STUDIES ON TEMPERATURE DISTRIBUTION AND HEAT PRODUCTION IN THE "CORE AREA" OF THE DOG.

A THESIS

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ABSTRACT.

Temperature distribution within the "core area" of fasting mongrel dogs was studied with thermocouples or "applicators" (the hot junctions of thermocouples - manufactured by ELLAB Ltd. Copenhagen). The highest intra-abdominal temperature was found in the lumen of the duodenum, followed in turn by temperatures within the lumen of the ileum, large intestine and the stomach, as well as temperatures in the liver, hepatic and portal veins. With the exception of the rectum, temperatures within the gastro intestinal tract, the liver and its associated vessels were found at least 0.3°C higher than that of aortic blood.

The effect of mild haemorrhage and environmental cooling on the pattern of distribution as well as the values of the organ-aorta temperature differentials within the "core area" was studied. This caused a rise in the organ-aorta temperature differentials of various regions of the g.i.t. with the exception of the rectum in which it caused a fall. It had no noticeable effect on the values of those of the liver, portal and hepatic veins.

Environmental cooling caused a rise in the values of the organ-aorta temperature differentials of all regions of the gastro-intestinal tract, the liver, portal and hepatic veins.

The blockade of adrenergic influences with bretylium tosylate in the warm environment caused noticeable but transient falls in the values of the organ-aorta temperature differentials of most regions of the gastro intestinal tract (except the rectum in which a rise was obtained),

and a slight fall in those of the liver and its associated vessels.

The response of these regions of the gastro-intestinal tract, and the liver to environmental cooling were slightly reduced after bretylium tosylate.

The effects of the blockade of cholinergic mechanisms with atropine sulphate and vagotomy were also studied. Atropine sulphate caused a distinct fall in the temperature differentials between the various regions of the gastro-intestinal tract and the aorta. It also caused a fall in that of a liver, but no change in those of the hepatic and portal veins. These reactions were also transient. The response of the stomach to environmental cooling was enhanced while those of the other regions of the g.i.t. were reduced by atropine sulphate. The response of the liver, hepatic and portal veins to environmental cooling were also reduced.

Cervical vagotomy in the warm environment caused a rise in the temperature differentials of almost all regions of the gastro-intestinal tract, and hepatic vein. It caused no significant alteration in the temperature differentials of the liver and portal vein. The response of the stomach and rectum to environmental cooling after abdominal vagotomy were enhanced while that of the large intestine was reduced. The response of the ileum was abolished and that of the duodenum was reversed.

Simultaneous administration of atropine sulphate and bretylium tosylate in the warm environment caused a fall in the temperature differentials of the upper regions of the gastro intestinal tract but a

rise in that of the rectum. The response of the stomach, ileum and large intestine and were reduced while that of the duodenum was abolished by these drugs. The response of the rectum was enhanced.

Gut sterilization with neomycin sulphate did not cause a material alteration in the values of the temperature differentials of the various regions of the gut, as well as those of the liver and its associated vessels. The response of the rectum and large intestine to environmental cooling after gut sterilization were slightly reduced while those of the other regions of the gut as well as those of the liver and its associated vessels, were either unaltered or enhanced.

The importance of these findings in the maintenance and regulation of the temperature of the "core area" is discussed.

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LITERATURE REVIEW

THE "CORE TEMPERATURE"

For more than two centuries after Sactorius (1625), in his commentary on the first book of Canon of Avicenna, introduced the first thermometric device for measuring temperatures within the animals body, the physiology of heat and temperature regulation was inundated with figures describing the "body temperature". This term "body temperature", seeks to define the temperature at which, like most biological systems, the animal body maintains a thermal balance between heat production and heat loss. The first accepted value for the "body temperature" was given by J. Davy in 1845, from his studies on the thermotopography of the skin. This temperature measured in the mouth of human subjects gave the value of "body temperature" as 98.4 °F. Since this report, many more temperatures have been measured in many other sites and they have all been variously described as the "body temperature". From some of the more recent work, it has become increasingly evident that the term "body temperature" does not in actual fact, refer to the temperature of the whole body, nor does it refer to the average body temperature. It is therefore considered a misnomer (Bazzett 1949). Burton and Edholm (1955) referred to a meeting held in Copenhagen in which "it was agreed that the term "body temperature" was misleading when it was based on measurement at any one locality". "It was agreed that it was better to measure the temperature at the selected site and to consider the phenomena recorded in relationship to the temperature of

the site rather than confuse the issue by calling that temperature body temperature".

The concept which is currently used is that of "core" and "shell" temperature. The "core" tissues are those whose temperatures are maintained within a relatively narrow range (Leithead & Lind 1964) varying not more than about 1.5°C and are immune to changes in environmental temperature (Nielsen and Nielsen 1962). The "shell" tissues, on the other hand, are those whose temperatures vary quite widely with environmental temperatures (Leithead & Lind 1964). Bazzett (1949) felt that "the conception that a man has an internal mass of tissues maintained at 37°C, surrounded by a thin layer with a steep temperature gradient such that the surface temperature is 33°C is common but inaccurate". Experimental data show that there is no such constancy of temperature within the core area. Davy (1839) and Claude Bernard (1856) showed definite thermal gradients between the liver and the rectum of lambs and dogs respectively. In view of these gradients therefore, even the concept of the core and shell, though useful, can be seen as an over-simplification (Burton and Edholm 1955; Leithead and Lind 1964 and Bregelman & Brown 1965).

One might then wonder what exactly is the anatomical boundary of the "core area" and whether the temperatures measured there are truly constant or not. If they are not constant, it might be interesting then to know if they do bear any constant relationship one to another.

The Anatomical boundaries of the "Core Area"

The "core area" was described by Bregelman & Brown (1965), as comprising the tissues, whose temperatures are within a few tenths of a degree, of the rectal temperature. This perhaps will include tissues, such as those found in the head and neck, thorax and abdominal cavity (Leithead & Lind 1964). These same authors considered the "shell" as comprising the superficial tissues of the areas mentioned above, as well as the superficial and deep tissues of the limbs.

It is difficult however, to give a formal definition of the extent of the "core area" or the "shell" on a strictly anatomical basis; knowing fully well that the boundaries so described, are liable to changes with the heat content of the body. It is known for instance that on exposing the body to a cool environment, there is cutaneous vasoconstriction which brings about a reduction in the blood flow through the shell. This reduces the thermal gradient between the skin and the environment and thereby increases the insulation of the 'core area' from the environment. In this case, the shell appears to increase in thickness while the core contracts (Spurr, Horvath, Hamilton and Hutt 1956; Aschoff & Wever 1958; Bregelman and Brown 1965). The converse is also true, that when there is vasodilatation in the shell, as occurs on exposure to a warm environment, the increase in the blood flow to the shell reduces the thermal insulation of the 'core area' from the environment. The "core area" in this case can then be visualized as comprising almost

the whole body with "shell" reduced to the thickness of the epidermis. In spite of these evident variations in the boundaries of the "core" and "shell", structures found in the brain, the thoracic and abdominal cavities could safely be regarded as belonging to the "core area" at all times.

TEMPERATURE DISTRIBUTION WITHIN THE "CORE AREA"

Temperatures have been measured in the "core area" for upwards of two and a half centuries. One of the earliest reports on this was written by Borelli in 1680. Using a simple thermometer, Borelli showed that there was not much difference between the temperatures of the heart of the stag and those of its liver, lungs and bowel. Since this report however, several other observations have been made, which reveal the existence of a definite thermal gradient within the deeper body tissues. (Davy 1839; Claude Bernard 1876; Horvath et al 1950; Grayson and Mendel 1956). This gradient might be quite small in the normothermic subjects, in normal circumstances, but it could be much increased under conditions of body cooling as was found by Libelli and Poggi (1946); Haterius and Maison (1948), and Stupfel & Severinghaus (1956). Only a few systematic measurements of the temperature distribution in the "core area" are obtainable. Most of the available work report on measurements taken from only two or three sites at a time. It is therefore difficult to give a systematic description of the thermotopography of the "core area" from these. In spite of this handicap however, an attempt will be made at a systematic picture of the thermal relationship between the various

organs found within the "core area".

The general picture which appears from these various reports is such that temperatures found in the brain are equal to, or slightly higher than those found in thoracic structures. These, on the other hand, are generally lower than the temperatures of abdominal structures.

This pattern of temperature distribution may be due to the fact that the most highly metabolising structures found in the "core area", are situated in the abdomen. These include the liver, kidney and gastro-intestinal tract. Besides high metabolic activities, these abdominal structures are known to be more insulated from environmental influences than thoracic structures. The thoracic structures, for instance, are in constant intimate contact with the respiratory air, which is invariably cooler than they are and so constitutes a cooling factor.

It is however the general concensus that there is no constancy of temperature within the "core area". The pattern of temperature distribution in human subjects appears to be different from the general pattern in animals. For instance, temperatures in human pelvis have often been found to be higher than those in the upper portions of the abdominal cavity, say below the liver (Ipsen 1926); whereas the converse is found in lower animals. Lomax (1966) found that the highest intra-abdominal temperatures in the rat were recorded at a point close to the diaphragm and below the liver.

The pattern of temperature distribution in both animals and human subjects are similar, in that the highest intra-abdominal temperature,

contrary to expectations, is not found in the liver but in one of the regions of the gastro-intestinal tract. There is however no general agreement on where this highest temperature is found. In man, it appears to be found in the rectum as is evident in the work of Graf (1955 and 1959). In lower animals however it may occur anywhere higher up in the intestine from the duodenum to the colon (Ito 1899 and Grayson et al 1966).

In giving a more detailed description of temperature distribution and thermal relations in the "core area", reference will not be made to absolute temperatures. This is because these have varied quite widely in the reports considered. It is therefore believed that a better picture can be built from a consideration of the various thermal relations rather than absolute temperatures.

TEMPERATURE DISTRIBUTION WITHIN THE THORAX

Relationship between right atrial and vena cavae temperatures

In the dog, right atrial blood temperature has been reported similar to the temperatures of blood in the vena cavae emptying into it. Benjamin and Horvath (1949) found no difference exceeding 0.1°F between right atrial and superior vena caval temperatures. This, for all practical purposes, can be considered negligible.

The situation in human subjects is however different. The figure obtained by Eichna et al (1949) shows that the right atrial blood is 0.28°C hotter than that in the superior vena cava.

Relationship between right atrium, right ventricle and coronary sinus temperatures.

The temperature of the blood in the right atrium and ventricle was found to be similar in human subjects (Zichna et al 1949). This is to be expected, since the only difference between the atrial and ventricular blood, is that the ventricle contains in addition, blood discharging into it through the Thebesian veins and luminal vessels. This, under physiological conditions, probably represents only a small fraction of the coronary inflow, which may not affect the ventricular temperature noticeably.

The relationship between the coronary sinus and the right ventricle, in the dog, has been controversial. Benjamin and Horvath (1949) for instance, found the blood temperature to be similar, while Horvath, Folts and Hutt (1949) on the other hand found the coronary sinus blood 0.2^{o}7 hotter than the right ventricle.

Relationship between the heart, lungs and the aortic temperatures

It is to be expected that blood flowing through the lungs might tend to loose heat by evaporation; in which case left atrial and ventricular and probably aortic temperatures might be slightly lower than the temperature of blood in the right side of the heart.

Christie and Loomis (1932) however, showed evidence that the blood temperatures in the two ventricles are similar. Mather, Mahas and Hemingway (1953) on the other hand found slight differences, but even

then, these never exceeded 0.08°C. This therefore means that the temperature of blood in the two ventricles is essentially similar. This indicates that not much heat could have been lost in the lungs. Grayson, Irvine and Kinnear (1966) concluded that since right atrial temperature was found equal to aortic temperature, there is a possibility of blood warming, by active process, in the lungs, as well as in the myocardium; thus compensating for the heat lost in the lungs. The warming of blood by the myocardial muscles had already been shown by Neil et al (1961).

Christie and Loomis (1932) suggested that the temperature of the lung is similar to both right and left ventricles. This was however not found in the monkey, in which Grayson et al (1966) found the tracheal bifurcation 0.5°C cooler than aortic blood.

TEMPERATURE DISTRIBUTION WITHIN THE ABDOMEN

The temperature of the liver, and its associated vessels

The liver has long been regarded as the hottest organ in the abdomen. (Masuzawa 1940, Chimvier and Fisikas, quoted by Fedorov & Shur 1942, and Grayson & Mendel 1956). More recent observations, especially those which include measurements from the hepatic vein and the lumen of various regions of the gastro-intestinal tract, have made it clear that the liver can no longer be regarded as the hottest organ in the body. This had earlier been suggested by H. Ito (1899) who observed duodenal temperature higher than liver temperature in the rabbit.

The relationship between the liver, aorta, portal and hepatic veins.

Nedzel (1933) pointed out that the "liver has a tendency to maintain its temperature at a higher level than the blood". This is said to be due to an accumulation of venous blood, which is normally hotter than arterial blood (Federov and Shur 1942). While this is true of the relationship between the liver and the arterial blood (Cavasine, Hirch, Mueller and Rolly 1894), it certainly has not been found true for the relationship between the liver and the hepatic vein.

There are considerable variations in the values given by different workers for the liver-aorta relationship. These values clearly show species variations. For instance, in the lamb, Davy (1839) found that the liver was 0.5°C hotter than the left ventricular blood. Nedzel (1933) found a difference of 0.2°C between the liver and aortic blood in anaesthetized dogs, while Grayson et al (1966) recorded a 0.1°C difference in anaesthetized monkey. In an attempt to explain this species variations, Graf (1959) made reference to the view points expressed by Kleiber (1941) and Waymount, Field and Kleiber (1942), that the liver metabolism bears an inverse relationship to body size. In other words, it might be expected that the liver in smaller animals might produce more heat, as a result of higher metabolic activities, than larger animals. Kleiber and his co-workers reported finding that the $\dot{Q}$ 02 (Oxygen utilised) by the liver amounts to $5.28 W^{0.228}$.

Besides the established species variations, intra-species variations in values have also been noted. This, as suggested by Graf (1959),

may be due to the existence of thermal gradients within the liver. Though Graf et al (1957) reported a thermal gradient of about 0.6°C between the various lobes of canine liver, Grayson and Kinnear (1962) denied its existence in human subjects.

The protagonists of the existence of thermal gradients explain this on the basis of streamlined portal flow into the liver. By streamlined portal flow is meant a pattern of flow where, for example, the splenic vein empties preferentially into either the left liver lobe (Bartlett, Coper and Long 1914; Himsworth and Glynn 1944 and More and Bidenbough 1951) or the right liver lobe (Bergstrand and Zikman 1955; Wannagut 1955). Although models of such streamlining have been built by Barnett and Cochrane (1956), modern trends do not support its existence in man (Popper and Schaffner 1957). This perhaps explains why Grayson and Kinnear (1962) did not obtain thermal gradient between the superficial and deep layers of the liver in West African adults.

One other reason which perhaps explains the variation in the values obtained in the same species, might be found in the proportion of blood contributed by the portal vein and the hepatic artery. Though it is generally accepted that the portal vein and hepatic artery contribute 80% and 20% respectively, (Grindlay, Herrick and Mann 1941), it has been shown that either of them alone could contribute about 90%. In this case therefore, any variations in the contribution of either vessel may cause variation in liver temperature.

The relationship between the portal vein and arterial blood has been a subject of controversy. Federov and Shur (1942) found the portal vein to be 0.2°C hotter than aortic blood in the anaesthetized dog. This is in contrast to Kosaka (1930) who found dog hepatic arterial blood was similar in temperature to portal vein. In the cat, however, Jitariu, Kook and Otto (1941) found portal vein hotter than hepatic arterial blood.

The relationship between the liver and the portal vein has been less controversial, for it is generally accepted that the liver is not much hotter than the portal vein (Grayson and Kendel 1956; Jitariu, Kook and Otto 1941).

