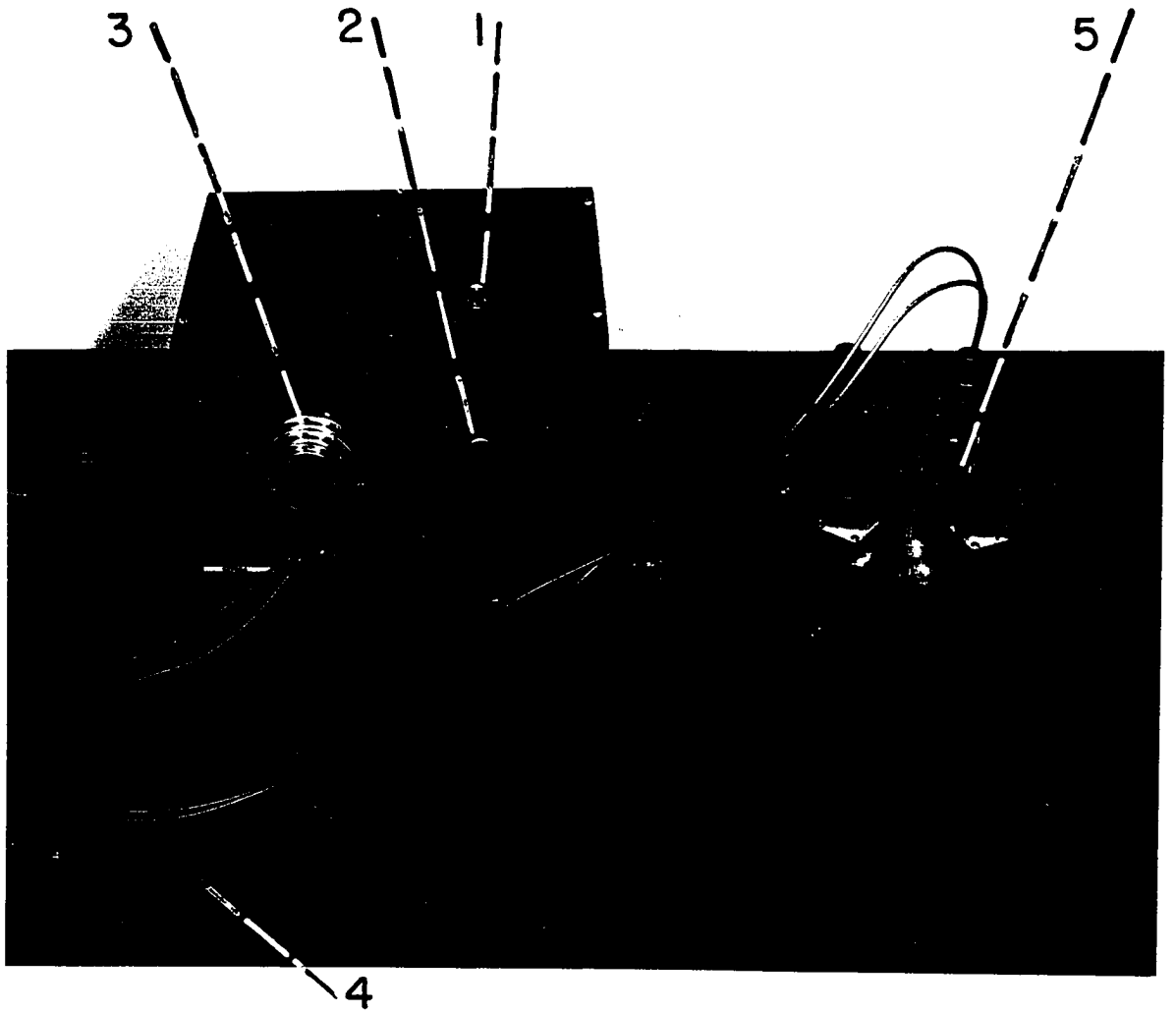
An experiment using five dogs was designed to determine the pain reaction threshold by applying an electric current through a metal filling in a tooth. An instrument (Painometer) was designed and constructed to deliver up to 45 volts (d.c.) to the metal fillings in the canine tooth (Figure 5). A Dekapot Model DP-311 Potentiometer was constructed in the stimulator to regulate the voltage. This potentiometer has a linearity of ± 0.005 per cent and an input resistance accuracy of ± 0.05 per cent. A constant input resistance of 10,000 ohms is made available and the instrument carries a power rating of 5 watts at 30°C rise. The maximum input volts of 220 volts RMS are present in the design. The voltage output is calculated by multiplying the dial reading x 44. The electrical design is presented in Figure 6.

Two silver alloy amalgam fillings were placed in each canine tooth in opposite positions so that pincer like electrodes would contact the two fillings. The cavities were drilled with an electric drill fitted with a 1/32" bit. The cavities were drilled as deep into the dentine as possible without entering the pulp chamber.

The silver alloy was mixed thoroughly with mercury in a mortar with a pestle. The excess mercury was squeezed out through a cloth until the silver amalgam was in a semisolid

Figure 5. Electrical tooth stimulator (Painometer)

1. Exposure button
2. Selector dial for battery number
3. Potentiometer dial
4. Spring type clamps
5. Detachable plate from Euthanair


3
2
1
5
4

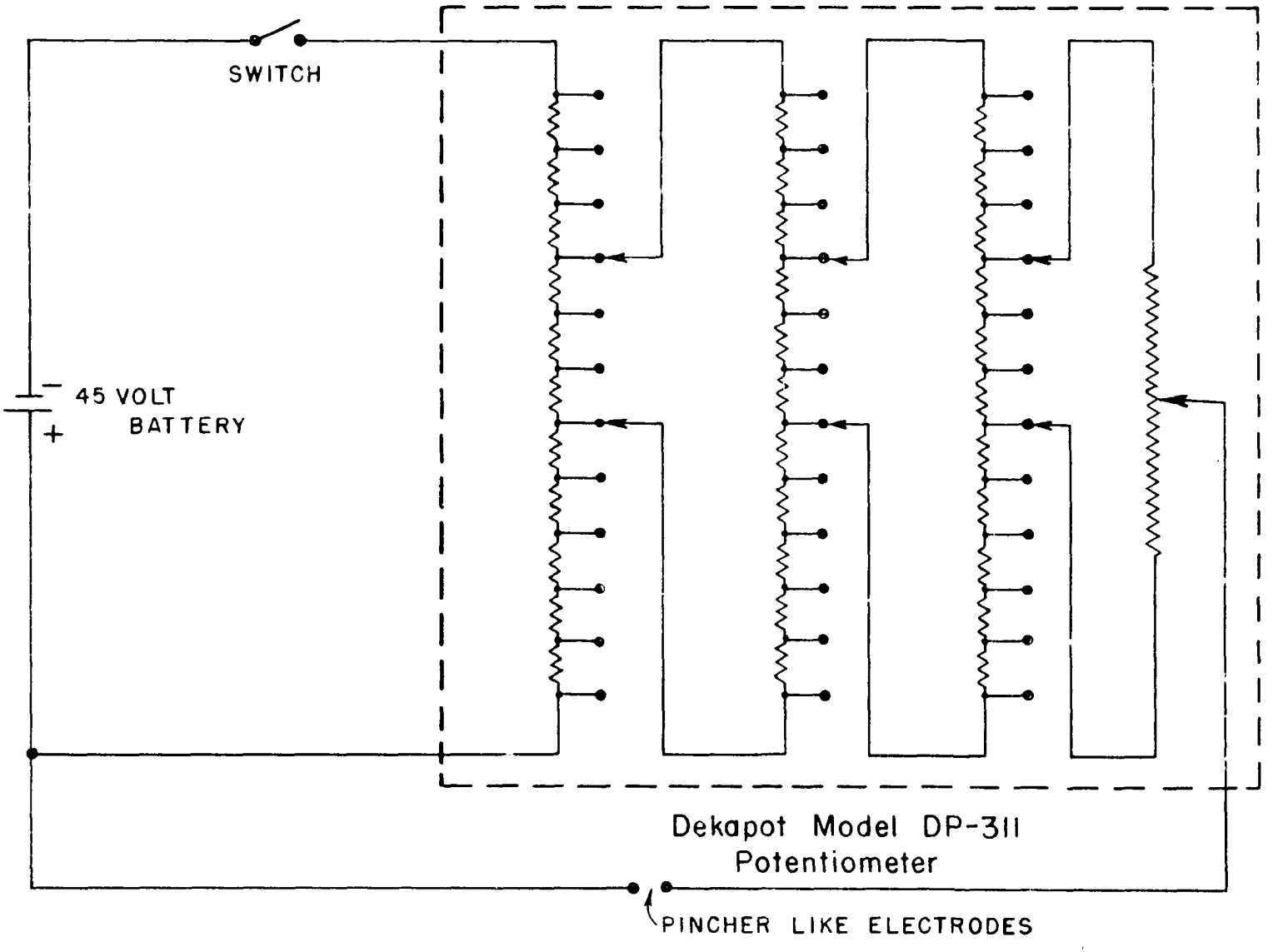


Figure 6. Electrical Design of the Electrical Tooth Stimulator

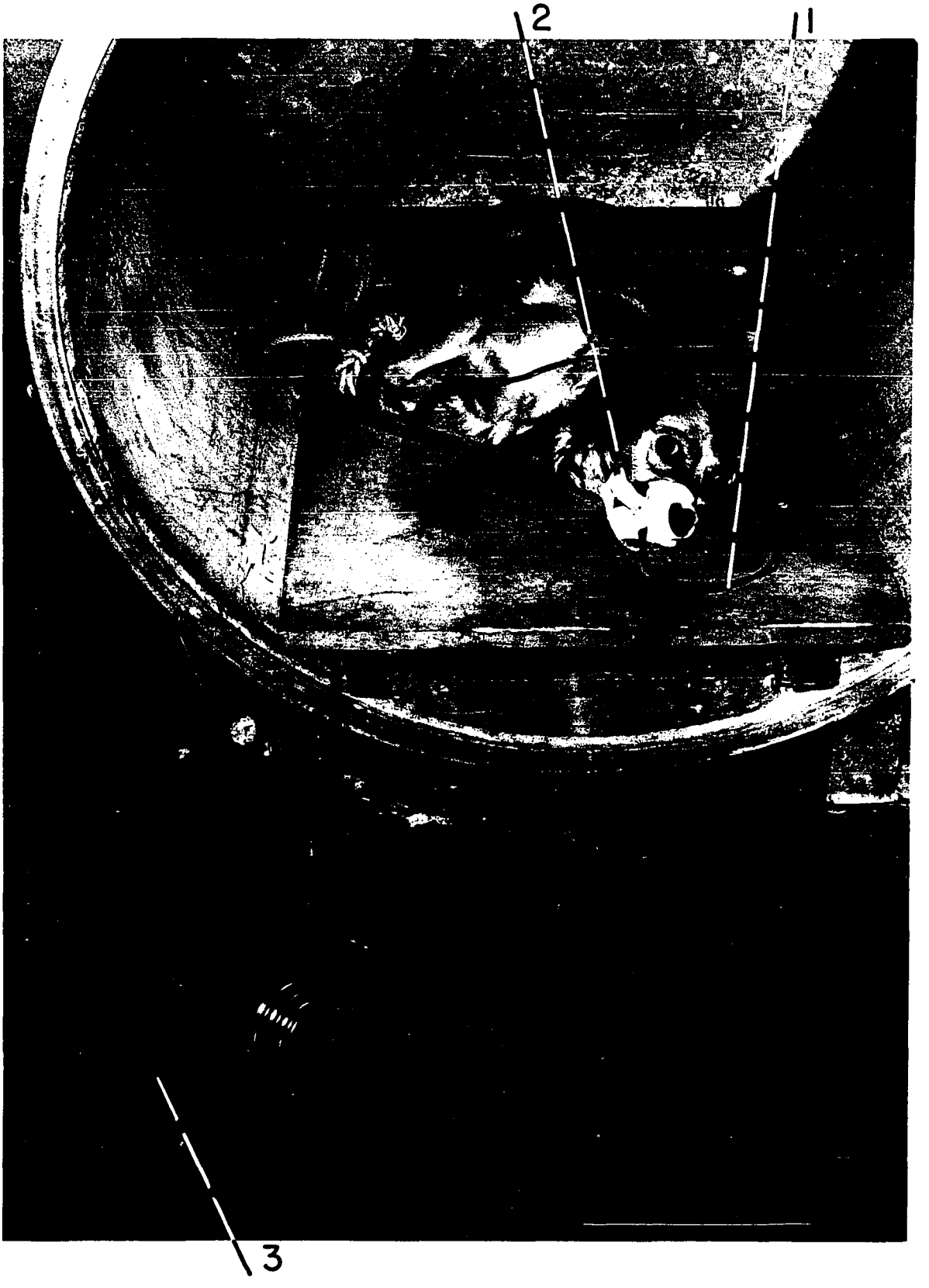
state. The cavities were then packed tightly and a small depression allowed for stabilization of the electrodes.

During the threshold reaction tests the dogs were restrained in a manner similar to that used in the study of the conduction of the pain reaction thresholds by the thermal technique. In addition the head was restrained by tying the collar to the platform (Figure 7). The upper lip was taped away from the canine tooth. Gauze packs were taped dorsal to the tooth to keep the area dry. A small block of wood was taped posterior to the canine tooth to keep the lower canines from removing the pincer like electrodes from the fillings. A mouth spectulum was used which gave good exposure to the teeth, but was found to interfere with observation of the contraction of the facial muscles.

A pain reaction threshold was taken as the smallest electric current applied to the metal filling of the tooth necessary to produce a twitching of the facial muscles. The threshold tests were recorded only when the experimental dogs were quiet. It was essential to restrain the animals in this manner several times previous to obtaining the pain reaction thresholds. It was also necessary not to allow the animals to observe the operator press the stimulator button or a conditioned reflex was soon manifested.