It is also generally accepted that hepatic venous blood is hotter than the portal vein. The figures given however show a wide variation; ranging from 0.05°C to about 0.5°C. (C. Bernard 1856; Kosaka 1930 and Federov and Shur 1942). This difference demonstrates the heat production of the liver, which might vary immediately after digestion (C. Bernard 1856).

The liver and rectal temperature

Cavazzani (1894); Claude Bernard (1856); Jacobson (1870); Lefevre (1911); Marsberk (1939) and Horvath et al (1950) have shown that in lower animals, the liver is hotter than the rectum. The values given by these authors however, show not only species variations but also intra-species variations. For instance in the dog, values ranging from 0.76 to 2.0°C have been published (Bernard 1856; Lefevre 1911;

Marshark 1939 and Horvath et al 1950), while in the rabbit the differences varied from 0.29°C to 1.4°C (Bernard 1856; Dietrick and Fritts 1952).

There is, on the other hand, no general agreement on the relationship between the liver and rectal temperatures in human subjects. Although Grayson and Kinnear (1962) found the liver of West African adults 0.03°C hotter than the rectum, there have been figures which show the opposite relationship. The values of the differences in this case range from 0.19°- 0.6°C; liver being cooler than the rectum (Graf et al 1955; Graf 1959). This situation is perhaps due to the fact that pelvic temperature in man is often found higher than temperature taken further up the abdominal cavity - especially below the liver (Ipsen 1926). Graf (1959) however, explained this on the basis of the differences between the blood supply of the rectum and the liver. He felt that, owing to the poor blood supply to the rectal mucosa, it is better insulated and so better able to conserve heat than the liver which has a massive blood supply.

Temperature Distribution Along The Gastro-Intestinal Tract

What can easily be deduced from the available work on thermal relations within the gastro-intestinal tract is that there is copious evidence for the existence of a thermal gradient along the gut. The general trend is that temperatures increase from the mouth and anal orifice to reach a peak somewhere along the length of the tract. Where this peak occurs is known to vary with animal species. It appears that

every region of the gastro intestinal tract has been mentioned at one time or the other as being the site of the peak temperature. The following, however is a more detailed description of the temperature distribution and thermal relations within the gastro-intestinal tract.

Oesophageal temperature

Oesophageal temperature cannot be said to be homogenous since thermal gradients have been observed along its length (Cranston, Gerbrandy and Snell 1954; Nielsen and Nielsen 1962). This thermal gradient is such that the temperatures increase from the oral pharynx to the cardiac end of the stomach. Cranston et al, (1954) showed that temperature recorded from a point 25cms from the lips of human subjects, was about 0.37°C lower than that recorded from a depth of 50cms down the oesophagus. At a distance of 47cms from the lips oesophageal temperature was found 0.09 ± 0.015°C hotter than sublinqual temperature in man. Batinkov (1939) gave a value of 0.1 to 0.4°C as the oesophageal - oral temperature differential. The thermal gradient found along the oesophagus is probably due to the influences of such structures as the trachea and descending aorta, which lie in close proximity to it.

The influence of the trachea was amply demonstrated by Cranston et al (1954) who showed that oesophageal temperature, recorded from a point where the trachea was in close proximity to the oesophagus, fell when subjects were made to breath cold air but rose while breathing warm air.

Lower oesophageal temperature, which has been suggested as a more

reliable index of "core temperature" by Cooper and Kenyon (1957) is known to be similar to aortic and heart temperatures (Cranston et al 1954; Stupfel and Severinghaus 1956; and Cooper & Kenyon 1957). This may perhaps be due to the influence of the aorta on the temperature of this portion of the oesophagus.

Gastric and Intestinal Temperatures

There is no clear relationship between gastric and oesophageal temperature. Batinkov (1939), for instance found that oesophageal and gastric temperatures were similar, except where there was gastric distention, in which case gastric temperature was lower. On the other hand Revutski (1955) observed that the empty stomach had a lower temperature than the oesophagus.

The conflicting observations reported are probably due in part, to differences in "thermometers" and methods of measurement, as well as in sites of measurement, within the stomach. It is known for instance that there exists a thermal gradient within the stomach. This gastric thermal gradient has been shown by Foged (1933) and Masek (1946), who found the cardiac end of the stomach to be cooler than the corpus and the fundic end respectively. The gradient may not be very much, probably about 0.05°C (Foged 1933). The observed gradient may perhaps be caused by the presence of gas bubbles in the cardiac end of the stomach (Masek 1946), as well as other contents of the stomach (Mead and Donmarito 1949). Variations observed in the values of gastric temperature could easily be produced by getting the thermometer in either the gas bubbles

or the other gastric content.

Not much is available on the relationship between gastric and aortic temperatures. Hyperaemia has been suggested to be capable of cooling the stomach (Mead and Bonmarito 1949); thus suggesting that the aortic blood is cooler than the stomach. Masuda, Ohara and Katsura (1953) on the other hand, attributed the rise in gastric temperature they observed on body surface cooling to reflex hyperaemia. They assumed, of course, that the arterial blood is warmer than the gastric cavity. The latter observation is in accord with the findings of Nedzel (1934) who found aortic blood in anaesthetized dogs 0.1°C hotter than gastric temperature.

Duodenal temperature was found by Nedzel (1934) to be 0.5°C cooler than aortic blood in anaesthetized dog. This is in conflict with the findings of Revutaki (1955), who observed upper intestinal temperatures 0.5°C hotter than oesophageal temperature and the findings of Grayson et al (1966) who found jejunal temperature 0.20°C hotter than aortic blood in the monkey.

Not much is known about the relationship between the intestines and the stomach. Upper intestinal temperatures recorded from the duodenum and jejunum, have however been reported lower than gastric temperature (Hepburn et al 1932 and Batinkov 1939). The differences given vary from 0.04 to 0.5°C.

The Rectal Temperature

Because of its accessibility, the rectum has been the most widely

used site for the study of "body temperature" and the response of the "core temperature" to changes either in the environmental temperature or in response to drugs.

It has for quite a time been taken as a reliable index of body temperature. Evidence, however, is already accumulating against its continued use as an index. Many other sites which have been severally regarded as more reliable have been suggested. These include, lower oesophageal temperature (Cranston et al 1954; Cooper and Kenyon 1957), abdominal cavity at a point below the liver and close to the diaphragm (Lomax 1966), femoral artery (Eichna et al 1949), and voided urine during thermal balance (Kitching 1943).

One of the criticisms against the use of the rectal temperature as an index of the "core temperature" is the existence of a thermal gradient along it's length. Rectal temperature has been found to increase as the "thermometer" is moved inwards from the anal orifice. The depth at which the highest temperature occurs varies, but in man it is between 2½ and 4 ins (Benedict and Slack 1911; Mead and Bonmarito 1949). In lower animals, it is also quite variable. Deeper insertions give lower values of rectal temperature, probably because of the presence of a rich venous plexus around the area of the rectum. Blood from the skin of the buttocks and external genitalia flowing through this plexus might constitute a cooling factor (Mead and Bonmarito 1949).

It therefore seems that variations in the depth of insertion per

so, could bring about differences in values of rectal temperatures observed. Other arguments against the continued use of the rectum as an index of 'core temperature' include the lack of similarity between the rectum and any other site in the "core area". Even when it differs from other sites the differences are never constant and are subject to variations (Spealman 1946; Libelli and Poggi 1946; Haverius and Maison 1948; Stupfel and Severinghaus 1956; Grayson and Kinnear 1962; Grayson et al 1966). It therefore follows that the rectal temperature does not represent the temperature of any other organ in the 'core area', and certainly not the hypothalamus, which is regarded as being the centre for temperature regulation (Fusco, Hammel and Hardy 1959).

Local factors, such as the presence of masses of faeces (Mead and Bonmarito 1949), muscular activity of the m. levator ani (Renbourn and Taylor 1956; Bilroth 1862), and local vasomotor changes brought about by environmental temperature changes (Grayson 1951; Grayson et al 1966), or by postural changes (Mead and Bonmarito 1949; Cranston et al 1954), have been shown to influence the rectal temperature. Hence it can be seen that the rectum cannot be considered a reliable index of "core temperature".

<u>The relationship between the rectal, the cardiac and aortic blood temperatures.</u>

With the exception of a few workers, it is commonly accepted that the rectal temperature is higher than temperatures measured from the various chambers of the heart. Values obtained for the differences

between right atrial, right ventricular blood and rectal temperatures vary from 0.2°C to 0.44°C in anaesthetized dogs (Eichna et al 1949; Horvath et al 1949 Horvath, Rubin and Folts 1950 and Mather, Manns and Hemingway 1953).

The situation in human subjects is quite similar and the differences could also be as much as 0.2°C (Eichna et al 1951). Harmer and Harris (1920) and Grayson et al (1966) however showed that rectal temperature in human subjects as well as monkey, could be lower than aortic temperature. Grayson and co-workers got a difference of 0.3°C.

The rectum and the other regions of the gastro-intestinal tract.

It is generally accepted that gastric temperature, particularly in human subjects, is lower than the rectal temperature. Values have been found to vary from 0.07 ± 0.054°C to 0.5°C. (Foged 1933; Hochrein and Schleicher 1948 and Graf 1959). The direction of the difference could however be reversed, as was found by Spealman (1945) who observed gastric temperature 0.8°C higher than rectum.

Not much is known about the relationship of the rectal temperature to intestinal temperatures. H. Ito (1899) showed evidence that duodenal temperature was higher than rectal temperature. Grayson et al (1966) also showed jejunal temperature 0.5°C hotter than rectal temperature in the monkey. This was however, not found by Hochrein and Schleicher (1948) who observed that sigmoidal temperature was 1.0° to 1.1°C hotter than duodenal temperature in human subjects.

THE ROLE OF THE VISCERA IN HEAT PRODUCTION

It still remains the general opinion that heat production in the body at rest depends mainly on the muscles, particularly the muscles of respiration as well as the liver (Nedzel 1933-34; Best and Taylor 1961).

Although it is admitted that metabolic activity occurs in the viscera, especially in the liver, which could generate quite a lot of heat, it is generally thought that when compared to the muscles, the visceral heat production is slight.

That the liver produces between 12 and 18% of the total heat of the body at rest is however widely accepted. Evidences for this have been furnished by Kosaka (1930); Lehman (1953); Behnke (1958), Dosekun et al (1960) and Grayson and Kinnear (1962).

The role of the gastro-intestinal tract, on the other hand, is still a subject of controversy. Some authors consider this as very slight. A figure of 7.6% of total heat production is quoted by Lehman (1953). Considering the great length of the gastro-intestinal tract and the high metabolic activities of both the muscular and the mucosal coat, as well as such heat producing processes as, the transport of food substances across membranes during absorption, the active mitotic activities associated with the cell turnover of the mucosa, and the tonic activities of the muscular wall, one cannot help feeling that the figure might be low. Grayson et al (1966) adduced evidence that the value could, indeed be as high as 40% of the total heat production in the resting body.

Much work clearly needs to be done to show how much heat is really being produced and what mechanisms are involved in the production.

THE RESPONSE OF THE "CORE" TEMPERATURE TO CHANGES IN ENVIRONMENTAL TEMPERATURE

The response of the core temperature to changes in environmental temperature has for sometime been a subject for controversy. The result is that even to date nothing very definite is known about this response. Controversy has arisen largely out of the variations in methods of experiment as well as "thermometers" used. More than these, there have been variations in the methods of analysis of the results obtained. Most authors based the interpretation of their results either on absolute temperature changes, or on the rate at which these changes occur. A few others used the temperature differentials between the various structures and the aorta. Interpretations of some have frequently been conflicting.

The effect of body surface cooling on the core temperatures.

Cooling the body surface of human subjects, Masuda, Ohara and Katsura (1953) and Grayson (1950) produced increases in gastric and rectal temperatures respectively while Nedzel (1934); Fedorov and Shur (1942) and Grayson et al (1966) working on pentobarbitone anaesthetized dogs and monkeys observed a continuous fall in gastric, duodenal, jejunal, liver and portal venous temperatures. Body warming was found on the other hand, in human subjects, to cause either a fall or a rise in

rectal temperature. Some authors found only a fall (Cooper and Keralake 1949), while others got a fall in some subjects and a rise in others (Hemingway 1948). Colostomy temperature, on exposure to sudden warmth was found by Grayson (1949) to undergo an initial fall followed by a rise. Environmental warming has also been shown to produce a general rise in the "core" temperatures of the monkey (Grayson et al 1966). Stupfel and Severinghaus (1956) on the other hand, did not observe any change in rectal and colonic temperatures in anaesthetized dogs. This may probably be due to differences in the depth of anaesthesia.

Mechanisms involved in the response of the "core" temperature to environmental cooling.

Vasomotor changes

In explaining the changes that occur in "core temperatures" on body surface cooling, some authors assumed that this is brought about mainly by blood flow changes (Grayson et al 1966). There is however no general agreement on what changes do occur in response to environmental cooling. Kaneda et al (1953) and Grayson (1950 a and b) have suggested that the rise in gastric and rectal temperatures observed during environmental cooling, is due to hyperaemia. Gastro intestinal vasoconstriction on the other hand, has been suggested to follow body surface cooling (Grayson 1966). Grayson (1949) however showed that intestinal vasoconstriction is secondary to an initial vasodilatation. He showed that vasodilatation was a reflex response, while the pronounced vasoconstriction which followed it was a direct effect of the

circulating blood on the bowel circulation.

Heat production

The participation of the viscera in thermogenesis during body cooling has been very controversial. Except for the rat, where definite non-shivering thermogenesis has been demonstrated (Davis and Mayer 1954; Sellers 1954), it is still the general opinion that, heat production in response to environmental cooling is mainly dependent upon shivering.

Evidence abounds however to show that some of the observed increases in "core" temperatures during body cooling are due in part to increased heat production. For instance, the liver is known to increase its heat production in response to body surface cooling (Kosaka 1930, Nedzel 1933). Increase in heat production along the gastro-intestinal tract has also been suggested (Fedorov and Shur 1942; Grayson et al 1966; Donhoffer et al 1962). This has however not been proved conclusively.

How much increase occurs in the gastro-intestinal tract heat production and what mechanisms are involved in this still awaits further research.

INTRODUCTION

Temperatures within the "core area" have been recorded for more than two and a half centuries. The measurement of temperatures along the length of the gastro-intestinal tract, other than from the mouth, rectum and colon, however did not start until the turn of the century (Thiessen and Snell 1933).

Before the present work there seems to have been no well defined thermotopographic mapping of the "core area" of most animals, especially the dog. There are however, a number of scattered measurements from a few sites in the core area - from which some form of temperature distribution could be synthesized. The first aspect of this work will therefore deal with a systematic study of the temperature distribution in the "core area" of the dog. Special emphasies will be laid on the thermal gradient along the gastro-intestinal tract and its relationship to the liver.

From their work, prompted by the observations of Graf and Graf (1957), Grayson and Kinnear (1962) showed that the liver temperature in human subjects was 0.44°C cooler than the bowel temperature. Basing their calculations on this differential; assuming the liver to be no cooler than the aorta and making assumptions as to total bowel blood flow, they estimated that the heat production of the gastro-intestinal tract must amount to at least 40% of the total body heat production (Grayson, Irvine and Kinnear 1966). This is much higher than the

generally accepted value of 7.6% (Lehman 1953). It was therefore decided that this work would include a study of the heat production of the gastro-intestinal tract of the dog, both in the warm environment and during environmental cooling.

Federov and Shur (1942) showed that in the dog there is evidence for an increase in the heat production of the gastro-intestinal tract during environmental cooling. Up till now, however, the mechanism whereby this increased heat production is accomplished is not known. This work will attempt to evaluate, in a semi-quantitative way, the role played by both adrenergic and cholinergic influences in this response. The role played by these influences in the determination of the temperature levels in the gastro-intestinal tract in the warm environment will also be studied.

APPARATUS AND EXPERIMENTAL METHOD.

INTRODUCTION

There are many good methods in use for the measurement of temperature within the animal body. These include the simple mercury in glass thermometers, thermocouples, thermopiles and thermistors. Apart from their higher sensitivities and shorter measuring time, thermistors, thermocouples and thermopiles have their smaller sizes and flexibility as added advantages over the mercury in glass thermometers. These therefore can be used in the measurements of temperatures in organs such as the liver and gastro intestinal tract with minimum of trauma and interference with normal functions. Higher sensitivity and shorter measuring time notwithstanding, thermistors have no real advantage over thermocouples in the present work, since the temperature changes are not too small and the rate of change of these temperatures are fairly slow. Thermocouples were therefore considered quite adequate for the present measurements.

The principle of thermocouples.

Thermocouples can be represented in principle by the diagram in Fig I. Junction A is the measuring or "hot" junction, while junction B is the reference or "cold" junction. C and D are the junctions between the thermocouple and the leads connecting it to the recording instrument.

Seebeck (1821) discovered that in a circuit made up of two dissimilar metals as in Fig I, if junction A is kept hotter than junction B, an electromotive force is developed between these two junctions which causes an electric current to flow in the circuit.

Fig 1. Diagramatic representation of a thermocouple.
Junction A. is the "hot" or measuring junction while
junction B is the "cold" or reference junction.
C and D are junctions between thermocouple and leads.

Provided junctions C and D are kept at the same temperature, the e.m.f. developed between A and B will then be given by the equation.

$$E = P\triangle T$$

When $\triangle T$ is small P is the "thermoelectric power" of the junctions at temperature T and it is determined mainly by the physical chemistry of the two metals. The above describes the Seebeck effect. When a low impedance electrical detector is used, some proportion of the current produced is abstracted for measuring purposes. This and the high resistance of the leads, contribute to reduce the current flowing in the circuit. A successful thermocouple therefore requires a high value of thermoelectric power and a high impedance detector (Kay 1964). This is perhaps why sensitive current measuring galvanometers are used with thermocouples. These abstract the least possible current, thereby not spoiling the open circuit Seebeck law with the Peltier effect (Kay 1964).

For most biological temperature measurements the common metallic combinations are, copper-constantan, constantan-chromel and bismuth-antimony.

In practise, there is a great need for keeping the temperature of the reference junction constant in order to avoid the generation of spurious e.m.f. (Gray and Axelrod 1953). In order to overcome these fluctuations workers have been known to keep the reference junctions in thermostats containing either ice water or alternatively a freezing mixture, or water kept at 37°C. Occassionally however, some other authors have introduced the reference junction into aortic blood.

Fig 2. The Electric thermometer.
Plate shows the thermometer with the light spot on its calibrated screen. The connection box is on the right hand side of the thermometer.

The Thermometer

Temperature measurement in the present work was done with the Electric Universal Thermometer type TE3. manufactured by Elektro-laboratoriet Ltd, Copenhagen. (See fig 2). This thermometer works on the principle of thermocouples, and the current generated between the hot and cold junction is monitored by a sturdily built galvanometer. The deflection of the galvanometer is reflected on to a calibrated screen, as a spot of light with a thin dark line running down its vertical diameter. The screen is calibrated in 0.1°C from 16°C-46°C. Although Graf (1959) felt that only about 0.05°C could easily be read on the instrument, with practise it became possible to read about 0.02°C with ease.

The "hot" or measuring junction of the thermocouples are made into detachable applicators, while the "cold" junction is incorporated within the thermometer. The effect of changes in atmospheric temperature on the "cold" junction is permanently, accurately and without adjustments compensated for by a built in device, which acts directly on the galvanometer. This therefore removes the problems of the generation of spurious e.m.f. as a result of fluctuations in "cold" junction temperatures. It is guaranteed that this compensation works correctly in ambient temperatures between 10 and 33°C. This covers the range of temperatures in which the work was done. The instrument has a guaranteed recording accuracy of ±0.3% of the scale range. This in the thermometer used means an accuracy of ±0.1°C.

Fig 3. The applicators.
Type F6 used for measuring aortic and liver temperatures.
Type RM4 used for measuring portal and hepatic vein as well as duodenal, ileal, large intestinal temperatures.
Type RK2 used for measuring rectal temperature.
Type OSG. used for measuring gastric temperature.

The Applicators

Four different types of applicators, F6, RM4, RK2. and OSC. manufactured by Elekrolaboratoriet Ltd, Copenhagen were used for the present measurements. (See fig 3) They are made of copper-constantan or chrome nickel-constantan. The "hot" junctions located at the tips of these applicators are positioned in such a way as to be very sensitive to the temperature they are measuring. The other free end of the applicators are connected to plugs which fit into sockets on the connection box (See Fig 2). The connection box has a number of buttons which when pressed bring different applicators into connection with the "cold" junction in turns.

Type F.6

This flexible applicator, diameter 0.8mm (gauge 21), was used for measuring temperatures in the liver and aorta.

The "hot" junction of this applicator and its leads are thin and so it requires no special contact cap.

Type RM4

This applicator used in the present work for measuring temperatures within the portal vein, hepatic vein, the lumen of the duodenum, ileum and large intestine, is encased in a plastic tubing (diameter 2.3mm). There is a stainless steel cap at the end of the tubing, with which the "hot" junction makes contact with the substance whose temperature is being measured.

Types RK2 and OSC.

The RK2 was used for measuring rectal temperature while the OSC was

used in measuring oesophageal temperature. They both have essentially the same structure except for a rubber ring around the RK2. which prevents it from slipping out of the rectum. The hot junction and the leads in both cases are enclosed within a rubber tubing of diameter size 6mm. There is a stainless steel contact cap at the end of each of them.

Checking the accuracy of the applicators

At the beginning of the series of experiments and also after every subsequent 72 hours, the temperature readings given by the applicators were checked against a standard thermometer.

All applicators used were tied around the bulb of the thermometer which was dipped into an insulated beaker of water. The water in the beaker was kept well stirred at different temperatures.

Whenever discrepancies occurred between the standard thermometer and the galvanometer readings, the zero reading on the electric thermometer was recalibrated. It was found that at normal room temperature of about 29.2 + 1.6°C the zero line had to be shifted 0.35°C, to give similar values with the standard thermometer.

Since analysis and interpretations in the present work are based on organ-aorta temperature differentials, correlation graphs were plotted between P6 and the other applicators (See Fig 4). Applicators giving more than a 0.03°C deviation were discarded. Readings observed with the different applicators were corrected for accordingly.

Fig 4 Correlation graph between F6 and other applicators (RK2 or OSO and KM+)

THE OPERATIONAL PROCEDURE

The animal and anaesthetic

Mongrel dogs of either sex weighing between 8 and 12 kgs were used. The animals were usually housed for four days before use and fed on a regular diet with low protein content. They were however made to starve for the last 24 hours before the experiment. This was done in order to ensure that the gastro intestinal tract was empty, and that transportation of food across the mucosal membrane during the experiment, was reduced to the barest minimum.

The dogs were anaesthetized with Sodium Pentobarbitone. B.P. Abbott's Veterinary Nembutal (1cc containing 60gms (1 gr.) of Nembutal dissolved in 10% alcohol and propylene glycol 20% v/w). A dose of between 0.6-1ml/kg was administered intraperitoneally. Injections of 0.5ml to 1ml nembutal was found necessary, twice or thrice during the course of the experiment to maintain the depth of anaesthesia.

The preparation of the animal

The trachea was cannulated and connected to a positive pressure pump with a stroke volume of 150cc and a rate of 12 cycles/minute.

The left femoral vein was cannulated for injection purposes while the left femoral artery was prepared ready for blood pressure recording.

Recording Gastric Temperature

The distance of the stomach from the mouth was roughly estimated and marked out on the applicator used with a ring of thread. After adequate lubrication, the applicator was introduced into the oesoph-

agus and pushed into the stomach until the required depth was reached. The position was checked radiographically. The applicator was then moved round gently until the point with the highest intragastric temperature was found.

Recording Hepatic Venous Temperature

The external jugular vein was exposed just above the clavicle. The approximate distance from the exposed vein to the opening of the hepatic vein into the inferior vena cava (about the level of the diaphragm) was determined and marked with a thread ring on the applicator. The applicator was then introduced into the jugular vein and pushed down beyond the heart into the inferior vena cava. When the mark on the applicator was reached, the applicator was gently manipulated into the hepatic vein. This was indicated by a sudden increase in the recorded temperature.

RECORDING TEMPERATURES WITHIN THE ABDOMEN

A midline incision about 12 cms long was made along the linea alba. Bleeding sites were meticulously sealed to prevent haemorrhage.

The Duodenal Temperature

After the duodenum had been identified and brought up to the body surface, the applicator was introduced into its lumen as described in Fig 5.

A purse string suture was made into the wall of the duodenum. This was followed by the introduction of the applicator, around which a loop had been tied, into the lumen through a small incision made

Fig 5. Diagramatic representation of an applicator into the lumen of the gut.

in the middle the suture. A thread at the end of the suture was passed into the loop around the applicator to fix it in position with a knot.

The ileal and large intestinal temperatures

After identifying the ileum and the large intestine, the above procedure was adopted for the introduction of the applicators into their lumen.

The Portal Venous Temperature

The portal vein was reached from a branch of the splenic vein. (See fig 6).

The spleen was brought up to the body surface and the main splenic vein emptying into the portal vein was identified. Loops of thread were then passed round this in preparation for the introduction of applicator. The applicator was introduced into the vein through an incision in its wall. It was then pushed into the main portal vein until a resistance indicating its entry into the liver was felt. It was thereafter withdrawn by about 1cm.

The liver temperature

Liver temperature was recorded from the left lateral lobe. A suture was made into the substance of the liver. One end of the loose thread of the suture was passed into a loop tied around the applicator after which it was pushed into the liver lobe piercing through the middle of the suture. The applicator was then fixed in position with a knot.

Fig 6. Diagramatic representation of the introduction of an applicator into the portal vein.

Hepatic artery ligation

In experiments where hepatic arterial ligation was required, the following preceeded all other procedures.

A longer midline incision was found necessary. This had to reach as far up as the xiphisternum. The liver lobes were then pushed up against the diaphragm, while the stomach was pulled towards the pelvis. This brought the hepatic arteries into full view. With a cotton wool dissection, the arteries were cleared free of mesenteries and loops of thread were passed around them, ready for ligation.

Ligation, except in some special cases, did not follow immediately, but came later on in the experiment.

Vagotomy.

Vagotomy was done in two ways in the present work. One was cervical vagotomy, in which the vagus nerves were sectioned in the neck. The other was abdominal vagotomy. In the latter, vagotomy was done in the abdomen, just below the diaphragm at the level of the oesophageal hiatus. (See fig 7).

Cervical Vagotomy

Before the introduction of the tracheal cannula, the vagus nerves were dissected free from the corresponding carotid artery of either side. Loops of thread were then passed round each of the nerves before they were returned to their original positions. Later in the experiment, they were brought out again for sectioning.

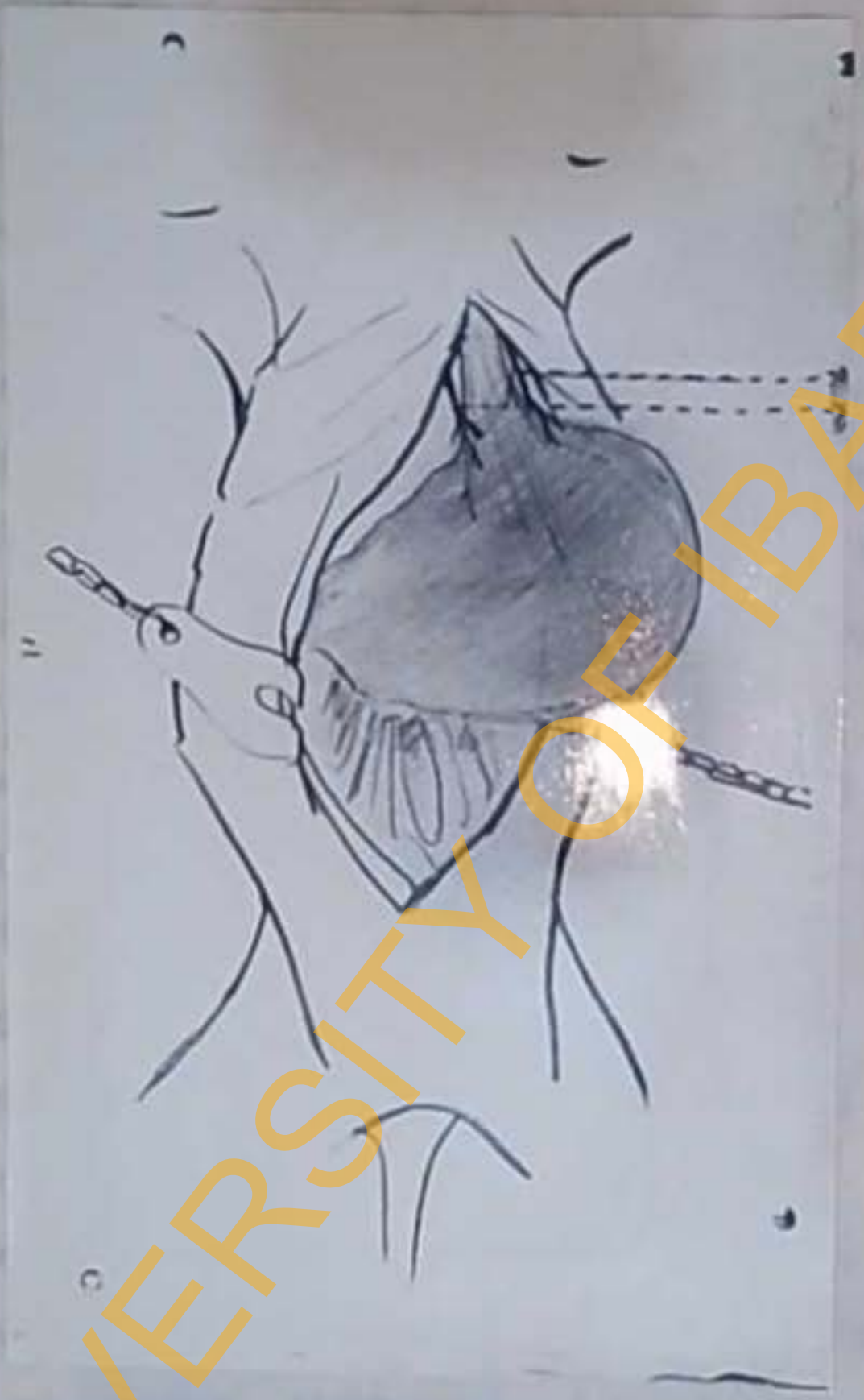

Fig 7. Diagram shows the anterior and posterior vagi at the point of sectioning.

Abdominal Vagotomy

In the case of abdominal vagotomy the following proceeded all other manuovres in the abdomen.

A long midline incision was needed, reaching as far as the xiphisternum. The abdominal walls were then retracted and the stomach pulled out to the right. Thus it was possible to get a good hold of the oesophagus. The peritoneal covering of the oesophagus was then opened with a pair of Spencer Well's forceps. It was then possible to get fingers around the oesophagus to feel for the anterior and posterior vagi. These were then sectioned.

It may be pertinent to mention here that the need for aspirating food from the stomach of the dogs did not a rise, since they were starved for the last 24 hours before the experiment.

Recording temperature in the rectum

Before the insertion of the applicator the rectum was always cleared of feaces with a cotton wool covered spatula.

This done, the applicator was inserted to a depth ranging from 8 - 10 cms or 3 - 3.5ins depending on the site where the highest temperature was obtained. Fig 8 shows an X-ray photograph of the rectal probe in position.

Recording Aortic temperature and blood pressure

Aortic temperature was recorded from the abdominal aorta from a point close to the origin of the coeliac artery. The applicator P6 was inserted into the abdominal aorta through the femoral arterial cannula. It was thus possible to record blood pressure and aortic

Fig 8. X-ray photograph of rectal applicator in position. Note the relationship of the thermojunction to the pelvis. X marks the position of the aortic applicator.

temperature simultaneously. Fig 9 shows the arrangement of the arterial cannula and applicator used.