Figure 7. Painometer assembled with dog restrained

1. Electrical leads to Painometer
2. Small piece of wood taped between molars
3. Electrical stimulator control box


2
1
3

Decompression of Morphinized Animals

Since morphine raises the pain reaction threshold, an experiment was designed to determine if there was any change in the anxiety and excitement during decompression while under the influence of morphine. It would appear that since morphine alleviates pain of moderate intensity, a decrease in anxiety and apprehension would be observed during decompression after morphinization if the animal was receiving pain from decompression. Conversely, if the animal receives no pain during decompression, there is reason to believe that one would observe no change in anxiety during decompression after morphinization.

Ten dogs were used in the experiment. Previous to the administration of morphine, each experimental animal was decompressed three times on different days to a state of unconsciousness. The amount of excitement and apprehension was recorded. A scale from 1 to 5 was used to record the varying degrees of anxiety with a recording of 5 denoting extreme excitement.

Morphine was injected subcutaneously at a dose of 1 mg./kg. One hour after the injection of morphine the dogs were decompressed to a state of unconsciousness and the amount of apprehension was again recorded. Movies were taken of the morphinized animals during decompression for detailed study. Pain reaction thresholds were determined with the Hardy-Wolff-

Goodell Dolorimeter on the dogs before administration of the morphine and one hour after its injection. Both types of pain reaction thresholds were recorded as in the previous experiments. Where high intensities of radiation were required to produce a response, the location of the projector with regard to the integument must be changed with each observation or severe burning with skin necrosis will result. The thermal stimulus is applied no oftener than at 60 second intervals.

Division of the Lateral Spinothalamic Tracts

It was found that animals vary considerably in the amount of excitement, apprehension and anxiety that they exhibited during the decompression. A surgical experiment was designed with 14 dogs to determine if the animal exhibited the same degree of excitement and anxiety after the animal was relieved of the sensation of pain. If the excitement exhibited during decompression was due partially or completely to the pain experienced, then severing certain spinal tracts to alleviate the pain sensation in the body should decrease the amount of excitement and anxiety during decompression. On the contrary, if the animal does not experience any pain during decompression, then the sectioning of these spinal tracts should not affect the amount of excitement observed during decompression.

Previous to the surgical treatment, each experimental animal was decompressed three times on different days to a state of unconsciousness and the amount of anxiety and apprehension was recorded. A scale was devised from 1 to 5 to record the varying degrees of anxiety with 1 designating the smallest amount of excitement and 5 the greatest amount of excitement. Approximately four weeks after the surgical division of the lateral spinothalamic tracts the dogs were again decompressed three times on different days and the amount of anxiety was recorded.

Animals used in the surgical procedures were determined to be in normal clinical health by means of a thorough physical examination. Subjects revealing any evidence of systemic disease of any nature were not used as an experimental subject. Food and water were withheld for twelve hours prior to surgery. The animals were anesthetized by the use of pentobarbital sodium which was given intravenously to produce the desired effect.

All surgery was done under aseptic conditions. Instruments, with the exception of Castroviego ophthalmic knife, were sterilized by steam in an autoclave by using 20 pounds pressure for 20 minutes. The Castroviego ophthalmic knife was sterilized by immersion in a 1/1000 aqueous solution of benzalkonium chloride for 30 minutes prior to use.

The hair over the anterior dorsal cervical region and external occipital protuberance was clipped with an electrical clipper fitted with a #10 clipper blade. The clipped area was then shaved and again scrubbed with soap and water. The area was rinsed with water to remove all traces of soap. The prepared skin was painted with 1/1000 tincture of benzalkonium chloride.

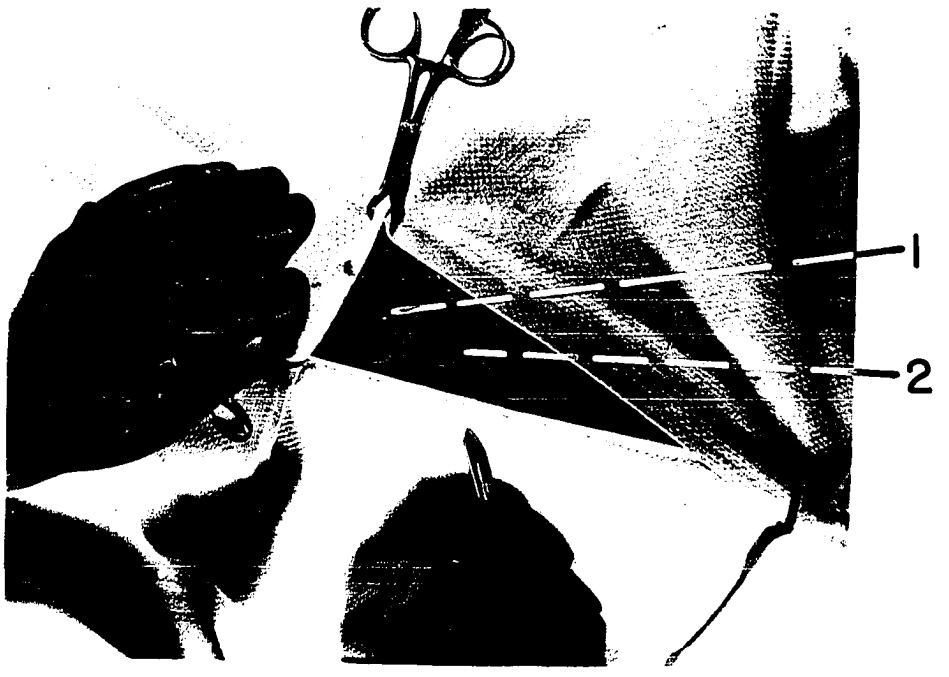
After the surgical field was prepared, the animal was placed on the operating table in a ventral recumbency. Sand bags were placed under the anterior part of the cervical area to allow for adduction of the head. A tracheal tube was inserted into the trachea since the weight of the head and neck was supported on the sand bags and exhibiting pressure on the larynx and anterior part of the trachea. The head remained in an adducted position to facilitate exposure of the area dorsal to the atlas.

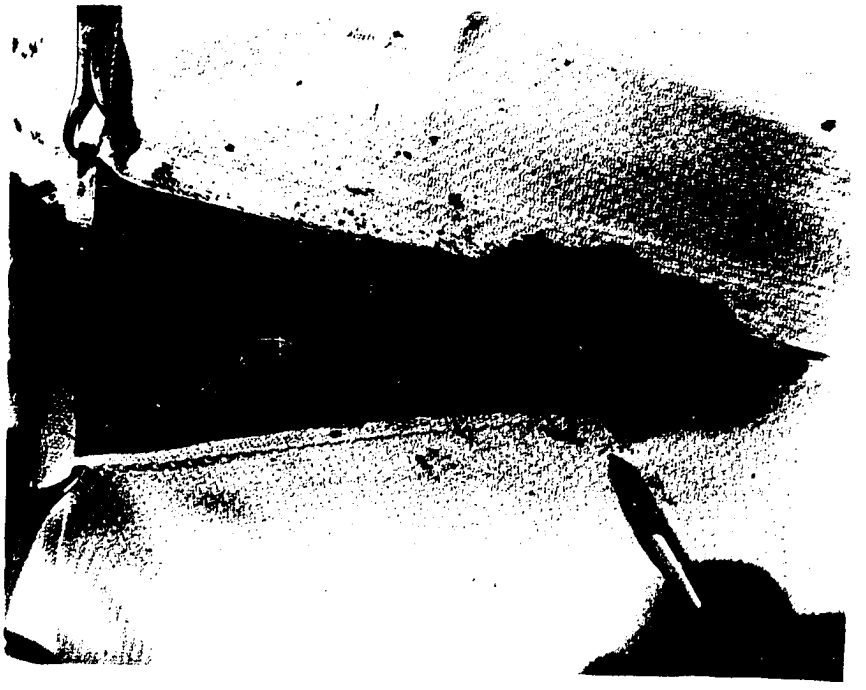
The operative field was draped with sterile towels and fixed with towel clamps so that only a small triangular operative skin area was exposed (Figure 8). The skin incision was made on the median line from a point slightly anterior to the external occipital protuberance caudal approximately four inches depending on the size of the dog (Figure 9). The depth of the incision was increased until the spine of the axis was exposed. The fascia and muscles were cut close to the spine of the axis, the cutting edge of the scalpel being directed

Figure 8. Exposure of operative field

1. Integument dorsal to external occiputal condyles
2. Integument dorsal to the spine of the axis

Figure 9. Skin incision exposing cervical muscles


1
2



against the sides of the spinous process. At this point an automatic retractor was inserted and the blades of the retractor were opened. By means of a Bucks Mastoid curette the soft tissues with the periosteum covering the spine and laminae of the axis, and the laminae of the atlas were cleanly scraped away from the bone until the laminae were well exposed (Figure 10). There was often considerable hemorrhage during these manipulations, but it was checked by using hemastats on the arteries and packing gauze into the cavity.

The spine of the axis was removed at its base with a Hartman rongeur (Figure 11). The anterior two thirds of the laminae of the axis and the posterior one half of the laminae of the atlas were then removed with a Kerrison rongeur (Figure 12). By this means the dura was exposed. All soft tissues were periodically bathed with a physiological saline solution.

The dura was grasped with a Castroviego fixation forceps and slightly elevated. A 4 mm. incision was made in the dura with a Castroviego ophthalmic knife adjacent to the forceps and a groove director was inserted into the small opening in the dura (Figure 13). With slight upward pressure on the groove director, the dura was split anterior and then posterior. The arachnoid was incised to expose the pia mater and the spinal cord.

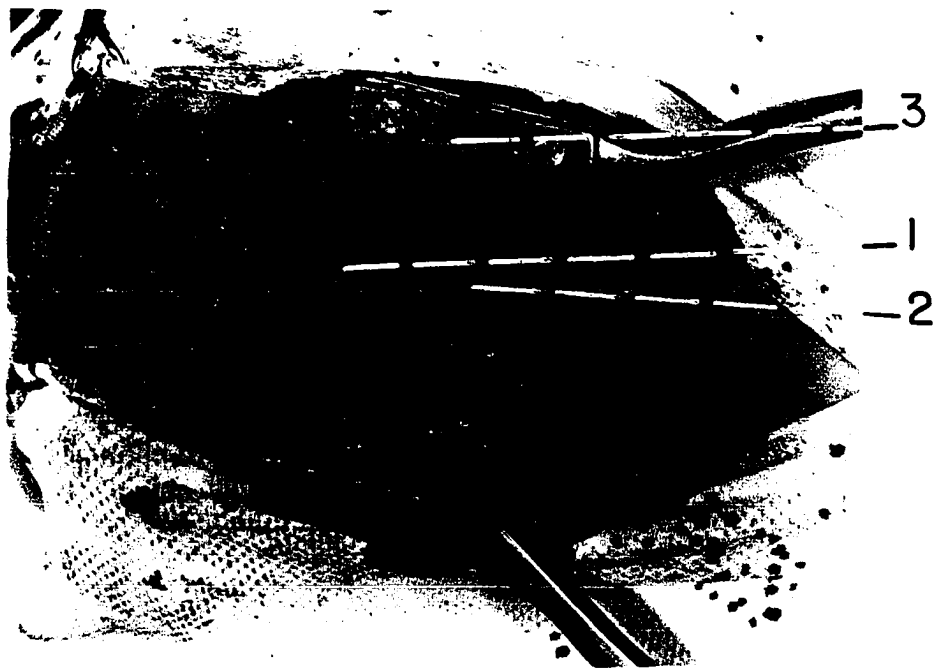
The cut edge of the dura on one side was now grasped with two Halsted mosquito forceps and laterally retracted. The

Figure 10. Exposure of the first and second cervical vertebrae

1. Atlas
2. Axis
3. Bowne tissue retractors

Figure 11. Removal of spine of axis

1. Hartman rongeur
2. Spine of axis


3
1
2

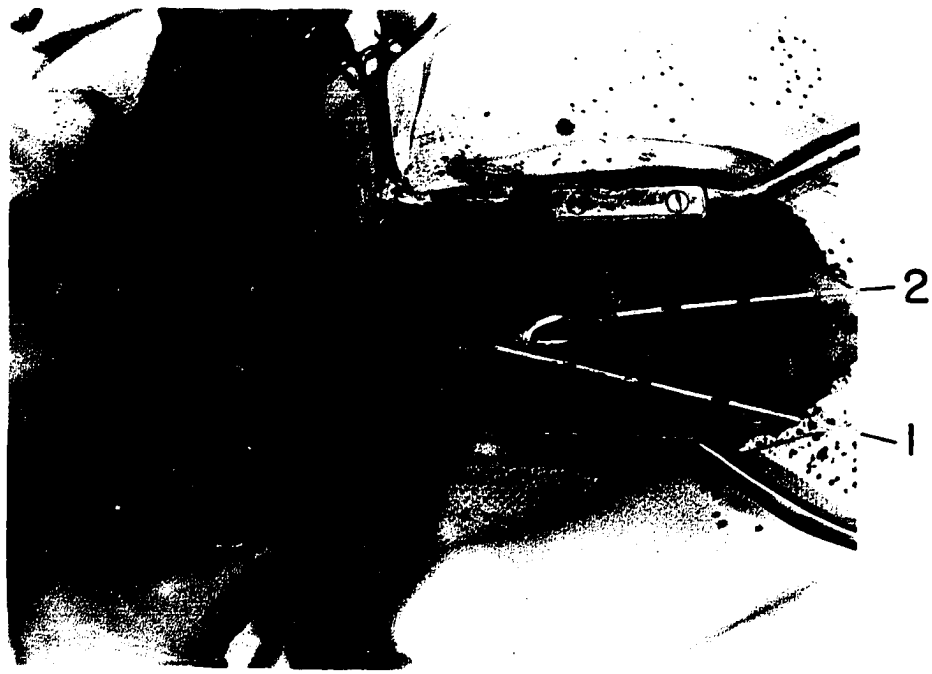

2
1

Figure 12. Removal of laminae of atlas

1. Dura mater
2. Kerrison rongeur
3. Atlas

Figure 13. Insertion of the groove director into a small opening in the dura mater

1. Second cervical nerve
2. Groove director
3. Castroviego ophthalmic knife
4. Dura mater


3
1
2


4
1
3
2

dorsal roots of the second cervical nerves were severed. The dentate ligament on one side was grasped with a dressing forceps and divided at its attachment to the dura (Figure 14). The cord was gently raised and rotated by grasping the cut dentate ligament adjacent to the cord to expose its ventrolateral surface. An incision was made in the cord between the dentate ligament and the second cervical nerve perpendicular to the anteroposterior axis of the cord (Figure 15). The Castroviego ophthalmic knife penetrated the cord at the level of the dentate ligament and emerged just ventral to the level of the ventral spinal root. The depth of the incision was approximately 1.5 mm. varying some with the size of the dog. It is possible that other tracts, for example, the ventral spinocerebellar tract, the spinotectal tract and a portion of the ventral spinothalamic tract were severed. If the area selected was free from visible blood vessels, bleeding did not result from the incision into the cord.