It was found necessary to push the tip of the applicator about 12 - 15cms inside the abdominal aorta to get to the desired point.

0.2ml (1000 units/ml) heparin was injected into the arterial cannula to prevent clot formation. After an hour, a further 0.2ml heparin was injected intravenously. Blood pressure was recorded with the aid of a mercury manometer.

After the operation, the abdomen of the animals were sutured in two layers and the positions of all the applicators were checked radiographically.

Fig 10 shows an animal fully prepared for recording while fig 11 shows an X-ray photograph of the various positions of the applicators after operation.

Ambient Temperature

The experiments in the present work were performed in two different ambient temperatures, denoted as the "warm" and "cool" environments. The 'warm' environment refers to the environmental conditions when the windows were opened to the exterior so that there was free exchange of air between the outside and the room. The ambient temperature then was usually 29.2 ± 1.6°C and the relative humidity was 72.8 ± 2.0%.

The laboratory is equipped with two units of the ordinary room

Fig 9. Plate shows the arrangement of the arterial cannula and applicator type F6 for the simultaneous recording of blood pressure and aortic temperature.

airconditioners (Westinghouse, 1.5 h.p.) When these were turned to the fullest, it was possible to cool the room to 21.8 ± 1.5°C. The relative humidity then fell to 61.5 ± 1.8%. These describe the 'cool' environment. Relative humidity was recorded with Zeal's whirling hygrometer.

Fig 10. Temperature measurement within the core area of the dog. Shown in place are applicators F6 for the measurement of liver temperature and R24 for the measurement of temperatures within the portal vein, duodenum, ileum and large intestine.

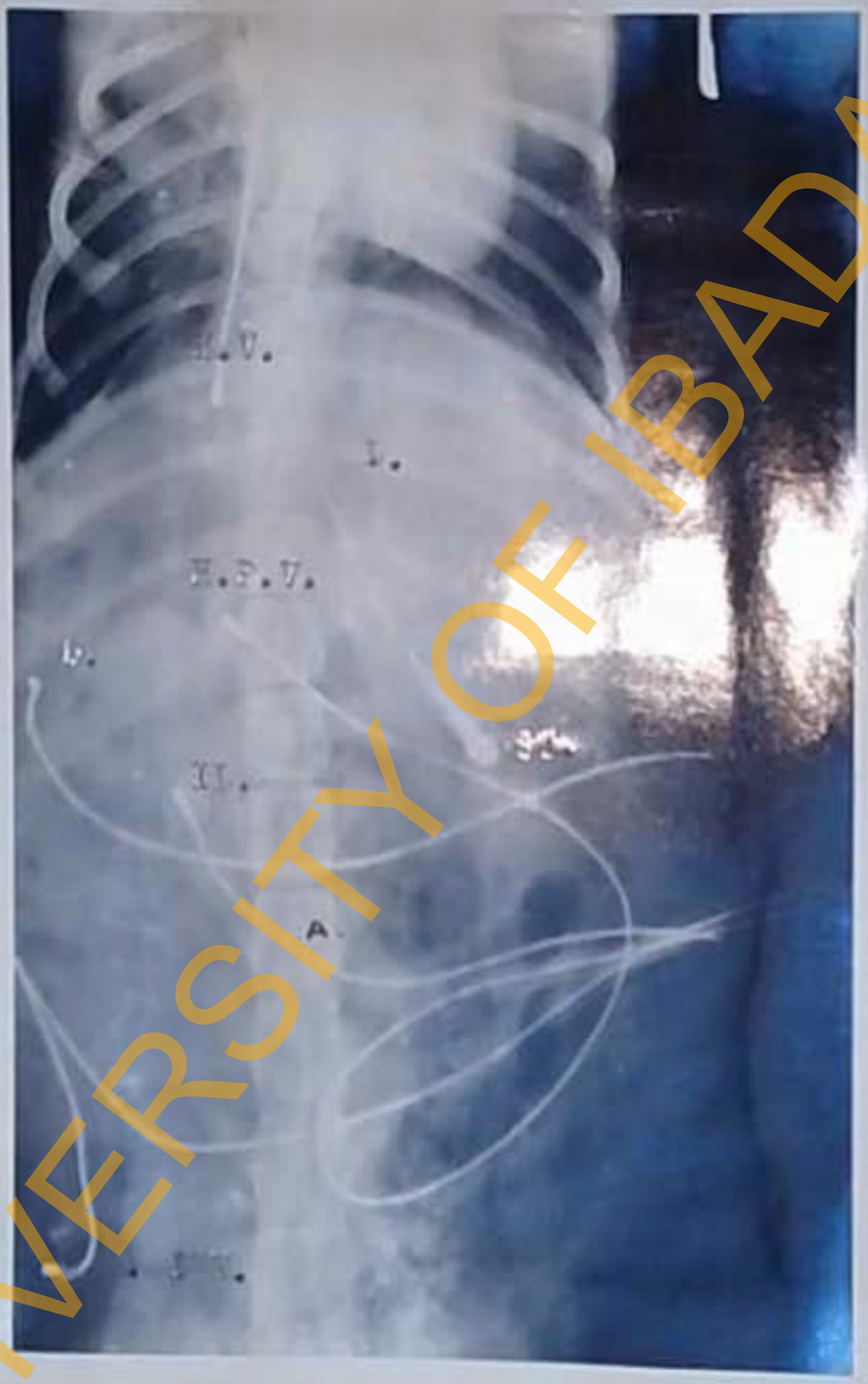

Fig 11. X-ray photograph of a dog showing applicators in position.
A - Aorta, D - Duodenum, H.p.v. - Hepatic portal vein, H.v. - Hepatic vein
IL - Ileum, L - Liver, L.I - Large intestine, ST- Stomach

EXPERIMENTAL RESULTS

TEMPERATURE DISTRIBUTION IN THE "CORE AREA" OF DOGS

Absolute temperatures recorded in the "core area" from various organs rose continuously when experiments were performed in the warm environment and fell continuously in the cool environment. During these periods however, the temperature differentials between these organs and the aorta were always, in the main, constant. The present observations and inferences were therefore, mainly based on the temperature differentials between these various organs and the aorta.

In one or two organs the temperature differentials varied from time to time. A regular oscillatory variation in the values of temperature differentials was observed for instance, in the hepatic vein. Here, the values varied about 0.15°C around the mean. This oscillation of values was found related to the respiratory cycle; temperatures being usually higher at expiration and lower at inspiration. This type of oscillations was however not observed anywhere in the gastro intestinal tract. Instead of this, some spontaneous erratic variations in the values of temperature differentials were observed occassionally but these were by no means regular.

Table 1 gives the mean values of temperature differentials between various organs in the "core area" and the aortic blood of 60 dogs, measured in the warm environment. The following pattern of distribution emerges from the table.

TABLE I.

Organ - aorta temperature differential distribution in the core area of the dog, warm environment only.
Dry bulb temperature = 29.2 ± 1.6°C
Relative humidity = 72.8 ± 2.0%

STOMACH	DUODENUM	ILEUM	LARGE INTESTINE	RECTUM	HEP. PORT. VEIN	LIVER	HEP. VEIN
0.41°C	0.57°C	0.49°C	0.44°C	-0.02°C	0.32°C	0.39°C	0.34°C

The above are means of sixty mean values taken from experiments composed of

(a) Means of preliminary measurements.

(b) Means of warm readings in ten control experiments

(c) Means of warm readings in ten atropine series before the administration of the drug.

(d) Means of warm readings in ten Bretylium series before the administration of the drug.

(e) Means of warm readings in ten Bretylium and atropine series before administration of the drugs.

(f) Means of warm readings in ten cervical vagotomy series before vagotomy.

THE GASTRO INTESTINAL TRACT.

Except for the rectum, the temperatures measured in the lumen of most regions of the gastro intestinal tract were substantially higher than the aortic blood temperature.

The mean value of the organ-aorta temperature differential obtained for the duodenum was 0.57°C, while that obtained for the ileum was 0.49°C. The mean value obtained for the large intestine was 0.44°C, while the value obtained for the rectum was - 0.02°C.

Table 1 shows clearly the existence of a definite thermal gradient along the gastro intestinal tract. Temperatures can be seen to increase from the stomach and anus, reaching a peak in the duodenum.

Besides being the hottest region of the gastro intestinal tract, it can be seen that the highest intra abdominal temperature differential was recorded in the duodenum. This was about 0.08°C hotter than the next hottest region, the ileum. The large intestine followed with a temperature 0.13°C cooler than the duodenum. The stomach was next with a 0.16°C difference between it and the duodenum. Most of these differences were quite constant and significant.

Rectal temperature recorded from the hottest region of the rectum (a point usually between 3 and 4 inches from the orifice) was found considerably cooler than all the other portions of the gastro intestinal tract. It was the only region of the gastro intestinal tract which was cooler than the aortic blood.

HEPATIC PORTAL VEIN

The mean portal vein-aorta temperature differential obtained in this series was 0.32°C. This is slightly lower than what was obtained for most regions of the gastro intestinal tract (with the exception of the rectum). It was about 0.07°C cooler than the liver and 0.03°C cooler than the hepatic vein. The mean temperature differential between the hepatic vein and the portal vein was never more than 0.10°C, a difference observed in the control cooling series. (See Table 3b).

The high portal vein-aorta temperature differentials demonstrates the significant role being played by the gastro intestinal tract in heat production.

THE LIVER.

The liver-aorta temperature differential recorded in this series was 0.39°C. This has already been pointed out as being about 0.07°C and 0.05°C hotter than the portal and hepatic venous blood respectively. It is 0.18°C cooler than the duodenum and 0.07°C cooler than the ileum. It is about as hot as the stomach being only about 0.02°C cooler. The liver in these dogs was however considerably hotter than the rectum. The difference between the liver and the rectal temperatures was 0.41°C.

THE HEPATIC VEIN

The mean of the hepatic venous blood-aorta temperature differential obtained in this series was 0.34°C. This is about 0.05°C cooler

than the liver and 0.02°C hotter than the hepatic portal vein. It was not unusual to find in individual experiments, hepatic venous blood temperatures rising higher than the liver temperature.

THE EFFECT OF HAEMORRHAGE ON THE ORGAN-AORTA TEMPERATURE DIFFERENTIAL DISTRIBUTION IN THE CORE AREA.

It has long been established that one of the vascular adjustments to haemorrhage is a redistribution of blood. This, amongst others, involves vasoconstriction in the gastro-intestinal tract. (Malcolm 1910, Mann 1915). A reduction in mesenteric blood flow on bleeding had been reported lately, thus confirming these earlier findings (Selkurt, Alexander and Patterson 1947; Selkurt and Brecher 1956; Gregg 1962). Scarborough (1952) reported a reduction in thermal conductivity of canine colonic mucosa on graded bleeding and interpreted this as vasoconstriction.

The effect of blood flow changes on the absolute temperatures measured in gastro-intestinal tract is controversial. For instance, while a fall gastric temperature on histamine injection was interpreted as reflecting hyperaemia (Henning Demling and Kinslmeier 1951)- a rise in gastric temperature (Masuda et al 1953) and a rise colostomy temperature (Grayson 1949) on body surface cooling were attributed to reflex vasodilatation. Grayson et al (1966) however - attributed the rise in the temperature of the jejunum relative to the aorta, in response to body surface cooling, to vasoconstriction.

In the present series it was intended to investigate the effect of haemorrhage and consequently vasoconstriction, on the pattern of distribution as well as the levels of the organ - aorta temperature differentials, in the 'core area' of the dog.

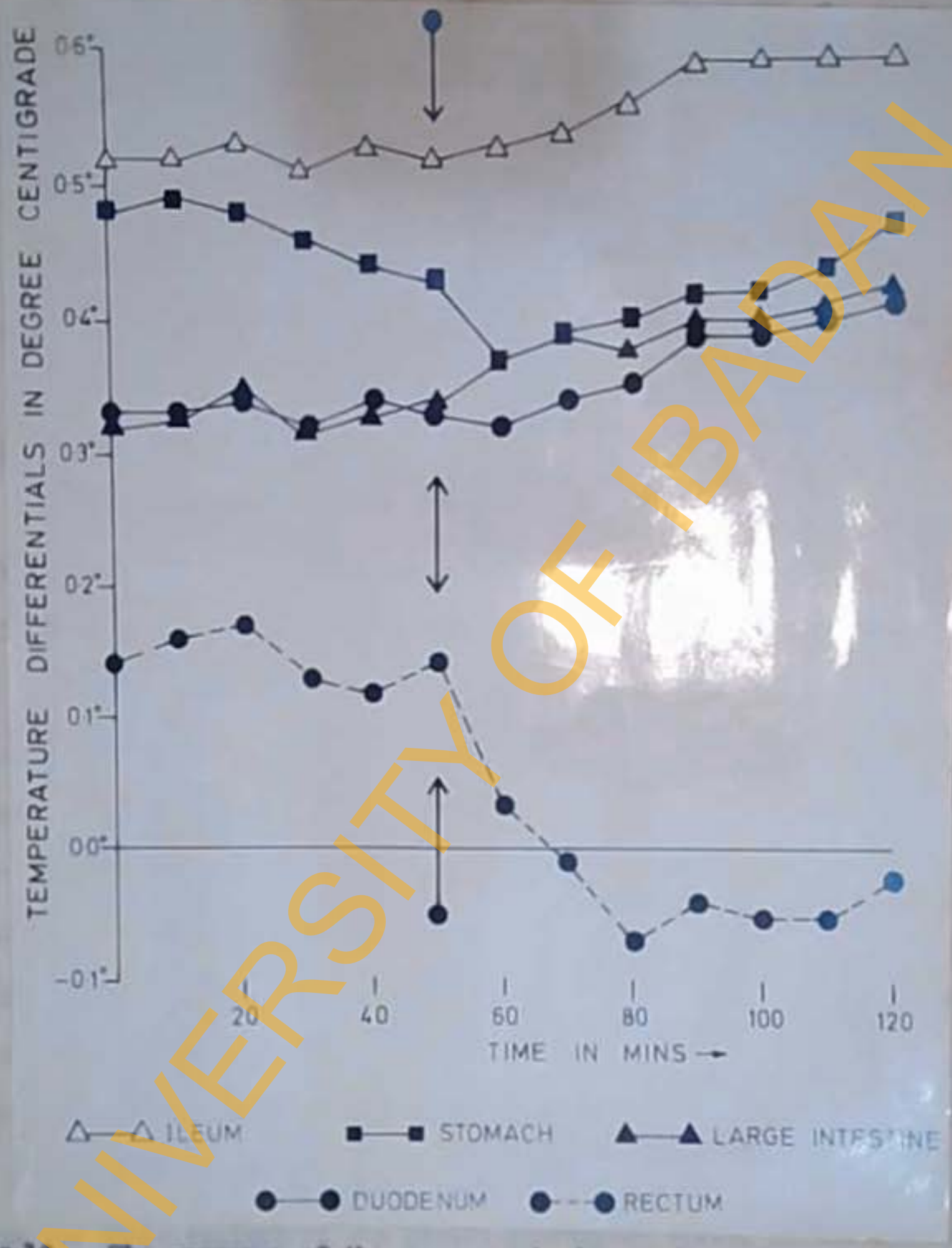

Fig 12. The response of the organ-aorta temperature differentials of various regions of the gastro intestinal tract to haemorrhage. Arrows mark the time of bleeding.

Animals were bled from the right femoral artery, after having previously obtained stable organ-aorta temperature differentials for about an hour. Bleeding was just enough to obtain a 20 mm Hg fall in the systemic blood pressure. Usually a blood withdrawal of about 40 ml was required to produce this fall.

The following was the picture obtained:-

Gastro-Intestinal Tract

Fig 12 demonstrates the response of the gastro-intestinal tract to bleeding. It can be seen from the graph that there was a slight fall, followed by a recovery in stomach-aorta temperature differential. The duodenum-aorta temperature differential rose distinctly after a brief latent period. The new level obtained after this rise was significantly different from the pre-bleeding value. The ileum - aorta temperature differential rose instantly and reached a new level after about thirty minutes. This new level was also significantly higher than the pre-bleeding value. The reaction of the large intestine-aorta temperature differential was very similar to that of the ileum except that it took longer to attain a new level.

The reaction of the rectum on the other hand was quite different from the other regions of the gastro intestinal tract, in that instead of rising as in other regions, the rectum-aorta temperature differentials fell sharply and instantly on haemorrhage. A new level was also reached in about thirty minutes.

The hepatic portal vein.

The portal vein-aorta temperature differential did not show

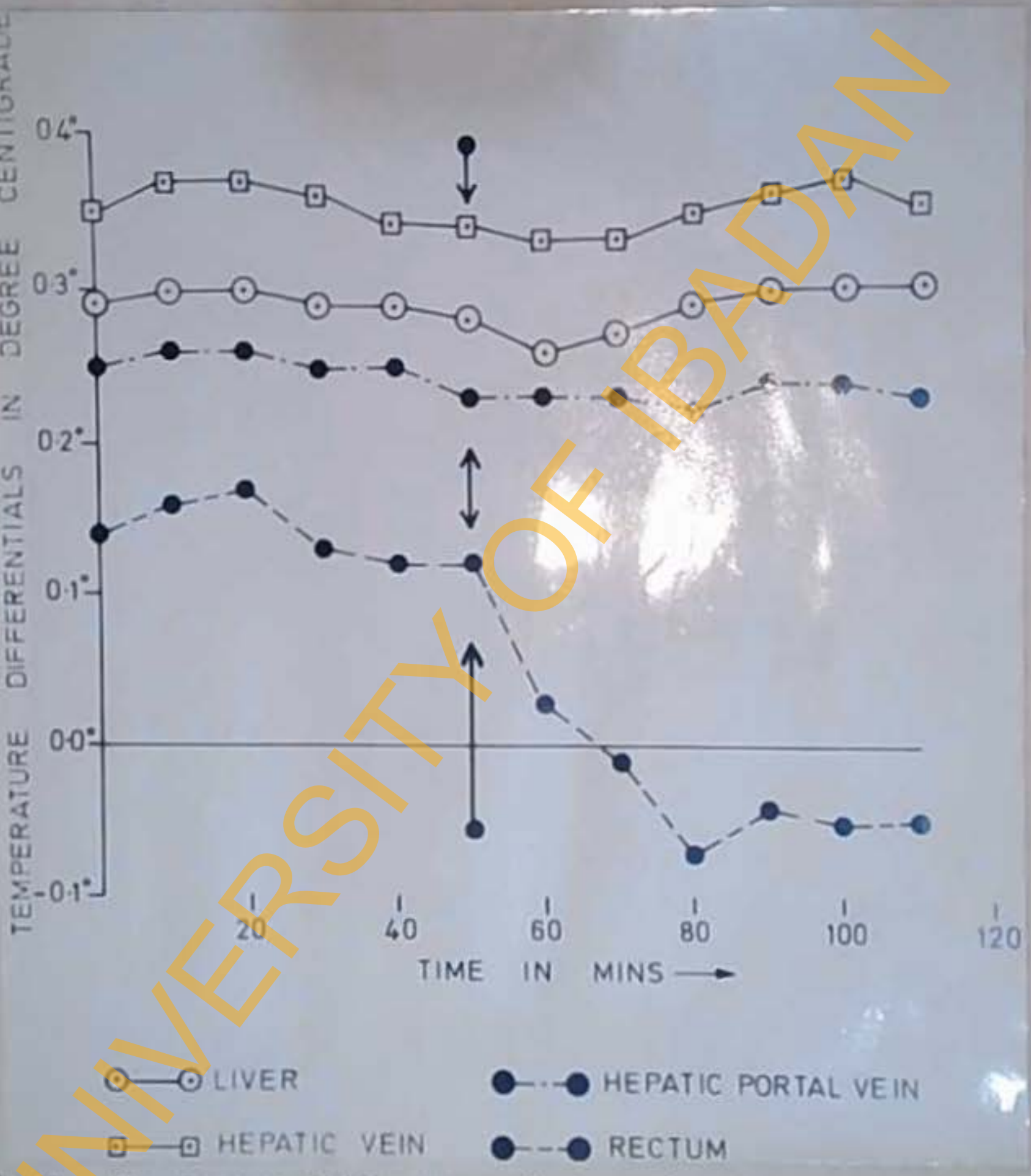

Fig 13. The response of the organ-aorta temperature differentials of the liver and its associated vessels to mild haemorrhage. Arrows mark the time of bleeding.

any distinct reaction to bleeding. The temperature differential remained substantially constant throughout the period of observations. (See Fig 13).

The Liver

Although there was a slight fall in the liver-aorta temperature differential, this transient reaction faded in about twenty minutes and left no trace of any marked response to bleeding. For most of the time therefore, it can be said that the liver did not respond to this type of bleeding in terms of temperature (See Fig 13).

The hepatic Vein

The hepatic vein did not respond in any significant way to bleeding. It showed some deflection, similar to that of the liver and like the liver, it was quite transient and negligible (See Fig 13).

EFFECT OF ENVIRONMENTAL COOLING ON THE TEMPERATURE DISTRIBUTION AND THE ORGAN - AORTA TEMPERATURE DIFFERENTIALS IN THE CORE AREA OF DOGS

Marshak (1939) reported a rise in the temperatures of the various inner organs in response to environmental cooling. He thus confirmed the earlier report of Fetscherin (1934) who reported a rise in liver temperature on environmental cooling. Although Grayson et al 1966 reported a fall in all the absolute temperatures measured, they observed a rise in the jejunum - aorta temperature differential, on moderately cooling the body surface of anaesthetized monkeys. A similar rise had earlier been observed in the hepatic portal vein - aorta temperature differential on cooling the body surface of non-anaesthetized dogs. (Federov and Shur (1942).

The present series of experiment was therefore performed to see the effect of environmental cooling on the values as well as the pattern of distribution of the organ-aorta temperature differentials, in the 'core area' of anaesthetized dog.

The experiments were performed on eleven dogs, weighing between 9 and 13 kgs. Cooling was commenced an hour after a constant organ-aorta temperature differential had been attained in most regions of the gastro-intestinal tract and the liver, in the warm environment. Cooling was carried out as previously described, using two Westinghouse (1½ h.p.) air conditioners. The desired temperature was attained in about thirty minutes. Cooling was usually not enough to produce visible shivering. Temperatures were then recorded for upwards of two hours.

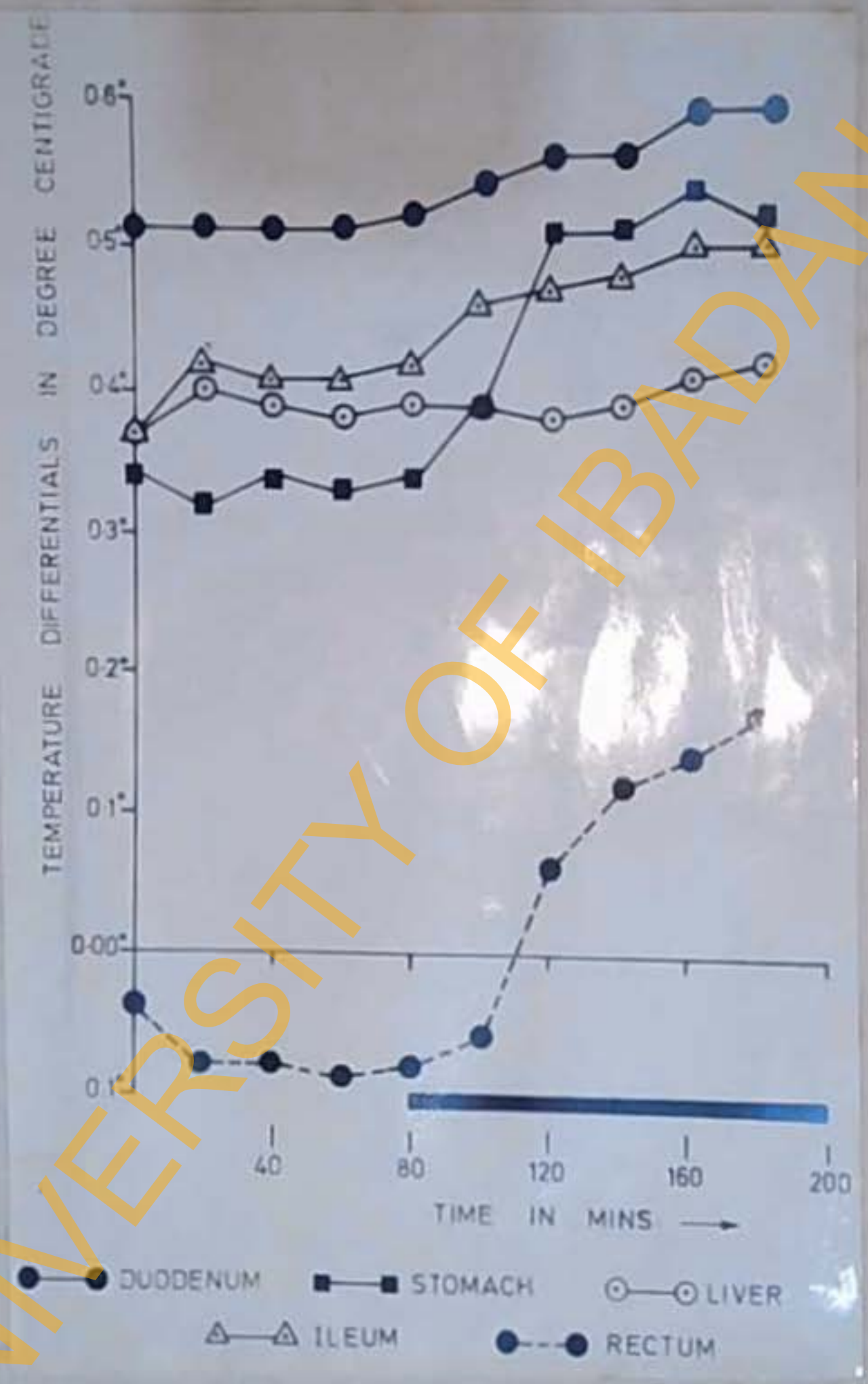

Fig 14. The response of the organ-aorta temperature differentials of various regions of the gastro intestinal tract to enviromental cooling. Thick horizontal line marks the period of cooling.

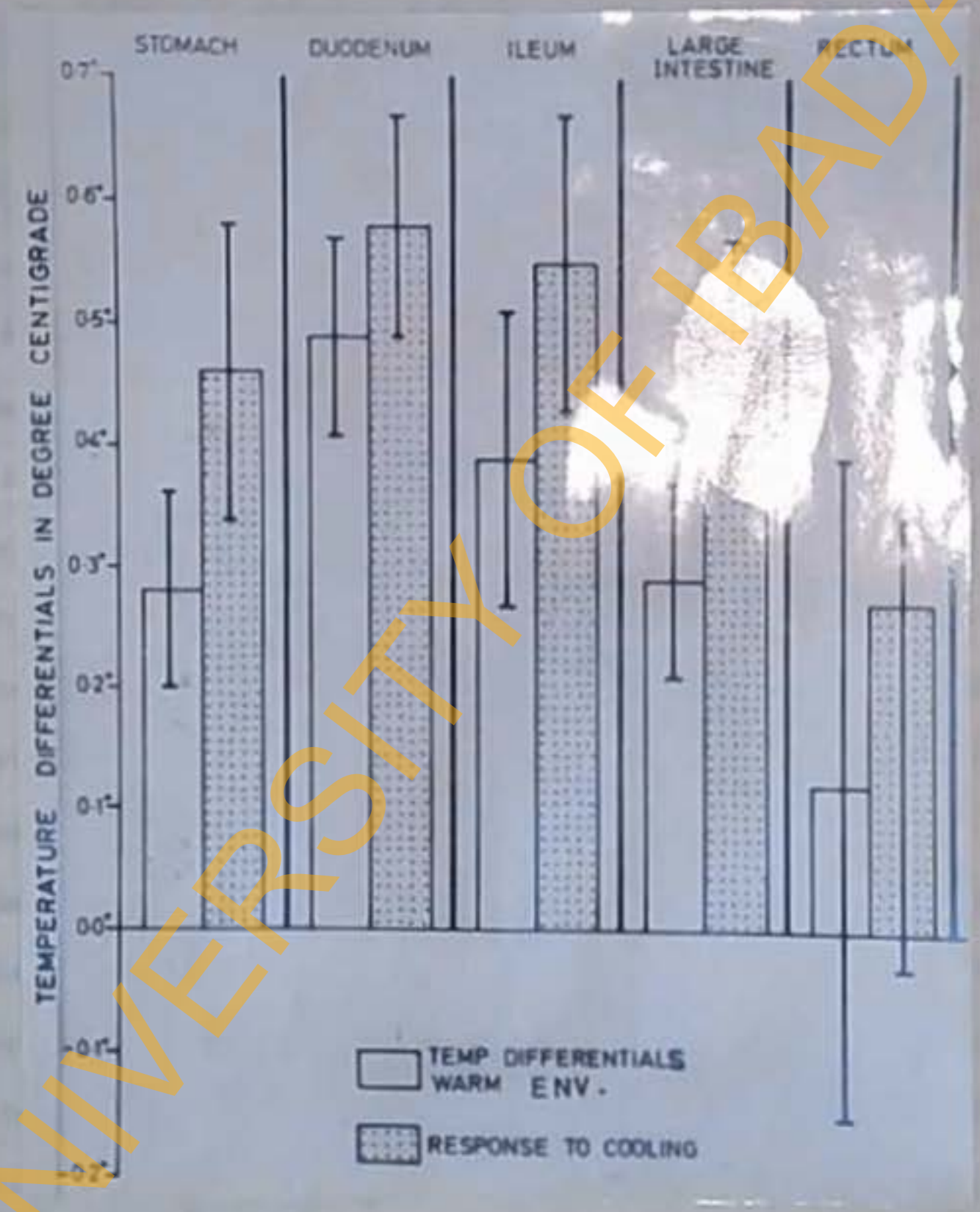

Fig 15. The effect of two hours of environmental cooling on the mean organ-aorta temperature differentials of various regions of the gastro intestinal tract.

The gastro-intestinal tract.

Table 2(a) gives the effect of environmental cooling on the absolute temperatures of various regions of the gastro-intestinal tract. Table 2(b) gives the corresponding mean organ-aorta temperature differentials of these regions during the hour preceeding cooling and after the second hour of cooling. Fig 14 shows the typical reaction of the organ-aorta temperature differentials (mean of 8 experiments) to environmental cooling. Fig 15 shows the mean values of the organ-aorta temperature differentials of the various regions of the gastro intestinal tract (mean of 10) one hour before and immediately after the second hour of cooling.

From the above, it is seen that the mean temperature differentials between the various regions of the gastro intestinal tract and the aorta increased during cooling. The most reactive regions were the stomach, the large intestine and the rectum.

The stomach - aorta temperature differentials increased steeply with the inception of cooling (see Fig 14). The rise was complete in about 40 minutes, after which a new but higher level of gastric-aorta temperature differentials was reached. The change from the pre-cooling value of $0.28^{\circ}C \pm 0.12$ was statistically significant at the 5% level ($t=3.7123$).

The rectum too showed a rise of $0.15^{\circ}C$ on cooling and this too was statistically significant at the 5% level ($t=1.987$).

The duodenum, on the other hand, did not show much change. There was a gradual rise which took about 50 minutes to reach completion.

TABLE 2B.

Organ-aorta "temperature differential" distribution along the gastro intestinal tract before and during the 2nd hour of environmental cooling.