The above procedure was then repeated on the opposite side of the cord so that the division of the lateral spinothalamic tract was bilateral. The dura was closed with interrupted sutures of 4-0 silk (Figure 16). The first cervical nerves were then isolated and divided as they emerged from the intervertebral foramina of the atlas (Figure 17).

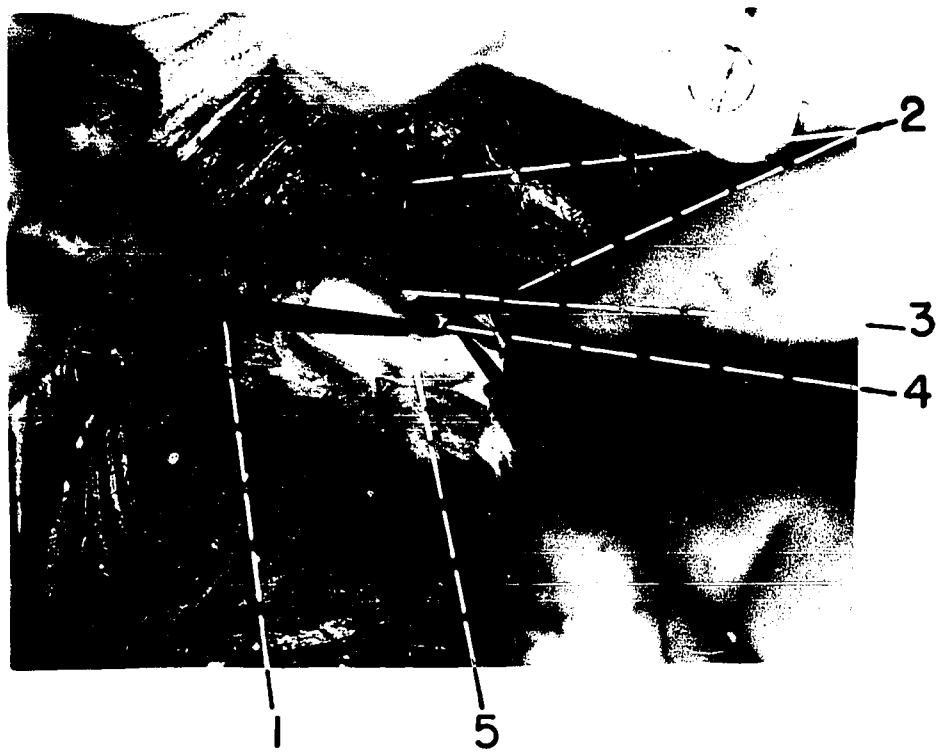
At first an attempt was made to divide the lateral spinothalamic tracts anterior to the emerging of the first cervical

Figure 14. Severing the dentate ligament

1. Dressing forceps
2. Halsted mosquito forceps
3. Second cervical nerve
4. Dentate ligament
5. Pia mater

Figure 15. Sectioning the right lateral spinothalmic tract

1. Dressing forceps
2. Second cervical nerve
3. Castroviego ophthalmic knife penetrating the spinal cord


2
3
4
1
5

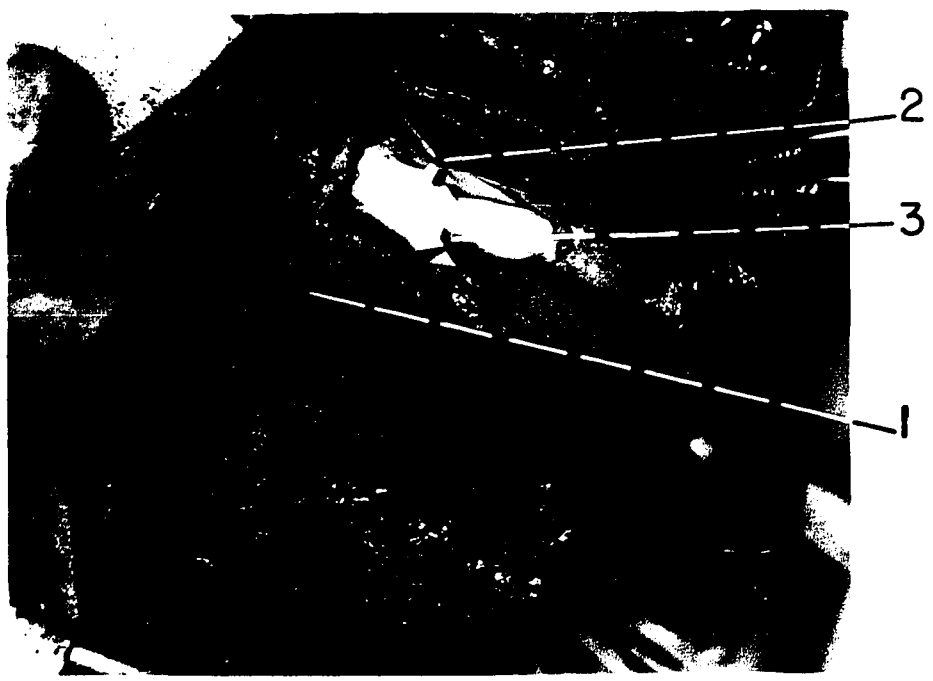
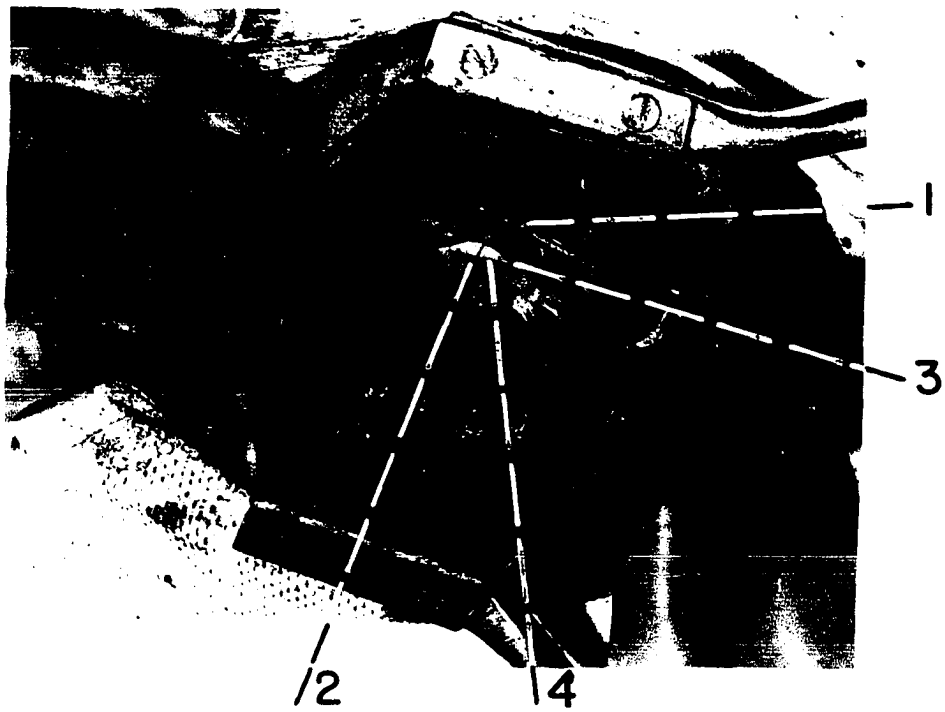

2
3
1

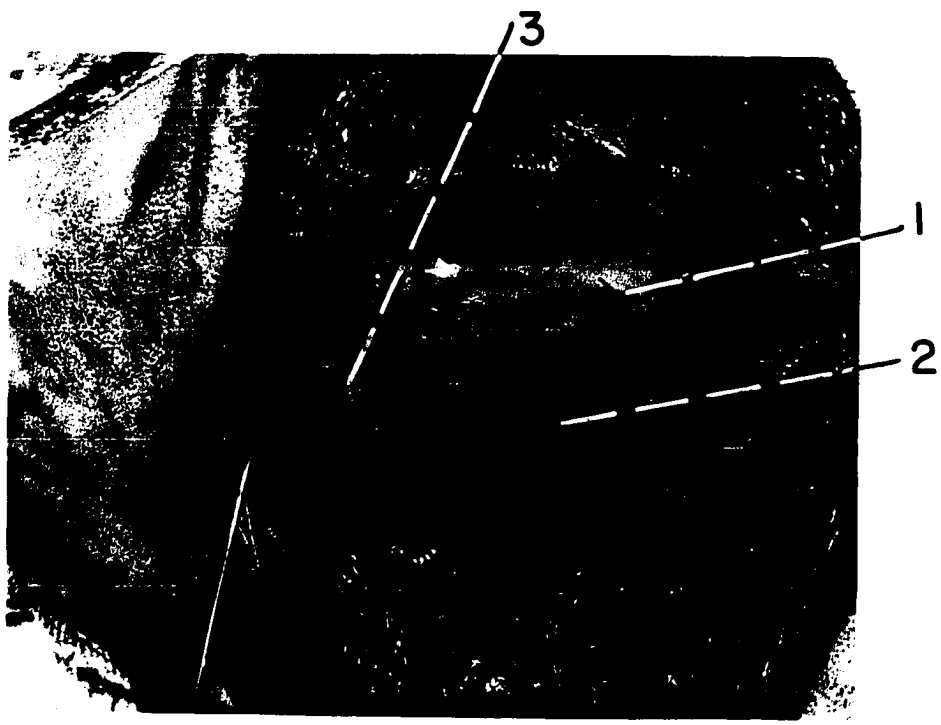
Figure 16. Suturing the dura edges into apposition

1. Kalt needle holder
2. One-half curved needle
3. Interrupted suture in place
4. Dura mater

Figure 17. Severing the first cervical nerve as it emerges from intervertebral foramen

1. Dura edges sutured in apposition
2. Five inch tissue scissors
3. First cervical nerve


1
3
2
4


3
1
2

nerves from the spinal cord, but an excessive amount of hemorrhage was encountered from the peridural longitudinal vertebral venous sinuses. Worthman (83) describing these sinuses in the dog in 1956 mentions that at their origin at the foramen magnum and throughout the atlas, they appeared ampullated and larger than any other point in their course. Within the atlas the large sinuses lay against the sides of the vertebral arches. Because of this lateral displacement, the first cervical nerve invariably penetrates the sinus of either side to emerge from the spinal canal.

If great care was exercised in the laminectomy and in the division of the lateral spinothalamic tracts between the emerging of the second and third cervical nerves, the peridural longitudinal vertebral venous sinuses were not penetrated. In the event of their penetration, electric cautery and packing with Gelfoam[1] were effective in controlling the hemorrhage.

The entire wound was washed with a physiological saline solution and all sequestrums were removed. The automatic retractors were removed and the muscles were united in layers by continuous 00 chromic catgut sutures. The edges of the superficial fascia were then united by interrupted 00 chromic catgut sutures, and those of the skin by interrupted nylon

---

[1]Marketed by the Upjohn Company, Kalamazoo, Mich.

sutures. A two inch strip of adhesive tape was then applied over the incision.

The postoperative care consisted of expressing the bladder twice daily for the first 48 to 72 hours and only occasionally longer. Constipation was usually observed and the bowels were emptied by enemas for a similar length of time. The experimental animals were given a 5 per cent dextrose solution subcutaneously at the rate of 10 cc. per pound per day until the animals were able to take food and water. This varied from 24 to 96 hours. Since the animals were down 3 to 7 days, it was essential to keep the cages dry and clean. The skin sutures were removed in 5 to 7 days.

RESULTS AND DISCUSSION

Determination of the Pain Reaction Threshold with the Hardy-Wolff-Goodell Dolorimeter

A total of 875 pain reaction thresholds were recorded with the Hardy-Wolff-Goodell Dolorimeter on 15 dogs. Four hundred and seventy of these observations were recorded with the projector adjacent to the cutaneous area of the right shoulder. The remaining observations were recorded with the thermal stimulus applied to the right lumbar region.

All integumental areas of the experimental animals were tested in an attempt to obtain a pain reaction threshold which manifested the greatest amount of accuracy in its reproducibility. It was essential to find a pain reaction in which the identification and reaction to pain were clear cut, and the same reaction observed each time the stimulus was applied. When the thermal stimulus was applied to the dog's forehead, the pain reaction was quite varied. A sudden withdrawal, or muscular twitches of the head and neck, or the palpebral reflex was observed. When a thermal stimulus was applied to the proximal part of the tail, a wiggle of the tail was often observed. Frequently, the animal would only struggle in an attempt to reflect its head laterally towards the tail. Other times a sudden lunge forward was observed.

The application of a thermal stimulus to the shoulder area resulted in a sudden lateral movement of the head. This pain reaction was found to be very constant and highly reproducible. It is observed in Table 2 that the average range was 226.7 to 252.1 mc./cm.^{2}/sec. with an over-all mean of 241.6 mc./cm.^{2}/sec. A mean range of 229.0 to 247.3 mc./cm.^{2}/sec. was observed between twelve dogs. In experimental animals 3 and 7 a range of only 15 mc./cm.^{2}/sec. was recorded.

In dogs 6, 9 and 11 a definite, reproducible pain reaction was not observed when a thermal stimulus was applied to the shoulder. Experimental animals 6 and 11 often exhibited a pain reaction by whining or yelping. This type of a pain reaction was most often observed in older dogs.

When radiant heat was applied to the dorsal lumbar region of the dog, a characteristic muscle twitch was often observed. An average range of 301.0 to 338.5 mc./cm.^{2}/sec. was observed which is a 12.2 mc./cm.^{2}/sec. larger range than the threshold range observed when the projector was focused on the shoulder. An over-all mean of 316.3 mc./cm.^{2}/sec. was noted which is 74.7 mc./cm.^{2}/sec. higher than the over-all mean of the first type of pain reaction measured. It is difficult to reason why a pain reaction threshold over the lumbar region should be that much higher than when the dolorimeter is applied to the shoulder. Very little difference in skin thickness is observed in these two areas.

Table 2. The pain reaction thresholds with their means and ranges using the Hardy-Wolff-Goodell Dolorimeter

Dog no.	Dolorimeter applied to the cutaneous area of right shoulder			Dolorimeter applied to the cutaneous area of right dorsal lumbar area		
	No. of observations	Mean[a]	Range[a]	No. of observations	Mean[a]	Range[a]
1	50	240.2	225-250	50	269.2	245-290
2	50	233.9	205-245	50	304.4	285-340
3	20	245.5	235-250	20	325.5	315-350
4	15	229.0	220-245	15	328.3	320-350
5	15	236.0	220-245			
6				20	313.5	300-330
7	20	241.0	235-250			
8	50	238.9	220-255	50	298.8	275-315
9				50	298.1	280-315
10	50	240.3	230-255			
11				50	351.9	335-390
12	50	246.4	235-255			
13	50	247.2	230-265			
14	50	242.6	230-250	50	333.0	315-340
15	50	247.3	235-260	50	352.4	340-365
Total observations	470			405		
Over-all mean		241.6			316.3	
Ave. range			226.7-252.1			301.0-338.5

[a] mc./cm.^{2}/sec.

Experimental animals 5, 7 and 12 did not give a characteristic muscular twitch when a thermal stimulus was applied to the lumbar region. Struggling and yelping were more frequently observed. Animals 10 and 13 did not give a muscular twitch with any consistency. Often a muscular twitch would result at about an average level, but a following thermal stimulus of 500 mc./cm.^{2}/sec. would fail to produce this pain reaction.

When intensities of 300 mc./cm.^{2}/sec. or higher were used, it was essential to frequently change the site of the projector or a necrosis of the integument would result.

As would be expected from observing the means in Table 2, an analysis of variance presented in Tables 3 and 4 revealed the differences in the pain reaction thresholds between

Table 3. Analysis of variance of the pain reaction thresholds applying the Hardy-Wolff-Goodell Dolorimeter to the cutaneous area of the right shoulder

Source of variation	Degrees of freedom	Sum of squares	Mean square
Over-all mean	1	27,434,163.20	27,434,163.20
Among dogs	11	11,069.20	1,006.29**
Replication	458	27,908.38	60.94
Total	470	27,473,140.78	

**$P \geq .01$

Table 4. Analysis of variance of the pain reaction thresholds applying the Hardy-Wolff-Goodell Dolorimeter to the cutaneous area of the dorsal lumbar region

Source of variation	Degrees of freedom	Sum of squares	Mean square
Over-all mean	1	40,518,504.45	40,518,504.45
Among dogs	9	296,358.10	32,928.67**
Replication	395	58,205.66	147.36
Total	405	40,873,068.21	

**$P \geq .01$

dogs to be highly significant ($P \geq .01$). This indicates that there is less than one chance in a hundred that these differences could be due to coincidence. Since the Bartlett's Test for the homogeneity of the variance shows that the error variance within dogs is heterogenous, the above test may be invalid.

To express the consistency of the determination of the pain reaction thresholds, approximate 95 per cent confidence intervals based on the pooled estimate of error were computed. The confidence intervals for the shoulder area and lumbar area were 241.58 ± 2.89 and 316.28 ± 17.81 respectively. The average standard error of the mean for the shoulder area was 1.47 and 9.08 for the lumbar area. By comparing the means of the two areas to their respective standard error of the mean, the standard errors appear quite small. This reveals that there is a high degree of consistency in the determination of

pain reaction thresholds of the two areas. It also points out that the pain reaction thresholds of the shoulder area are more consistent than those of the lumbar area. Therefore, the shoulder area is recommended over the lumbar area as the preferred anatomical location for pain reaction threshold determinations.

Determination of the Pain Reaction Threshold with the Hardy-Wolff-Goodell Dolorimeter during Decompression

Previous investigators (81) have pointed out that the intensity of two pains existing separately at the same time is not greater than that of the more intense of the two. Also the existence of one pain actually raises the threshold for perception of another. Therefore, if the pain reaction threshold is raised during decompression as measured with the Hardy-Wolff-Goodell Dolorimeter, the experimental animal is receiving pain from another source during decompression. Conversely, if the pain reaction threshold is not altered during decompression, there is reason to believe that the animal does not receive pain from the decompression.

It was highly essential when the control pain reaction thresholds were recorded at 734.4 mm. of Hg. (average barometric pressure at Iowa State College) to keep the environment identical to that when the animal was decompressed. No other factors were varied except pressure change when the thresholds were recorded at the various decompression levels. The animal

was restrained in a similar method, the Euthanair motor was operating but the door was opened approximately one inch and the chamber was illuminated. The animal was restrained and put in the chamber in this manner several times before the thresholds were obtained. By turning on the motor and putting the animal in strange surroundings in the chamber, a large increase in the pain reaction threshold was initially observed. Even after the animal became accustomed to the motor and chamber, the pain reaction threshold was some higher with the motor operating.

The animal was found to become unconscious at approximately a pressure of 124 mm. of Hg. The final threshold was obtained just prior to unconsciousness. Thresholds were recorded until the animal exhibited any degree of fatigue or discomfort. Then they were discontinued until another day.

Inspection of Table 5 shows that pain reaction thresholds were recorded over the shoulder area of seven dogs and over the lumbar region of three animals. The lateral movement of the head appeared to be a more constant pain reaction threshold and could be reproduced with more accuracy than the musculature twitch of the lumbar region. It is also observed from this table that the differences between the means at the various decompression levels were small.

Experimental animal 31 showed the greatest difference in pain reaction thresholds during the decompression. The mean

Table 5. The number of pain reaction thresholds and their means recorded at various decompression levels

Decompression levels		734.4 mm. of Hg.		582.0 mm. of Hg.		429.6 mm. of Hg.		277.2 mm. of Hg.		124.8 mm. of Hg.		
Dog no.	S[a] or L	No. of observations	Mean[b]	No. of observations	Mean[b]	No. of observations	Mean[b]	No. of observations	Mean[b]	No. of observations	Mean[b]	Over-all mean[b]
31	L	30	376.0	30	387.8	30	387.5	20	388.3	12	397.1	385.8
32	S	20	316.3	10	337.0	10	328.5	10	332.5	8	330.6	326.7
33	L	20	306.3	15	310.0	15	307.3	14	308.2	11	312.3	308.5
34	S	25	311.6	15	312.7	13	310.8	10	319.0	9	323.3	314.2
35	S	25	248.2	10	248.0	10	255.0	10	251.5	9	259.4	251.8
36	L	20	375.3	12	374.2	12	376.3	10	373.5	8	383.8	376.0
37	S	20	274.3	10	283.0	10	283.5	10	278.0	7	277.9	278.7
38	S	20	345.5	14	349.1	10	350.0	10	351.0	9	359.4	350.2
39	S	20	267.3	10	264.5	10	260.0	10	261.0	9	271.7	265.3
40	S	20	347.0	15	341.7	15	342.7	10	354.5	8	354.3	349.8

[a] S = dolorimeter applied to the cutaneous area on the right shoulder; L = dolorimeter applied to the cutaneous area on the right dorsal lumbar area.

[b] Mc./cm.^{2}/sec.

of 30 observations before decompression was 376.0 mc./cm.^{2}/sec. while a mean of 397.1 mc./cm.^{2}/sec. was recorded at a pressure of 124.8 mm. of Hg. The data reveal that dog 37 recorded only a 3.6 mc./cm.^{2}/sec. rise from 734.4 mm. of Hg. down to 124.8 mm. of Hg. However, this experimental animal actually exhibited a drop of 0.1 mc./cm.^{2}/sec. when decompressed from 277.2 to 124.8 mm. of Hg.

It is observed from Table 6 that a total of 700 pain reaction thresholds were recorded on 10 dogs. Two hundred and fifty nine of these reaction thresholds were registered with the projector over the loin area on 3 dogs and the remaining 441 were observed when the thermal stimulus was applied to the integument of the shoulder on 7 dogs. The over-all means reveal an increase of 9.4 mc./cm.^{2}/sec. from 734.4 to 124.8 mm. of Hg. when the projector is applied to the shoulder. A 11.9 mc./cm.^{2}/sec. increase is observed during the decompression when the radiant heat is applied to the lumbar region.

It is noted from Table 6 that one of the largest increases in pain reaction thresholds occurs between 734.4 and 582 mm. of Hg. As previously mentioned the only difference between the recording of these two observations is that the chamber door is closed quietly from a distance of 1 inch and the chamber is decompressed to 582.0 mm. of Hg. It was noticed that usually the animal observed the closing of the chamber door and there is some change in motor noise when the chamber

Table 6. The total number of pain reaction thresholds and their over-all means recorded at various decompression levels on ten dogs

Cutaneous area where dolorimeter was applied	734.4 mm. of Hg.		582.0 mm. of Hg.		429.6 mm. of Hg.		277.2 mm. of Hg.		124.8 mm. of Hg.	
	Total no. of observations	Over-all mean[a]	Total no. of observations	Over-all mean[a]	Total no. of observations	Over-all mean[a]	Total no. of observations	Over-all mean[a]	Total no. of observations	Over-all mean[a]
Shoulder	150	301.5	84	305.1	78	304.4	70	306.8	59	310.9
Loin	70	352.5	57	357.3	57	357.0	44	356.7	31	364.4
Total observations per decompression level	220		141		135		114		90	
Total observations in the chamber									700	

[a] mc./cm.^{2}/sec.

is closed to start decompression. These two factors may play a part in the slight increase in pain reaction thresholds at this early stage of decompression.

The greatest increase in pain reaction thresholds is observed in the final decompression stage from 277.2 to 124.8 mm. of Hg. Two known factors may play a role in this increase. One is that at the final stage of decompression the animal begins to show rapid and deep respirations. The other factor is that as the atmospheric pressure decreases, an animal has a correspondingly decreased oxygen tension and as a result may exhibit poor response to external stimuli.

It may be of interest, preliminary to a careful normal analysis of the data, to perform a quick nonparametric sign test on the dolorimeter reading differences for adjacent threshold levels in Table 5. This test reveals 25 increases and 15 decreases. For example, for animal 31, 376.0 to 387.8 represents an increase, whereas 387.8 to 387.5 represents a decrease, etc. A 95 per cent confidence interval for the "true" proportion of increases, based on binomial theory, covers the fraction 1/2 (note that the ratio 25:15 persists (13:7) if only the first and last differences are calculated). In other words, granted that the sign test is not powerful, the non-numerical aspects of the data examined by this test show no material evidence against the hypothesis that successive pain reaction threshold increments tend to be neither positive or negative.

Table 7. Analysis of variance of pain reaction thresholds at various decompression levels

Dog no.	Within decompression levels			Between decompression levels			F_o value
	Sum of squares	Degrees of freedom	Mean square	Sum of squares	Degrees of freedom	Mean square	
31	47,500.88	117	405.99	4,577.18	4	1,144.30	2.82*
32	134,442.32	53	2,536.65	3,662.58	4	915.65	0.36
33	9,583.70	70	136.91	312.25	4	78.06	0.57
34	7,692.32	67	114.81	1,351.47	4	337.87	2.94*
35	5.757.51	59	97.58	1,090.65	4	272.66	2.79*
36	9,167.46	57	160.83	598.98	4	149.75	0.93
37	7,429.60	52	142.87	817.48	4	204.37	1.43
38	9,371.94	58	161.59	1,227.30	4	306.83	1.90
39	8,585.62	54	158.99	926.60	4	231.65	1.46
40	12,451.83	63	197.65	2,280.00	4	570.00	3.29*

*$P \geq .05$.

Ten analyses of variance, presented in Table 7, of the pain reaction thresholds at various decompression levels show the differences in the observations at these decompression levels to be non-significant when tested at a significance level of 0.01 on a per dog basis, although four of the animals showed significance at the 0.05 level. It is noted that the significance probability shows considerable variation, ranging up to a value of 0.85. This wide range of levels of significance is due in part to the large fluctuations in inherent variability exhibited in Tables 7, 13 and 14, and discussed on page 97.