"Warm" environment; dry bulb temperature = 29.2 ± 1.6°C relative humidity:- 72.8 ± 2.0%

"Cool" environment; dry bulb temperature = 21.8 ± 1.5°C relative humidity:- 61.5 ± 1.8%

EXPT.	STOMACH-AORTA		DUODENUM-AORTA		ILEUM-AORTA		LARGE INTESTINE AORTA		RECTUM-AORTA	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	0.28	0.55	0.64	0.73	0.56	0.66			-0.10	±0.09
2	0.22	0.63	0.38	0.42	0.21	0.32			0.20	0.45
3	0.32	0.55	0.50	0.63	0.35	0.57			0.01	0.16
4	0.34	0.38	0.52	0.61	0.27	0.43			-0.16	-0.02
5	0.19	0.47	0.42	0.50	00.39	0.56	0.30	0.48	-0.21	+0.09
6	0.41	0.55	0.40	0.46	0.25	0.41	0.25	0.55	0.04	0.01
7	0.28	0.39	0.61	0.65	0.61	0.72	0.30	0.40	0.23	0.51
8	0.16	0.23	0.50	0.68	0.47	0.47	0.24	0.40	0.19	0.28
9	0.16	0.28	0.52	0.73	0.38	0.63	0.30	0.50	0.46	0.42
10	0.34	0.48	0.49	0.45	0.52	0.46	0.28	0.43	0.54	0.69
11	0.43	0.57	0.37	0.51	0.30	0.32	0.40	0.63		
MEAN	0.28	0.46	0.49	0.58	0.39	0.55	0.29	0.48	0.12	0.27
STANDARD DEVIATION	±0.08	±0.12	±0.08	±0.11	±0.13	±0.13	±0.05	±0.08	±0.24	±0.23

TABLE 2A.

Absolute temperature distribution along the Gastro intestinal tract of the dog, - before and during the 2nd hour of environmental cooling.

"Warm" environment:- dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

"Cool" environment:- dry bulb temperature = 21.8 ± 1.5°C relative humidity 61.5 ± 1.8%

EXPT. NOS.	AORTA		STOMACH		DUODENUM		ILEUM		LARGE INTESTINE		RECTUM	
	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	36.48	37.21	36.76	37.76	37.12	37.94	37.04	37.87			36.38	37.30
2	35.74	36.20	35.96	36.83	36.12	36.62	35.95	36.52			35.94	36.65
3	31.87	31.98	32.19	32.53	32.37	32.61	32.22	32.55			31.88	32.14
4	33.20	34.09	33.54	34.47	33.72	34.70	33.47	34.52			33.04	34.07
5	32.54	33.01	32.73	33.48	32.96	33.51	32.93	33.57	32.84	33.49	32.33	33.10
6	35.74	36.38	36.15	36.93	36.14	36.83	35.99	36.79	35.99	36.63	35.70	36.39
7	31.31	31.86	31.59	32.25	31.92	32.51	31.92	32.58	31.61	32.26	31.54	31.37
8	35.20	36.09	35.36	36.32	35.70	36.77	35.67	36.56	35.44	36.44	35.34	36.37
9	35.48	36.21	35.64	36.49	36.00	36.94	35.86	36.84	35.78	36.71	35.94	36.63
10	35.74	36.38	36.08	36.86	36.23	36.83	36.26	36.84	36.02	36.81	36.28	37.07
MEAN	35.06	36.20	35.49	36.77	35.43	36.71	35.36	35.52	35.46	36.83	35.18	36.47

Although the rise was only 0.09°C from the pre-cooling value to the post-cooling value, it was still statistically significant at the 5% level (t=2.0904).

The ileum showed a gradual rise from its pre-cooling value to a new post-cooling value. The rise amounting to about 0.16°C took about 100 minutes for completion and was significant (t=1.9808).

The large intestine too showed a marked rise in the temperature differentials between it and the aorta. The rise of about 0.19°C too was quite significant (t=5.016).

There was a slight alteration in the pattern of distribution of the organ-aorta temperature differentials following cooling. The stomach, which was initially cooler than both the duodenum and the ileum, became hotter than the ileum and the temperature differential between it and the duodenum fell from 0.21°C in the pre-cooling condition to 0.12°C in the post cooling condition. There was also a reduction in the difference between the large intestinal temperature and that of the duodenum after cooling. The difference fell from 0.20°C to 0.10°C after cooling.

Hepatic Portal Vein

Fig 16 shows the course of the reaction of the organ - aorta temperature differentials of the liver and its associated vessels during environmental cooling. Table 3(a) gives values of absolute temperatures during the last one hour before cooling and immediately after the second hour of cooling. Table 3(b) on the other hand, gives

Fig 16. The response of the organ-aorta temperature differentials of the liver and its associated vessels to environmental cooling. Thick horizontal line marks the period of cooling.

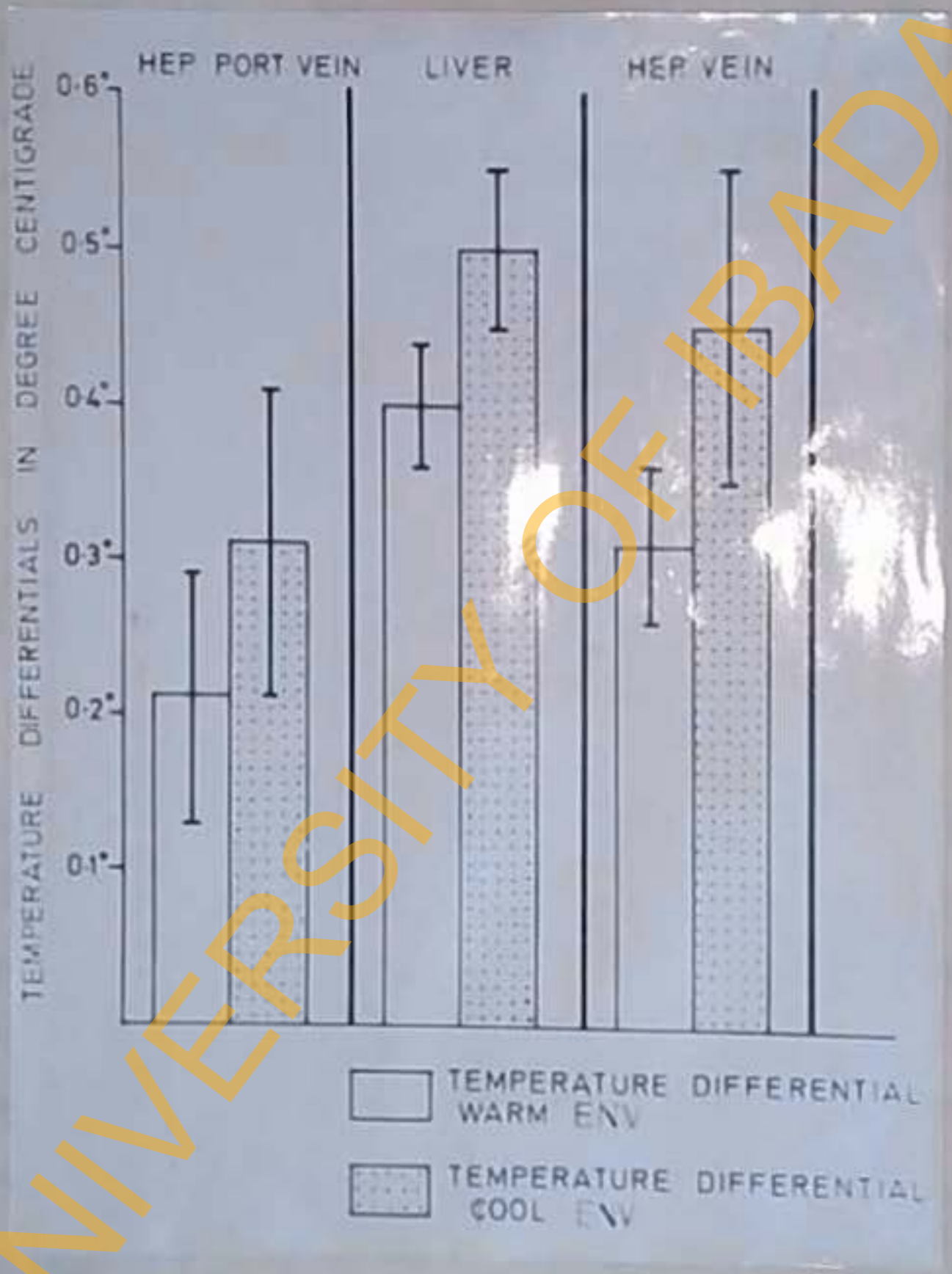

Fig 17. The effect of two hours of environmental cooling on the organ-aorta temperature differentials of the liver and its associated vessels.

values of the corresponding organ-aorta temperature differentials during the same periods. Fig 17 shows the effect of two hours of environmental cooling on the mean values of organ-aorta temperature differentials of the liver and its associated vessels.

Fig 16 shows a gradual rise in the portal venous blood-aorta temperature differentials from the pre-cooling value to a new post - cooling value. The difference between the mean pre-cooling and post cooling values was 0.10°C and it was found significant at the 5% level (t+2.869). It is noteworthy however that the rise in the portal vein-aorta temperature differential was less than in any of the regions of the gastro-intestinal tract. Splenic vein ligation did not significantly alter response (See Fig 18, Tables 4(a) and 4(b).

Liver

Fig 16 shows the response of the liver-aorta temperature differentials to environmental cooling. There was a rise of 0.10°C from the precooling level to the post-cooling level (as seen in Table 3(b). This was significant at the 5% level (t=4.741). Splenic vein ligation did not alter the response significantly. See fig 18, Tables 4a and 4b.

Hepatic vein.

The reaction of the hepatic venous blood-aorta temperature differential was similar to that of the portal vein. Fig 16 shows the gradual increase in the temperature differential of the hepatic vein-

TABLE 3A.

Absolute temperatures measured in the liver and its associated vessels - before and during the 2nd hour of environmental cooling.
"Warm" environment; dry bulb = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%
"Cool" environment; dry bulb = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT.	AORTA		HEP. PORT VEIN		LIVER		HEPATIC VEIN	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	36.48	37.21	36.64	37.48	36.85	37.70	36.74	37.67
2	35.74	36.38	35.91	36.69	36.13	36.84	36.01	36.79
3	35.06	36.20	35.23	36.45	35.44	36.66	35.38	36.66
4	31.87	31.98	32.05	32.20	32.22	32.53	32.16	32.29
5	33.20	34.09	33.37	34.34	33.55	34.53	33.55	34.49
6	32.54	33.01	32.74	33.38	32.92	33.50	32.93	33.50
7	35.74	36.38	36.14	36.12	36.86	36.16	37.03	35.74
8	31.31	31.86	31.54	32.16	31.79	32.41	31.56	32.15
9	35.20	36.09	35.36	36.37	35.68	36.69	35.46	36.55
10	35.48	36.21	35.71	36.55	35.91	36.72	35.80	36.80
MEAN	34.26	34.94	34.47	35.25	34.66	35.44	34.57	35.39

TABLE 3B.

Organ - aorta "temperature differential" measured in the liver and its associated vessels before and during the 2nd hour of **environmental** cooling.
"Warm" **environment**:- Dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%
"Cool" **environment**:- Dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT.	HEP. PORT. VEIN-AORTA		LIVER - AORTA		HEP. VEIN-AORTA	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL
1	0.16	0.27	0.37	0.49	0.26	0.46
2	0.17	0.31	0.39	0.46	0.27	0.41
3	0.17	0.25	0.38	0.46	0.32	0.46
4	0.18	0.22	0.35	0.55	0.29	0.31
5	0.17	0.25	0.35	0.44	0.35	0.40
6	0.20	0.37	0.38	0.49	0.39	0.49
7	0.40	0.54	0.38	0.48	0.42	0.65
8	0.23	0.30	0.48	0.55	0.25	0.29
9	0.16	0.28	0.48	0.60	0.26	0.46
10	0.23	0.34	0.43	0.51	0.32	0.59
MEAN	0.21	0.31	0.40	0.50	0.31	0.45
S.D.	±0.07	±0.09	±0.04	±0.05	±0.06	±0.11

aorta on environmental cooling. The rise of about 0.14°C in the differential on cooling, was also found significant (t=3.504).

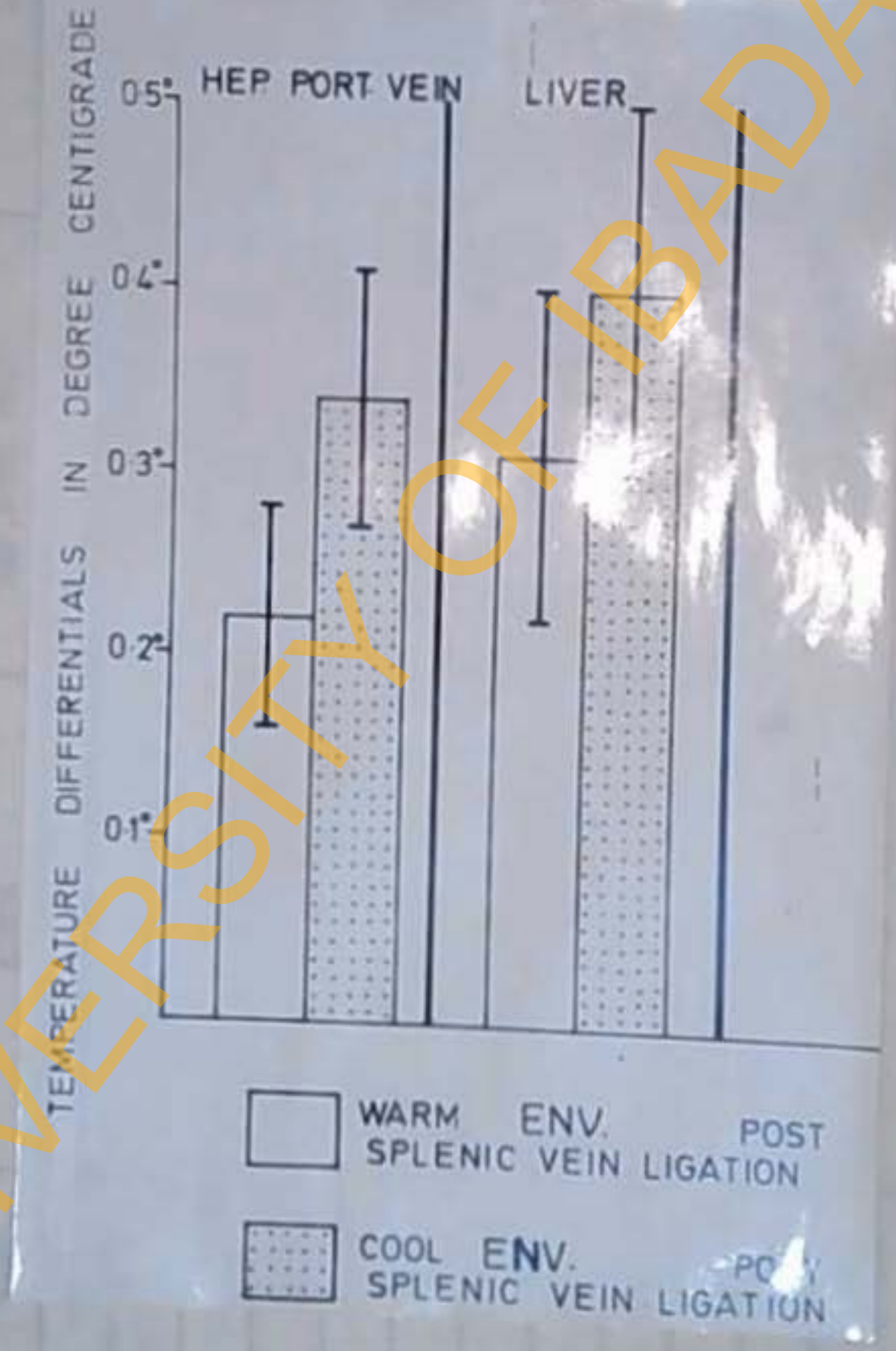

Fig 18. The effect of two hours of environmental cooling on the organ-aorta temperature differentials of the liver and portal vein - after splenic vein ligation.