The individual F analyses of Table 7 show the greater part of the useful statistical abstracting that seems warranted by the data. Nevertheless, it may be of interest to attempt an over-all evaluation of ten dogs used. This is done by Fisher's combination of independent tests of significance which allows one to test the over-all effect of decompression on the pain reaction thresholds. The calculation and results of this test are presented in Table 8. It is noted from this table that a value of 21.55 is obtained for the total $-\log_e P$ which gives an over-all significance level of 0.37. Individual shoulder and lumbar areas show values of ≥ 0.50 and 0.27. These relatively large levels of significance indicate that no material evidence has been adduced by the experiment and analysis against H_o: for the ten dogs (strictly speaking, "dog

Table 8. The combination of independent tests of significance of pain reaction thresholds at various decompression levels

Dog no.	F_o [a]	V_2 [b]	V_1 [c]	V_1F_o	$V_2+V_1F_o$	$\frac{V_2}{V_2+V_1F_o}$	P [d]	1/P	$-\text{Log}_e P$
31	2.82	117	4	11.30	128.3	0.913	0.03	33.3	3.51
32	0.36	53	4	1.44	54.4	0.976	0.85	1.2	0.18
33	0.57	70	4	2.28	72.3	0.969	0.67	1.5	0.41
34	2.94	67	4	11.80	78.8	0.851	0.03	33.3	3.51
35	2.79	59	4	11.20	70.2	0.840	0.03	33.3	3.51
36	0.93	57	4	3.72	60.7	0.940	0.42	2.4	0.88
37	1.43	52	4	5.71	57.7	0.901	0.22	4.6	1.53
38	1.90	58	4	7.60	65.6	0.884	0.11	9.1	2.21
39	1.46	54	4	5.84	59.8	0.903	0.20	5.0	1.61
40	3.29	63	4	13.20	76.2	0.827	0.02	67.0	4.20
Total									21.55[e]

[a] F_o = computed F from table.

[b] V_2 = degrees of freedom for replicates.

[c] V_1 = degrees of freedom for between decompression levels.

[d] P = probability derived from V_1, V_2 $\frac{V_2}{V_2+V_1F_o}$, (52).

[e] $X^2_{(20)}$ = P (.37).

body sites") used in the decompression experiment, pain reaction threshold (hence, by previously stated assumptions, pain) is not related to decompression level. Failure to adduce such evidence could be due to: 1) it is true that pain is not related to decompression. 2) the experiment was not precise enough to detect an existing pain-decompression relationship, perhaps due to the fluctuating inherent variability mentioned on page 80b. 3) the statistical test used (individual F's combined by Fisher's criterion) may have lacked the statistical power to detect an existing pain decompression level relationship. As a matter of fact, Appendix B describes a statistical technique which, if applied in this case, would have led to levels of significance higher than the 3 significance levels mentioned above. Reasons for featuring the present likely less powerful technique are given in the same appendix.

In connection with (3) above, the reader may wonder, irrespectively of the analysis he happens to favor, why the H_o considered here is the "no pain" hypothesis. This choice of H_o entails the assumption that the burden of proof is on "pain"; i.e., in order to believe "pain", pain effects large enough must be observed and statistical analysis powerful enough must be used, to sway the experimenter away from the "no pain" H_o. Clearly, the reader inclined to think that "pain" rather than "no pain" is to be expected would adopt "pain" as his H_o, requiring the experiment to be precise enough and the analysis

to be powerful enough to sway him to believing "no pain". Adopting the "pain" H_o requires defining dolorimeter readings corresponding to actual "substantial pain". If this were done, the data of this experiment could be used to test this new H_o, requiring now the burden of proof to be on "no pain", or the data could be used to decide between "pain" and "no pain" on a symmetric basis, with acknowledged probabilities of error of the first and second kind. Since neither H_o has been conclusively proven, it is presumptious to state that animals during decompression do or do not suffer pain. Further studies are necessary before definite conclusions can be drawn.

Pain Reaction Thresholds Determined by Electrical Stimulation of the Teeth

The pain reaction thresholds in the dog were ascertained by applying an electric current through a metal filling in the canine tooth and recording the lowest voltage at which the subject first experienced a painful sensation. Often the first painful sensation observed was a blinking of the eyelids, but this appeared to be inconsistent. It was observed that at a higher voltage a distinctly perceptible twitch of facial muscles appeared and this twitch was used as the pain reaction threshold. This muscle twitch appears to be quite constant compared to the other reactions observed and only occasionally would the animal struggle violently on electrical

Table 9. The pain reaction thresholds obtained by electrical stimulation of the teeth

Dog no.	Left canine tooth			Right canine tooth		
	No. of observations	Mean (Volts)	Range (Volts)	No. of observations	Mean (Volts)	Range (Volts)
301	20	31.49	24.75 - 44.00	20	33.13	26.84 - 40.04
302	20	36.34	24.04 - 43.26	20	39.64	29.92 - 44.00
303	20	38.79	33.44 - 42.24	20	38.59	31.24 - 44.00
304	20	30.58	23.85 - 36.95	20	39.29	34.76 - 44.00
305	20	35.12	20.24 - 44.00	20	33.66	27.28 - 40.48
Total no. of observations	100			100		
Overall mean		34.46			36.86	
Ave. range			25.26 - 42.09			30.01 - 42.50

stimulation of the tooth. As in previous experiments, it was highly essential to adapt the animal to the platform restraint methods, electrical stimulator and environment before recording the observations.

It is noted in Table 9 that 200 observations were recorded on 10 canine teeth of 5 dogs. This table reveals a wide mean range of 30.58 to 38.79 volts on the left canine tooth and a mean range of 33.13 to 39.64 volts on the right canine tooth. An average range of 25.26 to 42.09 volts was observed on the left canine tooth and 30.01 to 42.50 volts on the opposite canine tooth. Dog 305 revealed a 23.76 volt range on the left tooth and dog 302 exhibited a 14.08 volt range on the right tooth. It should be pointed out that the maximum voltage elicited by the painometer was 44.00 volts which is observed in Table 9 as the maximum range on at least one tooth of the experimental animals. Occasionally 44.00 volts failed to elicit a pain reaction in the animals.

Several factors may play a part in the wide variations observed in the pain reaction thresholds recorded by electrical stimulation of the canine tooth. Although care was exercised in placing the depth of the metal filling as nearly equal as possible in the canine teeth, a variation of 10,000 to 75,000 ohms resistance was still obtained across the teeth. This would obviously vary greatly the amount of current essential for stimulation. Even though the muscular twitch of the fa-

cial muscles appeared to be the most constant pain reaction upon electrical stimulation of the canine tooth, it did not offer as clear cut an identification of pain and with the consistency when compared to the reaction observed from thermal stimulation of the integument. The silver amalgam fillings were hand packed and some variation in the density of the filling is inevitable. The pincer like electrodes no doubt varied some in their contact on various inlays.

As would be expected from observing the mean thresholds, an analysis of variance, presented in Table 10, indicated the

Table 10. Analysis of variance of the pain reaction thresholds obtained by electrical stimulation of the teeth

Source of variation	Degrees of freedom	Sum of squares	Mean square
Over-all mean	1	254,327.12	254,327.12
Among teeth	9	2,036.33	226.26**
Among dogs	4	1,120.10	280.03**
Between (R and L) teeth	1	288.00	288.00
Dogs x (R and L) teeth	4	628.23	157.06
Replication	190	4,065.10	21.40[a]
Total	200	260,428.55	

**$P \geq .01$.

[a]The estimate of the true standard deviation = $\sqrt{21.40} = 4.58$.

difference in the means among the dogs and between the teeth to be highly significant ($P \geq .01$). Also attention is called to the large interaction (157.06) which makes the interpretation of the F values among dogs and among teeth less meaningful. A very high estimate of the true standard deviation (4.58) indicates a lack of reproducibility; hence, error is excessive in measuring the pain reaction threshold of the canine tooth by electrical stimulation. Because of this error observed in the control observations, no attempt was made to record the pain reaction thresholds during decompression by electrical stimulation of the tooth.

Anxiety and Excitement Observed during Decompression Pre- and Post-morphinization of the Experimental Animals

Dogs vary a great deal in the amount of apprehension they exhibit during decompression. Some animals lie quietly or "sniff" inquisitively at the chamber walls while other dogs yelp and make violent attempts to escape from the chamber. As Hardy *et al.* (28) pointed out, pain of moderate intensity can be eliminated by the opiates. This is well substantiated by observing Table 11. One mg./kg. of morphine raised the over-all mean pain reaction threshold 129 mc./cm.^{2}/sec. when the projector was applied to the shoulder of 9 dogs. The over-all mean pain reaction threshold was raised 106.2 mc./cm.^{2}/sec. when the thermal stimulus was applied to the lumbar area of 4

Table 11. The pain reaction threshold means before and after morphine administration using the Hardy-Wolff-Goodell Dolorimeter. Anxiety and apprehension observed during decompression are recorded before and after the injection of morphine

Dog no.	S[a] or L	No. of observations with dolorimeter	Dolorimetric means[b]		Anxiety and apprehension during decompression[c]	
			Before morphinization	After morphinization 1 mg./kg.[d]	Before morphinization	After morphinization 1 mg./kg.[e]
101[f]	S	20	240.2	289.5	2	3
	L	20	269.2	309.8		
102	S	50	233.9	378.1	3	1
	L	50	304.4	465.7		
103	S	50	238.9	341.0	3	2
	L	50	298.8	371.2		
104	S	50	265.6	385.3	1	1

[a]S = dolorimeter applied to cutaneous area of right shoulder; L = dolorimeter applied to cutaneous area on the right dorsal lumbar area.

[b]Mc./cm.^{2}/sec.

[c]Anxiety and apprehension expressed from numbers 1 to 5 with number 1 designating the smallest amount of excitement and number 5 the greatest excitement.

[d]Pain reaction thresholds recorded 1 hour after morphine administration.

[e]Decompressed 1 hour after administration of morphine.

[f]Appeared to be refractive to morphine as no salivation, vomition or depression was observed.

Table 11. (Continued)

Dog no.	S[a] or L	No. of observations with dolorimeter	Dolorimetric means[b]		Anxiety and apprehension during decompression[c]	
			Before morphinization	After morphinization 1 mg./kg.[d]	Before morphinization	After morphinization 1 mg./kg.[e]
105	S	50	240.3	406.1	2	1
106	L	50	351.9	463.1	4	1
107	S	50	246.4	359.0	2	1
108	S	50	247.2	421.4	1	1
109[f]	S	50	242.6	313.1	2	2
110	S	50	247.3	422.0	3	2
Overall mean	S		245.0	374.0		
	L		312.6	418.8		

dogs. This gives an increase of 34.5 per cent and 25.4 per cent when the projector was applied to the shoulder and lumbar area, respectively.

Further inspection of Table 11 reveals that in six out of the ten animals the amount of anxiety decreased during decompression after the injection of 1 mg./kg. of morphine. In only dog 101 did there appear to be some increase in apprehension. It should be pointed out that in addition to the rise in pain reaction threshold, the administration of morphine resulted in relaxation, and freedom of anxiety, lethargy and apathy before the animal was decompressed. This is well in agreement with reports by Oberst (49). Since the morphine decreased the anxiety and apprehension before decompression, it would appear that little or no emphasis can be assigned to the observation that the experimental animals exhibited less excitement during decompression post-morphinization.

It is interesting to note from Table 11 that in the control observations during decompression, 20 per cent of the dogs exhibited no apprehension and excitement, 40 per cent manifested some anxiety, 30 per cent appeared excited and only 10 per cent showed marked anxiety. This appears to well represent the amount of excitement exhibited by all of the animals decompressed here in these experiments at Iowa State College; that is, about one-half of the animals reveals some excitement and 1 out of every 10 exhibits marked anxiety.

It is also of interest to note from Table 11 that dogs 101 and 109 appeared to be refractive to morphine as no salivation, vomition or depression was observed. Nevertheless, an increase in pain reaction thresholds was observed but much less than the over-all mean increase.

Observations of the Anxiety and Apprehension during Decompression Before and After Severing the Lateral Spinothalamic Tracts

Elsberg (19) pointed out in his work on humans that a bilateral section of the lateral spinothalamic tracts results in a loss of pain sensibility in all structures below the segment through which the section was made including the viscera. A bilateral section of these tracts was made at the level of the second cervical vertebrae on 14 experimental dogs. The dorsal roots of the second cervical nerves were transected as well as the first cervical nerves as they emerge from the intervertebral foramina.

It may be noted from Table 12 that very little change in excitement and anxiety was observed in the nine dogs decompressed after the bilateral sectioning of the lateral spinothalamic tracts. Four dogs exhibited no apparent change while dogs 202 and 207 appeared to increase some in excitement. Animals 205, 210 and 211 exhibited some decrease in anxiety. In view of this little or no change in excitement

Table 12. The amount of anxiety exhibited during depression and the pain reaction thresholds recorded with the Hardy-Wolff-Goodell Dolorimeter observed before and after severing of the lateral spinothalamic tracts of the dog

Dog no.	Amount of anxiety exhibited during decompression[a]		Dolorimetric means - projector applied to lumbar region (mc./cm.^{2}/sec.)		Sensitivity to needle puncture caudal to shoulder area	Remarks
	Before severing lateral spino-thalamic tracts	After severing lateral spino-thalamic tracts	Before severing lateral spino-thalamic tracts (10 observations)	After severing lateral spino-thalamic tracts (10 observations)		
201	3	-	306.3	-	-	Respiratory paralysis observed when 2nd lat. spinothalamic tract was severed
202	1	2	325.6	392.6	Absent	-
203	4	-	296.4	-	-	Died in 5 days with central nervous disturbances
204	2	2	346.1	420.1	Absent	-
205	2	1	340.6	500+	Absent	-
206	1	-	305.6	-	-	Respiratory paralysis observed when 2nd lat. spinothalamic tract was severed

[a]Expressed from numbers 1 to 5 with number 1 designating the smallest amount of excitement and number 5 the greatest amount of excitement during decompression.

Table 12. (Continued)

Dog no.	Amount of anxiety exhibited during decompression[a]		Dolorimetric mean - projector applied to lumbar region (mc./cm.^{2}/sec.)		Sensitivity to needle puncture caudal to shoulder area	Remarks
	Before severing lateral spino-thalamic tracts	After severing lateral spino-thalamic tracts	Before severing lateral spino-thalamic tracts (10 observations)	After severing lateral spino-thalamic tracts (10 observations)		
207	2	3	310.6	440.1	Some on right thigh and abdominal wall	-
208	3	3	346.3	401.6	Very slight	-
209	2	-	321.3	-	-	Complete flaccid paralysis of limbs
210	3	2	336.3	425.0	Absent	-
211	4	3	300.6	435.2	Absent	-
212	3	3	297.4	500+	Some on right rear leg	-
213	4	-	312.6	-	-	Died two days after surgery
214	2	2	287.9	464.5	Very slight	-

after alleviating the animal of the pain sensation, there is reason to believe that the anxiety and excitement observed during decompression are not the result of painful stimuli. No doubt the motor and vacuum noise, and a strange enclosed environment play a major role in the excitement and apprehension exhibited during decompression.

Further inspection of Table 12 shows that the sensitivity to a needle puncture caudal to the shoulder was completely alleviated in dogs 202, 204, 205, 210 and 211. It was greatly decreased in the other four dogs tested. A pain reaction could be observed in the facial area as the result of cutaneous innervation by some of the cranial nerves. Also a pain reaction could be manifested by the needle puncture over the anterior part of the shoulder area as the result of the cutaneous innervation by the spinal accessory nerve.

The fact that a pain response could be observed by thermal stimulation and not by a mechanical stimulation is difficult to explain. It is observed in Table 12 that the pain reaction threshold was greatly increased after the bilateral sectioning of the spinothalamic tracts. In experimental animals 205 and 212 no pain reaction was exhibited when 500 mc./cm.^{2}/sec. were applied for 3 seconds. Severe integumental necrosis did result.

The data also reveal that two animals died when the second lateral spinothalamic tract was severed. It is highly possible that the incisions were deep enough to transect the respiratory tract resulting in respiratory paralysis. Peet et al. (53) points out that in man an upper bilateral cervical chordotomy should not be performed because of the danger of respiratory paralysis. They mention that the exact location of these tracts descending to these cell bodies is unknown. They point out that edema following the sectioning of the lateral spinothalamic tracts might involve these descending fibers as well as the tracts of the intercostal muscles, resulting in respiratory failure. It is highly possible that this may have been responsible for the death of animal 213 which died two days after surgery. Also a large quantity of edema surrounding the cord may have caused the central nervous disturbances observed in animals 203 and 209.

In the animals that survived the operation, urinary and fecal retention was a common sequela for 48 to 72 hours following surgery. The experimental animal was usually unable to rise until about the third to the seventh day. Some incoordination and ataxia were observed for 2 to 4 weeks after the operation. The ataxia was most prominent in the rear quarters. In approximately 4 weeks, the return of a normal gait and actions was observed.

The increases of 9.4 and 11.9 mc./cm.^{2}/sec. observed in Table 6 and discussed on page 77 are small if compared to the increases of about 50 mc./cm.^{2}/sec. which are frequently necessary to show a perceptible increase in a pain reaction. In other words, it requires an increase of about 50 mc./cm.^{2}/sec. above the pain reaction threshold to evoke a pain reaction revealing severe pain. A great deal of variation was observed among animals.

SUMMARY AND CONCLUSIONS

A series of preliminary experiments were performed to determine if pain is experienced during decompression in the dog. A total of 875 pain reaction thresholds were recorded with the Hardy-Wolff-Goodell Dolorimeter on 15 dogs.

The application of radiant heat to the shoulder of the dog was found to give a sudden lateral movement of the head towards the projector. The definite, reproducible pain reaction was quite constant and an over-all threshold mean of 241.58 mc./cm.^{2}/sec. was recorded for 470 observations. An average range of 226.7 to 252.1 mc./cm.^{2}/sec. was observed. The confidence interval for the shoulder area was 241.58 $\pm$ 2.89 and the standard error of the mean was 1.47. Thus, a high degree of consistency in the determination of the pain reaction thresholds of this area was observed.

When a thermal stimulus was applied to the dorsal lumbar region of the dog, a characteristic muscle twitch was observed. This pain reaction exhibits an over-all threshold mean of 316.28 mc./cm.^{2}/sec., a confidence interval of 316.28 $\pm$ 17.81 and a standard error of 9.08. These data reveal that the pain reaction thresholds of the shoulder area are more consistent than those of the lumbar area.

Seven hundred pain reaction thresholds were recorded at various decompression levels on ten dogs. A small increase of 9.4 mc./cm.^{2}/sec. was recorded in the over-all means from

734.4 mm. of Hg. (average barometric pressure at Iowa State College) to 124.8 mm. of Hg. when the thermal stimulus was applied to the shoulder of 7 dogs. An increase of 11.9 mc./cm.^{2}/sec. was recorded in the over-all means at similar decompression levels when the projector was applied to the lumbar area of 3 dogs. A statistical analysis of the data using a combination of independent tests of significance revealed the differences in the pain reaction thresholds at various decompression levels to be insignificant ($P \geq 0.50$ for the lumbar area, and $P = 0.27$ for the shoulder area), which means that according to this experiment, and analysis adopted, no convincing evidence against H_o (page 80b) has been uncovered.

This insignificance must be judged in the context of the qualifying remarks on pages 80b and 82, and also in the light of the following two considerations, all of which emphasize the exploratory nature of this work:

1. No attempt was made to randomly select dogs from a well defined population to which one might want to apply any inferences made on the basis of this work. As a matter of fact, selection, if carried out at all, was on the basis rather of experimental convenience (nervous stability and youth).
2. Under the standardized conditions outside of the chamber, some of the 15 dogs tested exhibited day to

day (inherent) variability comparable to the treatment variability exhibited by the ten dogs in the actual decompression experiment (Tables 7, 13 and 14). Unusually great inherent variability was also exhibited by dog 32 in the decompression experiment (Table 7). The nature of this occasionally large inherent variability is not completely understood. In addition, attention is drawn to the significant inter-dog variability exhibited in Tables 3 and 4. Since neither of the two H_o described on page 82 has been conclusively proven, it is presumptuous to state that animals during decompression do or do not suffer pain. Further studies are necessary before definite conclusions can be drawn.

Pain reaction thresholds were determined by electrical stimulation of metal fillings in the canine tooth. An electrical stimulator was designed with a capacity of 44 volts (d.c.). A total of 200 observations was recorded on 10 teeth of five dogs. A wide average range of 25.26 to 42.09 volts was observed in the pain reaction thresholds on the left canine tooth and an average range of 30.01 to 42.50 volts was recorded on the opposite canine tooth. A very high standard deviation (4.58) indicated the lack of reproducibility of the pain reaction thresholds by electrical stimulation of the canine tooth. Because of this large error of obtaining pain

reaction thresholds by this method, no attempt was made to record the pain reaction thresholds during decompression.

The injection of 1 mg./kg. of morphine increased the pain reaction thresholds 34.5 per cent and 25.4 per cent when the dolorimeter was applied to the shoulder and lumbar region, respectively. The majority of the animals exhibited a decrease in anxiety during decompression after the injection of morphine. It was evident that in addition to the rise in pain reaction threshold, the administration of morphine resulted in a relaxation, and a freedom from anxiety and lethargy before the animal was decompressed. Since the opiate decreased the excitement and apprehension before decompression, it appears that little or no emphasis can be attributed to the observation that the experimental animals exhibited less excitement during decompression post-morphinization. The data point out that approximately one-half of the animals decompressed reveals a small amount of excitement and only 1 out of 10 exhibits marked anxiety.

The bilateral sectioning of the lateral spinothalamic tracts of the dog, which may have involved the severing of other tracts of that area, markedly decreased pain sensitivity and completely alleviated pain reaction due to mechanical stimulation caudal to the shoulder in 5 animals. There appeared to be little or no change in anxiety and excitement during decompression following the bilateral sectioning of the lateral spinothalamic tracts. This indicates that the anxiety and

apprehension observed during decompression are not manifestations of painful stimuli.

LITERATURE CITED

1. Andrews, H. L. and Workman, W. Pain threshold measurements in the dog. J. Pharm. and Exp. Ther. 73: 99-103. 1941.

2. Armstrong, H. G. Principles and practice of aviation medicine. The Williams and Wilkins Co. Baltimore, Md. 1939.

3. Bishop, G. H. The peripheral unit for pain. J. Neurophysiol. 7: 71-80. 1944.

4. Boring, E. G. The sensations of the alimentary canal. Am. J. Psychol. 26: 1-57. 1915.

5. Bruce, A. N. and Schafer, P. The tract of Gowers. Quart. J. Exp. Physiol. 3: 391-407. 1910.

6. Burch, B. H. and Hitchcock, F. A. X-ray observations on dogs following explosive decompression to 30 mm. of Hg. Fed. Proc. 9: 19. 1950.

7. _____, Kemph, J. P., Vail, E. G., Frye, S. A. and Hitchcock, F. A. Some effects of explosive decompression and subsequent exposure to 30 mm. of Hg. upon the hearts of dogs. J. of Avia. Med. 23: 159-167. 1952.

8. Cadwalader, W. B. and Sweet, J. E. Experimental work on the function of the anterolateral column of the spinal cord. J. Am. Med. Assoc. 58: 1490-1493. 1912.

9. Chapman, W. P., Herrera, R. and Jones, C. M. A comparison of pain produced experimentally in lower esophagus, common bile duct and upper small intestine with pain experienced by patients with diseases of the biliary tract and pancreas. Surg., Gynec. and Obst. 89: 573-582. 1949.

10. _____ and Jones, C. M. Variations in cutaneous and visceral pain sensitivity in normal subjects. J. Clin. Invest. 23: 81-91. 1944.

11. Clark, W. E. The termination of the ascending tracts in the thalamus of the Macaque monkey. J. Anat. 71: 7-40. 1936.

12. D'Amour, F. E. and Smith, D. L. A method for determining loss of pain sensation. J. Pharm. and Exp. Ther. 72: 74-79. 1941.

13. Dogliotti, M. First surgical section in man, of the lemniscus lateralis (pain, temperature path) at the brain stem for the treatment of diffused rebellious pain. Anesth. and Analg. 17: 143-145. 1938.

14. Eddy, N. B. Studies of morphine, codeine and their derivatives. J. Pharm. and Exp. Ther. 45: 339-344. 1932.

15. _____. Studies on hypnotics of barbituric acid series. J. Pharm. 33: 43-52. 1938.

16. Edelmann, A. and Hitchcock, F. A. Observations on dogs exposed to an ambient pressure of 30 mm. of Hg. J. Appl. Physiol. 5: 807-812. 1951.

17. Edinger, L. Vergleichend-entwichlungsgeschichtlich und anatomische Studien in Bereiche des Centralnerven Systems: II. Ueber die Fortsetzung der hinteren Ruchenmarkswurzeln zum Gehirn. Anat. Anz. 4: 121-128. 1889.

18. Elo, J. and Nikula, A. Zur Topographe des Warmesinnes. Skan. Arch. fur Physiol. 24: 226-246. 1910.

19. Elsberg, C. A. Surgical diseases of the spinal cord, membranes and nerve roots. P. B. Hoeber, Inc. New York, N.Y. 1941.

20. Gaensler, E. A. Quantitative determination of the visceral pain threshold in man. J. Clin. Invest. 30: 406-420. 1951.

21. Gasser, H. S. Pain producing impulses in peripheral nerves. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 44-61. 1943.

22. Gluzek, F. R. Dolorimetry: a quantitative method of measuring pain and deep sensibility. Ohio State Med. J. 40: 49-56. 1944.

23. Goetzl, F. R., Bien, C. W. and Ivy, A. C. A critical analysis of algesimetric methods with suggestions for a useful procedure. Northwestern Univ. Med. Sch. Quart. Bull. 17: 280-291. 1943.

24. Goldscheider, A. Die spezifische Energie der Gefuhlsnerven der Haut. Monatschr. Prakt. Dermatol. 3: 283-291. 1884.

25. Hardy, J. D. and Goodell, H. Studies on pain: an investigation of some quantitative aspects of the dol scale of pain intensity. J. Clin. Invest. 27: 380-386. 1948.

26. _____ and Javert, C. T. Studies on pain: measurements of pain intensity in childbirth. J. Clin. Invest. 28: 153-162. 1949.

27. _____, Stoll, A. M., Cunningham, D., Benson, W. M. and Greene, L. Responses of the rat to thermal radiation. Am. J. Physiol. 189: 1-5. 1957.

28. _____, _____, and _____. Pain sensations and reactions. The Williams and Wilkins Co. Baltimore, Md. 1952.

29. _____, Wolff, H. G. and Goodell, H. Studies on pain. A new method for measuring pain threshold: observations on spatial summation of pain. J. Clin. Invest. 19: 649-657. 1940.

30. _____, _____, and _____. Studies on pain: discrimination of differences in intensity of a pain stimulus as a basis of a scale of pain intensity. J. Clin. Invest. 26: 1152-1158. 1947.

31. Harris, S. C. and Blockus, L. E. The reliability and validity of tooth pulp algesimetry. J. Pharm. and Exp. Ther. 104: 135-148. 1952.

32. _____ and Brandel, N. E. Tooth pulp as algesimetry site. J. Dent. Res. 29: 68-72. 1950.

33. _____ and Worley, R. C. Evaluation of a new analgesic. J. Appl. Physiol. 7: 84-88. 1954.

34. Haugen, F. P. and Livingston, W. K. Experiences with the Hardy-Wolff-Goodell Dolorimeter. Anesth. 14: 109-116. 1953.

35. Hyndman, O. R. and Van Epps, C. Possibility of differential section of the spinothalamic tract. Arch. Surg. 38: 1036-1053. 1939.