TABLE 4A.

Absolute temperatures measured in the liver and its associated vessels before and during the 2nd hour of environmental cooling - post splenic vein ligation.
"Warm" environment dry bulb temperature = 29.2 ± 1.6°° relative humidity = 72.8 ± 2.0%
"Cool" environment dry bulb temperature = 21.8 ± 1.5°° relative humidity = 61.5 ± 1.0%

EXPT.	AORTA		HEP.PORT VEIN		LIVER	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL
1	36.39	37.12	36.56	37.51	36.65	37.45
2	35.74	36.38	35.97	36.72	35.96	36.69
3	37.11	37.66	37.29	37.92	37.59	38.20
4	31.87	32.04	32.10	32.37	32.25	32.49
5	35.11	36.20	35.28	36.55	35.37	36.50
6	37.70	38.50	37.90	38.89	38.08	38.89
7	34.10	35.28	34.29	35.54	34.32	35.56
8	36.20	37.12	36.34	37.36	36.43	37.41
9	38.16	38.73	38.31	39.06	38.54	39.32
10	35.39	36.12	35.73	36.59	35.69	36.51
MEAN	35.78	36.51	36.00	36.85	36.09	36.91

TABLE 4B.

Organ - aorta temperature differentials measured in the liver and its associated vessels - before and during the 2nd hour of environmental cooling post splenic vein ligation.
"Warm" environment:- dry bulb temperature = 29.2 ± 1.6°C
relative humidity = 72.8 ± 2.0%
"Cool" environment:- dry bulb temperature = 21.8 ± 1.5°C
relative humidity = 61.5 ± 1.8%

EXPERIMENT	HEP. PORT VEIN - AORTA		LIVER - AORTA	
NOS.	WARM	COOL	WARM	COOL
1	0.17	0.39	0.26	0.33
2	0.23	0.34	0.22	0.31
3	0.18	0.26	0.48	0.54
4	0.23	0.33	0.38	0.45
5	0.27	0.35	0.26	0.30
6	0.20	0.37	0.38	0.49
7	0.19	0.28	0.22	0.30
8	0.24	0.24	0.23	0.29
9	0.25	0.33	0.38	0.59
10	0.34	0.47	0.30	0.39
MEAN	0.22	0.34	0.31	0.40
S.D.	±0.05	±0.06	±0.08	±0.11

ROLE OF CHOLINERGIC MECHANISMS IN THE DETERMINATION AND REGULATION OF THE TEMPERATURE AND THE ORGAN-AORTA TEMPERATURE DIFFERENTIAL OF THE CORE AREA

It is well known that spontaneous contraction of smooth muscle occurs in the gastro intestinal tract. This spontaneous contraction may be primarily of a myogenic origin but it is certainly known to be influenced by nervous and humoral factors. Textor (1963) stated that the automatic action of the smooth muscles of the gut is modified by the influence of both the intrinsic and extrinsic nerve plexa, found in the walls of the gastro intestinal tract.

Acetylcholine is known to be continuously produced and released in the wall of the gastro intestinal tract. Although the release could be independent of the nervous activities of the extrinsic nerves of the g.i.t, yet its production has been attributed to the intramural ganglion cells in the plexa of Auerbach and Meissner. (Dikshit 1933). Le Heux (1918-1919) and Magnus (1920) noted a constant production of choline from the wall of the intestine and expressed the views that this release is mainly for motor activities. This could either be those of the smooth muscles of the gut wall or of the villi (Woznak 1936). There are other functions which the released acetycholine could serve, secretion being one of them.

Sato (1935) reported increased gastric motility on subjecting rabbits to cold stress. This was also observed in human subjects by Bisgard and Nye (1940) who attributed it to a primary increase in gastric acid secretion. Whatever the mechanism bringing this about,

Fig 19. The effect of atropine sulphate (1mg/kg body weight) on the blood pressure.

it appears increased gastro-intestinal motility is one of the mechanisms whereby the body responds to cold exposure.

Although Masek (1946) suggested that increased motility as well as increased secretion - could account for a rise in gastric temperature, it appears that the relationship between these cholinergic mechanisms and temperature distribution in the core area, is not yet well established. It was therefore intended to study the effect of the blockade of these cholinergic mechanisms on both the absolute temperature distribution and the levels, as well as the pattern of distribution of the organ-aorta temperature differentials, in the core area of the dogs.

Parasympathectomy was carried out in two main ways in the present series. This first was a pharmocologic parasympathectomy using atropine sulphate, while the second was by vagotomy.

It is a well known fact that atropine inhibits intestinal motility (Youmans et al 1943). It does this by reducing if not blocking completely, by a process of surmountable antagonism the effect of the released acetylcholine in the wall of the gastro intestinal tract (Innes and Nickerson 1965). In these experiments, atropine sulphate was injected in doses of 1mg./kg. body weight intravenously. The drug was administered one hour after the organ-aorta temperature differentials in most of the regions of the gastro intestinal tract had stabilized, in the warm environment.

The first noticeable reaction of the drug was on the blood pressure (See Fig 19). There was an instant fall lasting about 5 minutes, at the end of which the blood pressure stabilized at a lower level.

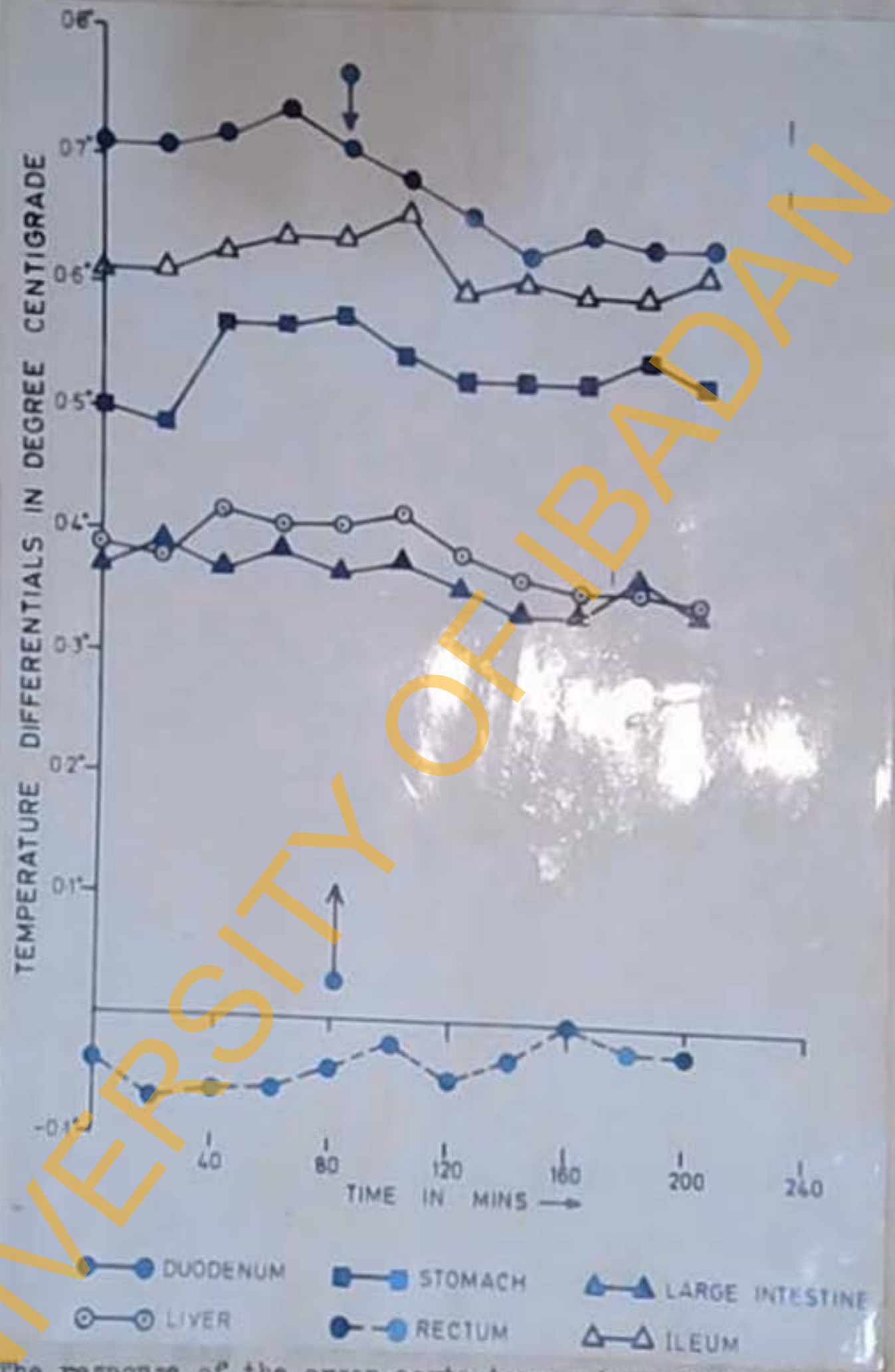

Fig 20. The response of the organ-aorta temperature differentials of the various regions of the gastro intestinal tract to the injection of atropine sulphate (1 mg/kg body weight)

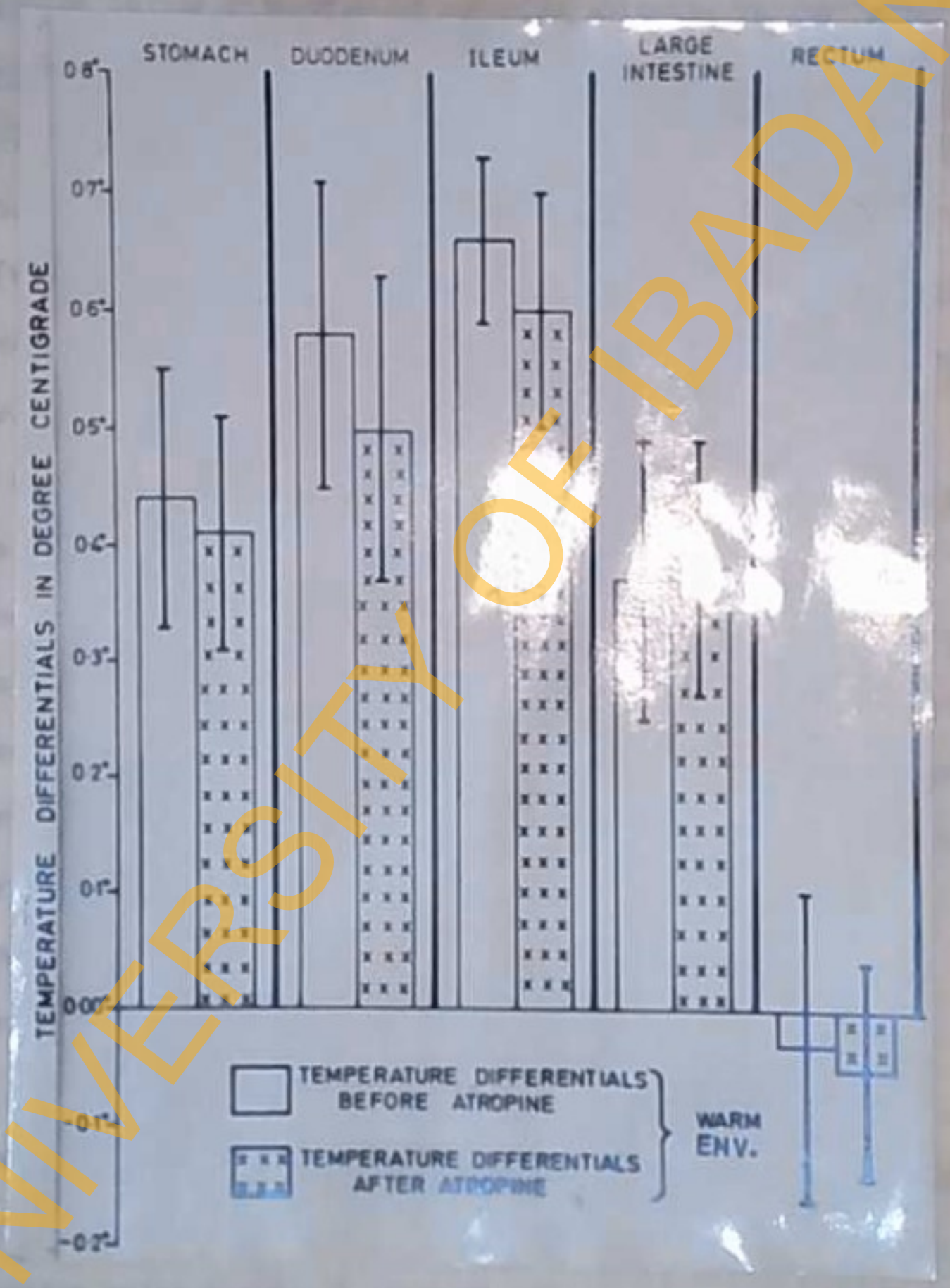

Fig 21. The effect of atropine sulphate (1mg/kg body weight) on the mean organ-aorta temperature differentials of various regions of the gastro intestinal tract. (Warm environment only).

I. THE EFFECT OF ATROPINE SULPHATE ON CORE TEMPERATURES

The Gastro Intestinal Tract

A. Response to the injection of atropine sulphate in the "warm" environment.

Table 5(a) shows the effect of atropine sulphate on the absolute temperatures of various regions of the gastro intestinal tract. Table 5(b) and Fig 21 give the corresponding values of organ-aorta temperature differentials of these regions one hour before and after two hours of atropine sulphate administration. Fig 20 shows the typical course of the response of the organ-aorta temperature differentials of the g.i.t. to the injection mean of 8 experiments).

From fig 20 it can be seen that the stomach-aorta temperature differentials fell significantly during the first 40 minutes after the injection of the drug. After another fourty minutes, there was a recovery towards the pre-injection level. The new value attained was only about 0.03°C lower than the pre-injection value. This difference is not statistically significant (P= 0.6).

The duodenum displayed the most pronounced fall of all the regions of the gastro intestinal tract. This lasted about 1 hour. There was some recovery towards the pre-injection value after about two hours of the injection. The reduction of about 0.08°C from the pre-injection value was found statistically significant. It was the greatest reduction suffered by any part of the gastro intestinal tract.

The ileum showed a fall in the value of its temperature differe-

TABLE 5A.

Absolute temperature distribution along the gastro intestinal tract before and 2 hours after the intravenous injection of (1mg/kg body weight) atropine sulphate.
"Warm" environment:- dry bulb temperature = 29.2 ± 1.6° relative humidity = 72.8 ± 2.0%

EXPT.	AORTA		STOMACH		DUODENUM		ILEUM		LARGE INTESTINE		RECTUM	
NOS.	PRE ATR	POST ATR	PRE ATR	POST ATR	PRE ATR	POST ATR	PRE ATR	POST ATR	PRE ATR	POST ATR	PRE ATR	POST ATR
	WARM	WARM	WARM	WARM	WARM	WARM'	WARM	WARM	WARM	WARM	WARM	WARM
1	33.96	34.12	34.49	34.48	34.61	34.77	34.70	34.83	34.22	34.36		
2	36.69	37.13	37.21	37.63	37.39	37.80	37.53	37.86	36.94	37.42	36.61	37.05
3	34.59	35.55	35.83	35.80	35.68	35.85	35.18	36.15	34.82	35.87	34.68	35.45
4	33.96	34.60	34.19	34.83	34.44	35.03	34.43	35.04	35.26	34.89	34.49	34.45
5	37.62	39.33	38.03	39.71	38.41	40.04	38.28	40.10	38.21	39.92	34.00	39.36
6	36.39	37.07	37.05	37.63	37.17	37.80	37.00	37.63	36.22	37.58	36.61	37.08
7	37.11	37.34	37.62	37.71	37.61	37.74	37.75	37.93	37.61	37.89	36.92	37.22
8	34.10	34.73	34.72	35.20	34.76	35.20	34.79	35.28	34.58	35.10	35.95	34.82
9	35.16	34.26	35.61	34.65	35.53	34.56	35.86	34.98	35.47	34.56	35.03	34.15
10	36.71	37.87	36.98	38.13	37.06	38.27	37.32	38.41	36.93	34.55		
11	35.14	34.26	35.59	34.73	35.74	34.74	35.79	34.68			35.16	34.20
MEAN	35.58	36.02	36.02	36.43	36.16	36.52	36.24	36.62	35.95	36.40	35.55	35.97

TABLE 5B.