36. Kemph, J. P., Beman, F. M. and Hitchcock, F. A. Subcutaneous pressure developed in dogs following explosive decompression to 25 or 30 mm. of Hg. Am. J. Physiol. 168: 601-604. 1952.

37. _____, Burch, B. H., Beman, F. M. and Hitchcock, F. A. Further observations on dogs explosively decompressed to an ambient pressure of 30 mm. of Hg. J. of Avia. Med. 25: 107-112. 1954.

38. _____ and Hitchcock, F. A. Changes in blood and circulation of dogs following explosive decompression to low barometric pressure. Am. J. Physiol. 168: 592-600. 1952.

39. Kiesow, F. The problem of the condition of arousal of the pure sensation of cutaneous pain. J. Gen. Psychol. 1: 199-212. 1928.

40. Kuhn, R. A. and Bromiley, R. B. Human pain thresholds determined by the radiant heat technique and the effect upon them of acetyl-salicylic acid, morphine sulfate and sodium phenobarbital. J. Pharm. and Exp. Ther. 101: 47-55. 1951.

41. Lacey, J. I., Lacey, B. C. and Dallenbach, K. M. Areal and temporal variations in pain sensitivity. Am. J. Psychol. 54: 413-417. 1941.

42. Lewandowsky, M. Hanbuch der Neurologie. Berlin. Verlag Von Julius Springer. 1911.

43. Libman, E. Observations on sensitiveness to pain. J. Am. Med. Assoc. 102: 335-341. 1934.

44. Lloyd-Smith, D. L. and Mendelssohn, K. Tolerance limits to radiant heat. Brit. Med. J. 16: 975-982. 1948.

45. Macht, D. I. and Macht, M. B. Quantitative studies on pain threshold after administration of various drugs. J. Am. Pharm. Assoc. 29: 193-199. 1940.

46. Martin, E. G., Withington, P. R. and Putman, J. J. Variations in the sensory threshold for faradic stimulation in normal human subjects. III. The influence of general fatigue. Am. J. Physiol. 34: 97-105. 1914.

47. McAuliffe, G. W., Goodell, H. and Wolff, H. G. Experimental studies on headache: pain from the nasal and paranasal structures. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 185-208. 1943.

48. Mott, F. W. Experimental inquiry upon the afferent tracts of the central nervous system of the monkey. Brain 18: 1-20. 1895.

49. Oberst, F. M. Chairman of symposium on "Can the euphoric, analgetic and physical dependence effects of drugs be separated?" Fed. Proc. 2: 187-188. 1943.

50. Oppel, T. W. and Hardy, J. D. Studies in temperature sensation. I. A comparison of the sensation produced by infra-red and visible radiation. J. Clin. Invest. 16: 517-524. 1937.

51. Palmer, W. L. The pain of a peptic ulcer. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 302-326. 1943.

52. Pearson, E. S. and Hartley, H. O. Biometrika tables for statistics. Cambridge Univ. Press, Baltimore, Md. 1: 32. 1954.

53. Peet, M. M., Kahn, E. A. and Allen, S. S. Bilateral cervical chordotomy for relief of pain in chronic infectious arthritis. J. Am. Med. Assoc. 100: 488-489. 1933.

54. Pelner, L. The determination of sensitivity to pain. J. Lab. and Clin. Med. 27: 248-253. 1941.

55. Pfeiffer, C. C., Sonnenschein, R. R., Glassman, L., Jenny, E. H. and Bogolub, S. Experimental methods for studying analgesia. Ann. New York Acad. Sc. 51: 21-29. 1948.

56. Putman, T. J. Myelotomy of the commissure. A new method of treatment of pain in the upper extremities. Arch. Neurol. and Psychiat. 32: 1189-1193. 1934.

57. Quensel, F. and Kohnstamm, O. Praparate mit Aktiven Zelldegenerationen nach Hirnstamm Verletzung bei Kaninchen. Neurol. Zentralbl. 26: 1138-1139. 1907.

58. Revici, E. and Ravich, R. A. The painful focus. I. Physiological and pathological pain. Bull. Inst. Appl. Biol. 1: 12-21. 1949.

59. Robertson, H. S., Goodell, H. and Wolff, H. G. Studies on headache: the teeth as a source of headache and other pain. Arch. Neurol. and Psychiat. 57: 277-286. 1947.

60. Rosenthal, S. R. Histamine as a possible chemical mediator for cutaneous pain. Dual pain response to histamine. Proc. Soc. Exp. Biol. and Med. 74: 167-170. 1950.

61. Schartz, H. G. and O'Leary, J. L. Section of the spinothalamic tract in the medulla with observations on the pathway for pain. Surgery 9: 183-193. 1941.

62. Simons, D. J., Day, E., Goodell, H. and Hardy, H. G. Experimental studies on headache: muscles of the head and neck as a source of pain. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 228-243. 1943.

63. Sonnenschein, R. R., Jenny, F. H. and Pfeiffer, C. C. Effects of tetraethyl-ammonium chloride on pain thresholds in man. J. Appl. Physiol. 2: 141-147. 1950.

64. Spiller, W. G. The location within the spinal cord of the fibers for temperature and pain sensations. J. Nerv. and Ment. Dis. 32: 318-320. 1905.

65. _____ and Martin, E. The treatment of persistent pain of organic origin in the lower part of the body by division of the anterolateral columns of the spinal cord. J. Am. Med. Assoc. 58: 1489-1490. 1912.

66. Stone, L. J. and Dallenbach, K. M. Adaptation to the pain of radiant heat. Am. J. Psychol. 46: 229-242.

67. Vail, E. G. and Hitchcock, F. A. Effect of explosive decompression on the temperature of the lungs. Fed. Proc. 155: 473-474. 1948.

68. Walker, A. E. The spinothalamic tract in man. Arch. Neurol. and Psychiat. 43: 284-298. 1940.

69. _____. The thalamus of the chimpanzee. I. Terminations of the somatic afferent system. Confina Neurol. 1: 99-127. 1938.

70. Weddell, G. The pattern of cutaneous innervation in relation to cutaneous sensibility. J. of Anat. 75: 346-367. 1941.

71. Weitz, J. A further study of the relation between skin temperature and cutaneous sensitivity. J. Exp. Psychol. 30: 426-431. 1942.

72. Wells, H. S. Temperature equalization for the relief of pain. Arch. Phys. Med. 28: 135-139. 1947.

73. White, J. C. Sensory innervation of the viscera. Studies on visceral afferent neurons in man based on neurosurgical procedures for the relief of intractable pain. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 373-389. 1943.

74. _____. Spinothalamic tractotomy in the medulla oblongata: an operation for the relief of intractable neuralgias of the occiput, neck and shoulder. Arch. Surg. 43: 113-127. 1941.

75. Whitehorn, W. V. Circulatory responses to exposure to barometric pressures of 30 mm. of Hg. Fed. Proc. 7: 133. 1948.

76. Winder, C. V. Distribution of resting pain-reaction thresholds in guinea pigs with statistical concept of gradation of biological effect. Yale J. Biol. and Med. 19: 289-308. 1947.

77. Wolf, S. and Hardy, J. D. Studies on pain: observations on pain due to local cooling and on factors involved in the "cold pressor" effect. J. Clin. Invest. 20: 521-533. 1941.

78. Wolff, H. G., Hardy, J. D., and Goodell, H. Studies on pain. Measurement of the effect of morphine, codeine and other opiates on the pain threshold and an analysis of their relation to the pain experience. J. Clin. Invest. 19: 659-680. 1940.

79. _____, _____, and _____. Measurement of the effect on the pain threshold of acetysalicylic acid, acetanilid, acetophenetidin, aminopyrine, ethyl alcohol, trichlorethylene, a barbiturate, quinine, ergotamine tartrate and caffeine: an analysis of their relation to the pain experience. J. Clin. Invest. 20: 63-80. 1941.

80. _____, _____, and _____. Studies on pain. Measurement of the effect of ethyl alcohol on the pain threshold and on the "alarm" reaction. J. Pharm. and Exp. Ther. 75: 38-49. 1942.

81. _____ and Wolf, S. Pain. 1st ed. C. C. Thomas, Springfield, Ill. 1951.

82. Woollard, H.H., Weddell, G. and Harpman, J. A. Observations on the neurohistological basis of cutaneous pain. J. Anat. 74: 413-437. 1940.

83. Worthman, R. P. The longitudinal vertebral venous sinuses of the dog. I. Anatomy. Am. J. Vet. Res. 17: 341-348. 1956.

84. Ziskin, D. E. and Wald, A. Observations on electrical pulp testing. J. Dent. Res. 17: 79-89. 1938.

LITERATURE REVIEWED BUT NOT CITED

1. Andrell, O. Cutaneous pain elicited in man by thermal radiation: dependence of the threshold intensity on stimulation time, skin temperature and analgesics. Acta Pharm. et Toxicol. 10: 30-37. 1954.

2. Benjamin, F. B. Effect of pain on simultaneous perception of nonpainful sensory stimulation. J. of Appl. Physiol. 8: 630-634. 1956.

3. Bentley, F. H. and Smithwick, R. H. Visceral pain produced by balloon distension of the jejunum. Lancet. 2: 389-391. 1940.

4. Bigelow, N., Harrison, I., Goodell, H. and Wolff, H. G. Studies on pain: quantitative measurements of two pain sensations of skin, with reference to the nature of 'hyperalgesia' or peripheral neuritis. J. Clin. Invest. 24: 503-512. 1945.

5. Bishop, G. H. The responses to electrical stimulation of single sensory units of the skin. J. Neurophysiol. 6: 361-382. 1943.

6. Bloomfield, A. L. and Polland, W. S. Experimental referred pain from the gastro-intestinal tract. Part II. Stomach, duodenum and colon. J. Clin. Invest. 10: 453-473. 1931.

7. Brashear, A. D. Innervation of the teeth. J. Am. Dent. Assoc. 23: 662-668. 1936.

8. Cannon, B. A method of stimulating autonomic nerves in the unanesthetized cat with observations on the motor and sensory effects. Am. J. Physiol. 105: 366-372. 1933.

9. Cannon, W. B. Bodily changes in pain, hunger, fear and rage. Appleton and Co. New York, N.Y. 1929.

10. Chiodi, H. Blood picture at high altitude. J. Appl. Physiol. 2: 431-436. 1950.

11. Cole, C. H., Chamberlain, D. M., Kemph, J. P., Burch, B. H. and Hitchcock, F. A. Pathological effects of explosive decompression to 30 mm. of Hg. J. Appl. Physiol. 6: 96-104. 1953.

12. Davis, L. The surgical treatment of intractable pain. J. Am. Med. Assoc. 101: 1921-1925. 1933.

13. _____ and Pollock, L. J. The peripheral pathway for painful sensations. Arch. Neurol. and Psychiat. 24: 883-898. 1930.

14. Dill, D. B. and Pentrod, K. E. Man's ceiling as determined in the altitude chamber. J. Appl. Physiol. 1: 409-417. 1948.

15. Eggleton, P., Elsden, S. R., Fegler, J. and Hebb, C. O. A study of the effects of rapid 'decompression' in certain animals. J. Physiol. 104: 129-150. 1945.

16. Fisher, R. A. Statistical methods for research workers. 12th ed. Oliver and Boyd. London. 1954.

17. Frazier, C. H. Surgery of the spine and spinal cord. D. Appleton and Co. New York, N. Y. 1918.

18. Gelfan, S. and Werner, A. Y. Cardiovascular responses following explosive decompression of Macaque monkeys to extreme altitudes. J. Appl. Physiol. 4: 280-309. 1951.

19. Goetzl, F. R., Bien, C. W. and Go Lu. Changes in blood pressure in response to presumably painful stimuli. J. Appl. Physiol. 4: 161-170. 1951.

20. Gordon, G. and Whitteridge, D. Conduction time for human pain sensation. Lancet. 2: 700-701. 1943.

21. Grant, F. C. Surgical Methods for relief of pain. J. Am. Med. Assoc. 116: 567-571. 1941.

22. Gregg, E. C. Physical basis of pain threshold measurements in man. J. Appl. Physiol. 4: 351-363. 1951.

23. Harrison, I. B. and Biglow, N. H. Quantitative studies of visceral pain produced by the contraction of ischemic muscle. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 154-165. 1943.

24. Hitchcock, F. A. and Edelman, A. The response of normal dogs to explosive decompression to 30 mm. of Hg. Fed. Proc. 6: 130. 1947.

25. _____, Whitehorn, W. V. and Edel, A. Tolerance of normal men to explosive decompression. J. Appl. Physiol. 1: 418-429. 1948.

26. Hoffman, C. E., Clark, R. T., and Brown, E. B. Blood oxygen saturations and duration of consciousness in anoxia at high altitudes. Am. J. Physiol. 145: 685-692. 1945.

27. Houston, C. S. The effect of pulmonary ventilation on anoxemia. Am. J. Physiol. 146: 613-621. 1946.

28. Jackson, H. The effect of analgesic drugs on the sensation of thermal pain in man. Brit. J. Pharm. and Chemother. 7: 204-214. 1952.

29. Jones, C. M. Digestive tract pain. Macmillan, New York, N.Y. 1938.

30. Kemph, J. P. and Hitchcock, F. A. Respiratory effects of high intrapulmonic pressure at a stimulated altitude of 72,000 feet (30 mm. of Hg.). J. of Avia. Med. 24: 5-13. 1953.

31. Kendall, D. Some observations on central pain. Brain 62: 253-273. 1939.

32. Kuntz, A. A text book of neuro-anatomy. Lea and Febiger. Philadelphia, Pa. 1950.

33. Lasagna, L. Symposium on pain and its relief. J. of Chronic Dis. 4: 1-110. 1956.

34. Lewis, T. Pain. The Macmillan Co. New York, N. Y. 1942.

35. _____ and Pochin, E. E. The double pain response of the human skin to a single stimulus. Clin. Sci. 3: 67-76. 1938.

36. _____ and _____. Effects of asphyxia and pressure on sensory nerves of man. Clin. Sci. 3: 141-155. 1938.

37. Lipkin, M., Bailey, O. and Hardy, J. D. Effect of ultraviolet irradiation upon the cutaneous pain threshold. J. Appl. Physiol. 7: 683-687. 1955.

38. Malmo, R. B., Shagass, C. and Davis, J. F. Pain as a standardized stimulus for eliciting differential physiological responses in anxiety. Am. Psychologist. 2: 344. 1947.

39. Meehan, J. P., Stoll, A. M. and Hardy, J. D. Cutaneous pain threshold in the native Alaskan Indian and Eskimo. J. Appl. Physiol. 6: 397-400. 1954.

40. Miller, L. C. A critique of analgesic testing methods. Ann. New York Acad. Sc. 51: 34-46. 1948.

41. Pattle, R. E. and Weddell, G. Observations on the electrical stimulation of pain fibers in an exposed human sensory nerve. J. Neurophysiol. 11: 93-98. 1948.

42. Potelunas, C. B., Meixner, M. D. and Hardy, J. D. Measurement of pain threshold and superficial hyperalgesia in diseases of the skin. J. Invest. Dermat. 12: 307-316. 1949.

43. Rahn, H. and Hammond, D. Vital capacity at reduced barometric pressure. J. of Appl. Physiol. 4: 715-723. 1951.

44. _____ and Otis, A. B. Alveolar air during simulated flights to high altitudes. Am. J. Physiol. 150: 202-221. 1947.

45. Ranson, S. W. The anatomy of the nervous system. W. B. Saunders Co. Philadelphia, Pa. 1931.

46. Ray, B. S. The management of intractable pain by posterior rhizotomy. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 391-407. 1943.

47. Roth, G. M., Johnson, D. A. and Craig, W. M. Physiologic effect of anterolateral chordotomy in man. J. Appl. Physiol. 5: 261-266. 1953.

48. Schamp, J. R. and Schamp, H. M. Variability of the pain threshold in man. J. of Dent. Res. 25: 101-104. 1946.

49. Schumacher, G. A. The influence of inflammation on the pain threshold of the skin in man. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 166-175. 1943.

50. _____, Goodell, H., Hardy, J. D. and Wolff, H. G. Uniformity of the pain threshold in man. Science 92: 110-112. 1940.

51. Snedecor, G. W. Statistical methods. 4th ed. Ames, Iowa. Iowa State College Press. 1946.

52. Sonnenschein, R. R. and Ivy, A. C. Failure of oral anti-pyretic drugs to alter normal human pain thresholds. J. Pharm. and Exp. Ther. 97: 308-313. 1949.

53. Starr, I. and McMichael, M. Oxygen transport, circulation and respiration in healthy subjects at simulated altitudes of 16,000-18,000 feet. J. Appl. Physiol. 1: 430-440. 1948.

54. Stookey, B. The management of intractable pain by chordotomy. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 416-433. 1943.

55. Swetlow, G. I. Alcohol injections into nerve tissues for the relief of pain. Am. J. Med. Sci. 171: 397-407. 1926.

56. Tilney, F. and Elsberg, C. Sensory disturbances in tumors of the cervical spinal cord. Arch. Neurol. and Psychiat. 15: 444-454. 1926.

57. Tower, S. Pain: definition and properties of the unit for sensory reception. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 16-43. 1943.

58. Villiger, E. Brain and Spinal Cord. Philadelphia, Pa. and London. J. B. Lippincott Co. 1931.

59. Weddell, G., Sinclair, D. C. and Feindel, W. H. An anatomical basis for alterations in quality of pain sensibility. J. Neurophysiol. 11: 99-109. 1948.

60. Whitehorn, W. V., Lein, A. and Edelmann, A. The general tolerance and cardiovascular responses of animals to explosive decompression. Am. J. Physiol. 147: 289-298. 1946.

61. _____, _____, _____, and Hitchcock, F. A. The effect of explosive decompression on cerebrospinal fluid pressure. Am. J. Physiol. 148: 253-258. 1947.

62. Winder, C. V., Pfeiffer, C. C. and Maison, G. L. The nociceptive contraction of the cutaneous muscle of the guinea pig as elicited by radiant heat, with observations on the mode of action of morphine. Arch. Internat. de Pharm. 72: 329-359. 1946.

63. Windle, V. F. Experimental proof of the types of neurons that innervate the tooth pulp. J. Comp. Neurol. 43: 347-356. 1927.

64. Wolf, S. and Wolff, H. G. Pain arising from the stomach and mechanisms underlying gastric symptoms. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 289-301. 1943.

65. Wolff, H. G. and Goodell, H. The relation of attitude and suggestion to the perception of and reaction to pain. Proc. Assoc. Res. Nerv. and Ment. Dis. 23: 434-448. 1943.

66. _____ and Hardy, J. D. On the nature of pain. Physiol. Rev. 27: 167-199. 1947.

67. Zollinger, R. and Walter, C. W. Localization of pain following faradic stimulation of the common bile duct. Proc. Soc. Exper. Biol. and Med. 35: 267-268. 1936.

68. Zotterman, Y. Touch, pain and tickling: an electrophysiological investigation on cutaneous sensory nerves. J. Physiol. 95: 1-27. 1939.

ACKNOWLEDGMENTS

The writer wishes to express appreciation to his graduate committee and especially to his major professor, Dr. E. A. Hewitt, for their helpful suggestions and encouragement throughout this study. Special gratitude is due to Dr. R. Getty and Dr. J. G. Bowne for counsel and technical advice in the sectioning of the lateral spinothalamic tracts.

The author is deeply indebted to Dr. L. C. Payne for his invaluable guidance, untiring efforts in designing the experiments and constructive criticisms in the execution of this study.

The writer is also indebted to Dr. Herbert David of the Statistical Laboratory for assistance with the statistical analysis; to Mr. Dean Symonds of the Instrument Shop for his invaluable help in the designing and construction of the electrical tooth stimulator; to Mr. L. A. Facto of the Iowa Agricultural Experiment Station for his excellent photographs; to the Department of Veterinary Physiology and Pharmacology for furnishing the animals and facilities used in the investigation; to the Euthanair Engineering and Sales Company, Los Angeles 43, Calif., for making available the Euthanair; and to Dr. B. W. Kingrey, Department of Veterinary Medicine and Surgery, for the use of equipment and facilities for the conduction of the surgical experiment.

APPENDIX A

Table 13. Bartlett's test for inter-dog homogeneity of variances of the pain reaction thresholds applying the Hardy-Wolff-Goodell dolorimeter to the cutaneous area of the right shoulder

Dog no.	Sum of squares	Degrees of freedom (N-1)	$\frac{1}{N-1}$	Mean square (S^2)	Log S^2	(N-1) Log S^2
1	1748	49	0.0204	35.67	1.55230	76.063
2	2840	49	0.0204	57.96	1.76313	86.393
3	545	19	0.0526	28.68	1.45758	27.694
4	2985	14	0.0714	213.21	2.32879	32.603
5	1260	14	0.0714	90.00	1.95424	27.359
7	480	19	0.0526	25.26	1.40243	26.646
8	5865	49	0.0204	119.69	2.07773	101.809
10	2471	49	0.0204	50.43	1.70269	83.432
12	3152	49	0.0204	64.33	1.80841	88.612
13	4112	49	0.0204	83.92	1.92387	94.270
14	1412	49	0.0204	28.82	1.45969	71.525
15	1611	49	0.0204	32.88	1.51693	74.330
Total	28,481	458	0.4112			790.736[a]

[a] X^2 unadjusted = 70.90, versus a 5 per cent value of 19.68 and a 1 per cent value of 24.72.

Table 14. Bartlett's test for inter-dog homogeneity of variances of the pain reaction thresholds applying the Hardy-Wolff-Goodell dolorimeter to the cutaneous area of the dorsal lumbar region

Dog no.	Sum of squares	Degrees of freedom	$\frac{1}{N-1}$	Mean square (S^2)	Log S^2	(N-1) Log S^2
1	7968	49	0.0204	162.61	2.20112	107.855
2	12382	49	0.0204	252.69	2.40243	117.719
3	2655	19	0.0526	139.74	2.14520	40.759
4	923	14	0.0714	65.93	1.81908	25.467
6	1355	19	0.0526	71.32	1.85321	35.211
8	4688	49	0.0204	95.67	1.98078	97.058
9	3595	49	0.0204	73.37	1.86552	91.410
11	16615	49	0.0204	339.08	2.53020	123.980
14	3341	49	0.0204	68.18	1.83366	89.849
15	2461	49	0.0204	50.22	1.70088	83.343
Total	55983	395	0.3194			812.651[a]

[a] X^2 unadjusted = 75.53 versus a 5 per cent value of 16.92 and a 1 per cent value of 21.67.

Table 15. Bartlett's test for intra-dog homogeneity of variances of pain reaction thresholds, for four dogs selected randomly from the ten in the decompression experiment

Dog	Decompression level mm. of Hg.	Sum of squares	Degrees of freedom (N-1)	$\frac{1}{N-1}$	Mean square (s^2)	Log s^2	(N-1) Log s^2
31[a]	734.4	13,381	29	0.0345	461.4	2.66408	77.258
	582.0	12,618	29	0.0345	435.1	2.63849	76.516
	429.6	10,482	29	0.0345	361.4	2.55799	74.182
	277.2	8,927	19	0.0526	470.0	2.67210	50.770
	124.8	2,093	11	0.0909	190.3	2.27921	25.071
Total		47,501	117	0.2470			303.797
33[a]	734.4	1,669	19	0.0526	87.9	1.94389	36.934
	582.0	1,450	14	0.0714	103.7	2.01494	28.209
	429.6	1,127	14	0.0714	80.5	1.90596	26.683
	277.2	2,244	13	0.0769	171.1	2.23325	29.032
	124.8	3,112	10	0.1000	311.2	2.49304	24.930
Total		9,582	70	0.3723			145.788
35[a]	734.4	973	24	0.0417	40.5	1.60810	38.594
	582.0	692	9	0.1111	76.9	1.88589	16.973
	429.6	1,525	9	0.1111	169.4	2.22891	20.060
	277.2	1,594	9	0.1111	177.2	2.24846	20.236
	124.8	972	8	0.1250	121.5	2.08458	16.676
Total		5,756	59	0.5000			112.539

[a] X^2 unadjusted: dog 31 (lumbar area) = 3.23 versus a 5 per cent value of 9.49, dog 33 (lumbar area) = 8.66 versus a 5 per cent value of 9.49, dog 35 (shoulder area) = 11.72 versus a 5 per cent value of 9.49 and a 1 per cent value of 13.28, and dog 37 (shoulder area) = 1.57 versus a 5 per cent value of 9.49.

Table 15. (Continued)

Dog	Decompression level mm. of Hg.	Sum of squares	Degrees of freedom (N-1)	$\frac{1}{N-1}$	Mean square (S^2)	Log S^2	(N-1) Log S^2
37[a]	734.4	2,313	19	0.0526	121.9	2.08529	39.621
	582.0	860	9	0.1111	95.5	1.98028	17.823
	429.6	1,452	9	0.1111	161.4	2.20790	19.871
	277.2	1,610	9	0.1111	178.9	2.25261	20.273
	124.8	1,193	6	0.1667	198.8	2.29842	13.791
Total		7,428	52	0.5526			111.379

APPENDIX B

Table 16. A two-way analysis of variance of the pain reaction thresholds obtained from the decompression experiment when the dolorimetric projector was applied to the right shoulder area, with the two coordinates respectively, decompression level and dogs

Source of variation	Degrees of freedom	Sum of squares	Mean square
Among dogs	6	48,403.1	8,067.2
Among decompression levels	4	341.4	85.4
Dogs x decompression levels	24	518.0	21.6
Determination/dogs	406	16,164.6	39.8

Table 17. A two-way analysis of variance of the pain reaction thresholds obtained from the decompression experiment when the dolorimetric projector was applied to the lumbar region, with the two coordinates respectively, decompression level and dogs

Source of variation	Degrees of freedom	Sum of squares	Mean square
Among dogs	2	18,128.6	9,064.3
Among decompression levels	4	219.6	54.9
Dogs x decompression levels	8	97.0	12.1
Determination/dogs	244	4,503.9	18.5

APPENDIX C: EXPLANATION OF APPENDIX

The alternative method of analysis mentioned on page 82 is to perform a two-way analysis of variance, with dogs the second category. General methods for handling two-way analysis of variance in the presence of variance heterogeneity are not as yet known, and standard method of analysis applied in the presence of variance heterogeneity may be biased. For the data of the decompression experiment, there is very significant dog to dog heterogeneity, as shown in Tables 13 and 14 (this contrasted to the evidence for within-dog variance homogeneity, Table 15). Possible bias introduced into the standard analysis by this variance heterogeneity are suggested by the fact that the dogs x decompression mean square is less than the determination/dog mean square for both shoulder and lumbar areas, and significantly so (0.025) for the shoulder area.

The reader may feel that the likely greater power of the two-way analysis outweighs the danger of bias due to variance inhomogeneity. For such a reader the two-way analysis based on Tables 16 and 17 is summarized below.

For dogs considered fixed, the appropriate error term is the determination/dog mean square, leading to levels of significance of .08 and .02, respectively for shoulder and lumbar areas.

For dogs considered random, the correct error term technically is the dogs/decompression mean square, although its use in this case is open to question due to its magnitude compared to the determination/dog mean squares as discussed above. Nevertheless, if the tests are carried through with the dog/decompression denominator, one obtains significance of 0.015 and 0.035 for shoulder and lumbar areas, respectively. Therefore, it is possible that the dogs may have experienced some pain from decompression.