Organ - aorta temperature differentials measured along the gastro intestinal tract before and 2 hours after the intravenous injection of (1mg/kg body weight) atropine sulphate.

"Warm" environment:- Dry bulb temperature = 29.2 ± 1.6° Relative humidity = 72.8 ± 2.0%

EXPT.	STOMACH-AORTA		DUODENUM-AORTA		ILEUM-AORTA		LARGE INTEST-INE AORTA		RECTUM-AORTA	
NOS.	PRE ATRO-PINE	POST ATRO-PINE	PRE ATRO-PINE	POST ATRO-PINE	PRE ATRO-PINE	POST ATRO-PINE	PRE ATRO-PINE	POST ATRO-PINE	PRE ATRO-PINE	POST ATRO-PINE
1	0.53	0.46	0.65	0.65	0.74	0.71	0.26	0.24		
2	0.52	0.50	0.70	0.67	0.74	0.73	0.25	0.29	-0.08	-0.08
3	0.24	0.25	0.49	0.30	0.59	0.60	0.23	0.32	0.09	-0.10
4	0.23	0.23	0.48	0.43	0.47	0.44	0.30	0.29	-0.10	-0.15
5	0.41	0.38	0.79	0.71	0.68	0.77	0.59	0.59	+0.04	+0.03
6	0.66	0.56	0.78	0.73	0.61	0.56	0.53	0.51	+0.22	+0.01
7	0.51	0.43	0.50	0.40	0.64	0.59	0.50	0.55	-0.19	-0.12
8	0.62	0.57	0.66	0.47	0.69	0.55	0.48	0.37	-0.15	+0.09
9	0.45	0.39	0.37	0.30	0.70	0.72	0.31	0.30	-0.13	-0.11
10	0.27	0.26	0.35	0.40	0.61	0.54	0.22	0.29		
11	0.45	0.47	0.60	0.48	0.65	0.42			0.02	-0.06
MEAN	0.44	0.41	0.58	0.50	0.66	0.60	0.37	0.38	-0.03	-0.05
STANDARD DEVIATION	±0.14	±0.11	±0.16	±0.15	±0.09	±0.11	±0.13	±0.12	±0.13	±0.08

ntial during the first 80 minutes of the injection of atropine sulphate (see fig 20). After another 40 minutes it finally rose to a new stable level. The 0.06°C difference between the pre- and post-injection values was found not to be statistically significant. (P = 0.2 - 0.1).

The reaction of the large intestine on the other hand was more gradual although it also lasted about 80 minutes. The 0.01°C difference between the pre-injection and the post-injection values was also not significant at the 5% level (P = 0.8).

The rectum did not show marked signs of response to atropine administration. The rectum-aorta temperature differential was however reduced by 0.02°C and this was also not found statistically significant.

B. Response to environmental cooling after atropine sulphate

After obtaining constant organ-aorta temperature differentials in most of the regions of the gastro intestinal tract, the environment was cooled.

Fig 22 shows the typical reaction of various regions of the gastro intestinal tract to environmental cooling after atropine sulphate (mean of 8 experiments). Table 7(a) gives values of the absolute temperatures of various regions of the gastro intestinal tract during the last hour before and the second hour of environmental cooling post-atropine. Table 7(b) and Fig 23 on the other hand give the corresponding values of organ-aorta temperature differentials.

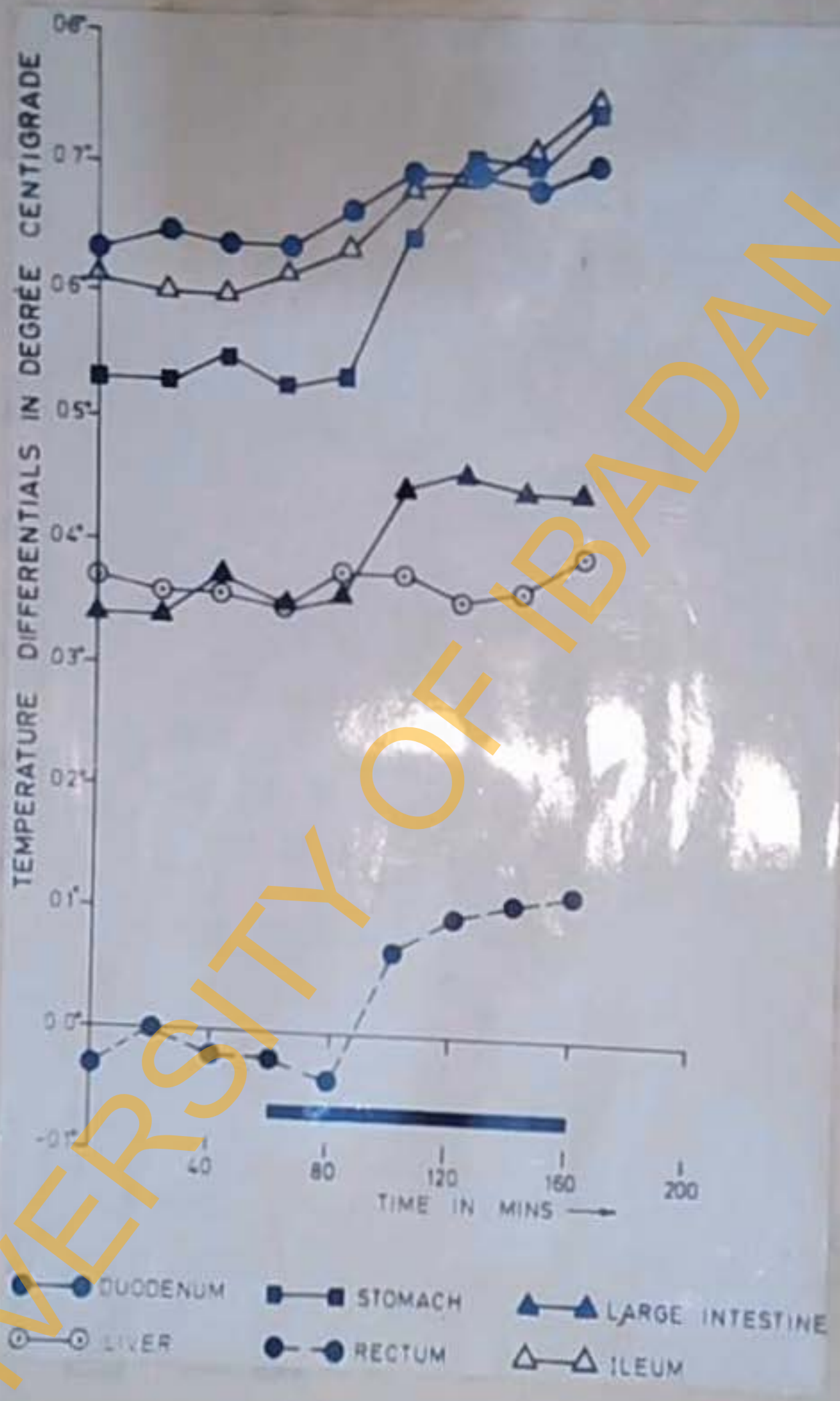

Fig 22. The response of the organ-aorta temperature differentials of various regions of the gastro intestinal tract, to environmental cooling after atropine sulphate (1mg/kg body weight). Thick horizontal line indicates the period of cooling.

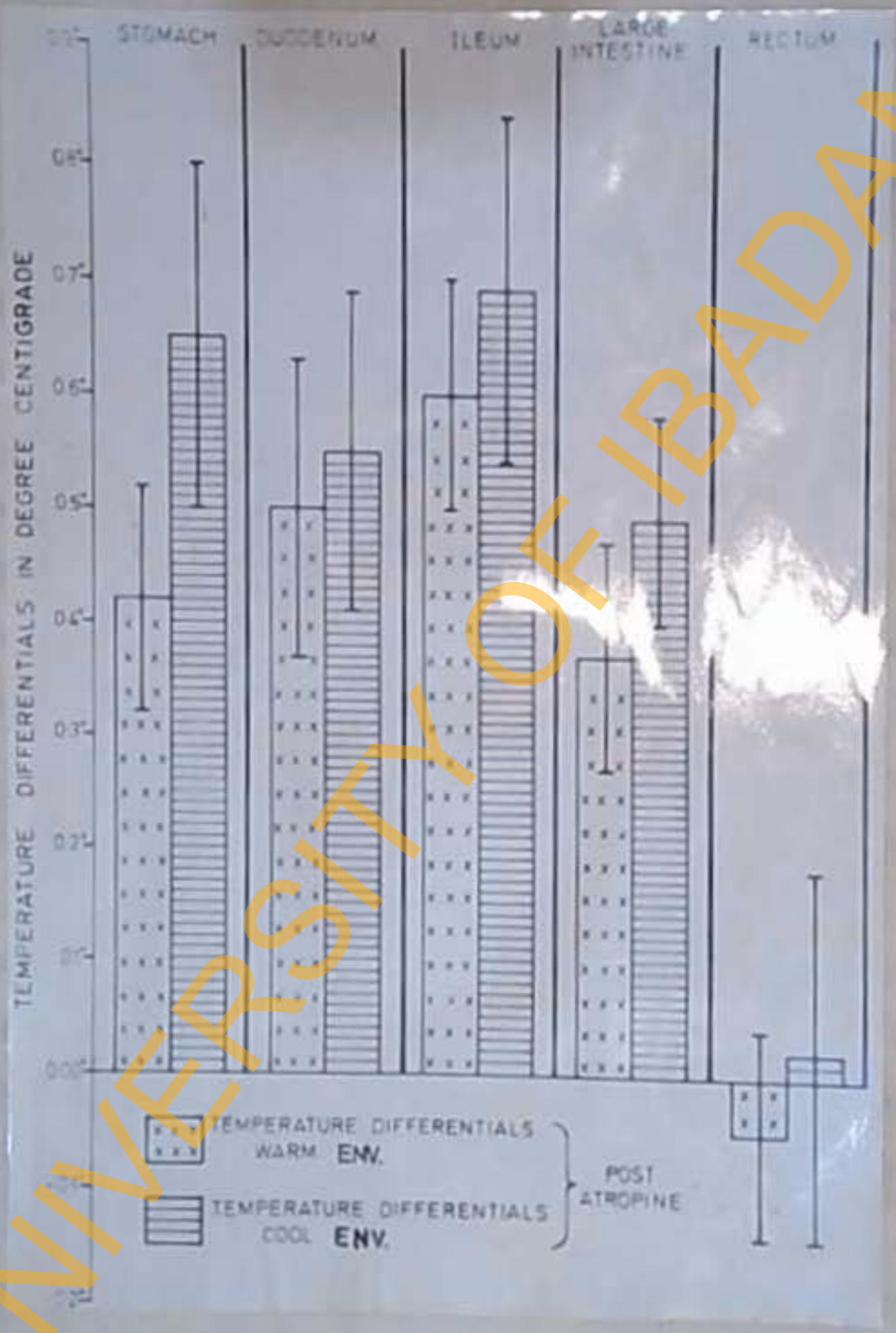

Fig 23. The effect of environmental cooling on the mean organ-aorta temperature differentials of various regions of the gastro-intestinal tract, after atropine sulphate (1 mg/kg body weight).

Table 8, compares the changes which occured in the organ-aorta temperature differentials during environmental cooling in the control experiment with those of the post-atropine series. This shows the effect of atropine on the response of the gastro intestinal tract to body surface cooling.

Fig 22 shows that the stomach displayed the highest response to environmental cooling. Gastric-aorta temperature differentials rose after a latent period of about 20 minutes to a new post-cooling value, which was 0.23°C higher than the pre-cooling value. This difference is significant statistically (P = 0.01).

The duodenum gave a slight response to environmental cooling, although the response started much earlier than in the stomach. At the end of the rise, the post cooling value of the duodenum-aorta temperature differentials was about 0.05°C higher than the pre-cooling value. This change was not significant at the 5% level.

The ileum was more reactive to environmental cooling than the duodenum; its response started earlier and the differential was even still rising at the end of 2 hours. The mean post cooling value was higher than the pre-cooling value by 0.09°C. This difference is significant (P = 0.05-0.02).

The large intestine too was quite reactive. It responded after a brief latent period of about ten minutes, rising 0.12°C from the pre-cooling value to the post cooling value. This rise was statistically significant (P = 0.02).

The rectum too reacted noticeably to environmental cooling. It

TABLE 6A.

The effect of environmental cooling on the absolute temperature distribution along the gastro intestinal tract after an intravenous injection of (1mg/kg body weight) atropine sulphate.

"Warm" environment:- Dry bulb temperature = 29.2 ± 1.6°° Relative humidity 72.8 ± 2.0%

"Cool" environment dry bulb temperature = 21.8 ± 1.5°° Relative humidity 61.5 ± 1.8%

EXPT. NOS.	AORTA		STOMACH		DUODENUM		ILEUM		LARGE INTESTINE		RECTUM	
	POST ATR	POST ATR	POST ATR	POST ATR	POST ATR	POST ATR	POST ATR	POST ATR	POST ATR	POST ATR	POST ATR	POST ATR
	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	34.12	33.98	34.58	34.68	34.77	34.80	34.83	34.85	34.36	34.34		
2	37.13	36.88	37.63	37.70	37.80	37.61	37.86	37.69	37.42	37.26	37.05	36.91
3	35.55	36.39	35.80	36.88	35.85	36.63	36.15	37.05	35.07	36.71	35.45	36.43
4	34.60	34.56	34.83	34.93	35.03	34.84	35.04	34.98	34.89	34.96	34.45	34.41
5	39.33	40.26	39.71	40.84	40.04	40.76	40.10	40.51	39.92	40.64	39.36	40.20
6	37.07	36.51	37.63	37.04	37.80	37.07	37.63	37.24	37.58	37.05	37.08	36.71
7	37.34	37.18	37.77	38.01	37.74	37.96	37.93	37.99	37.89	37.79	37.22	37.10
8	34.73	34.38	35.20	35.16	35.20	34.21	35.28	34.97	35.10	34.89	34.82	34.42
9	34.26	32.19	34.56	32.94	34.56	32.66	34.98	32.86	34.56	32.80	34.15	32.52
10	37.87	37.34	38.13	38.13	38.27	37.86	38.41	38.11	34.55	37.95		
11	34.26	32.17	34.73	32.75	34.74	32.50	34.68	32.97			34.20	32.32
MEAN	36.02	35.62	36.44	36.27	36.52	36.17	36.62	36.31	36.39	36.11	35.97	35.64

TABLE 6B.

The effect of environmental cooling on the organ - aorta temperature differential distribution along the gastro intestinal tract after intravenous injection of (1mg/kg body weight) atropine sulphate.
"Warm" environment:- dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%
"Cool" environment:- dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT.	STOMACH-AORTA		DUODENUM-AORTA		ILEUM-AORTA		LARGE INTES-TINE AORTA		RECTUM-AORTA	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	0.46	0.70	0.75	0.82	0.71	0.87	0.24	0.36		
2	0.50	0.82	0.67	0.73	0.73	0.81	0.39	0.38	-0.08	0.03
3	0.26	0.49	0.30	0.24	0.54	0.66	0.29	0.32		
4	0.25	0.37	0.30	0.28	0.60	0.42	0.32	0.40	-0.10	-0.04
5	0.47	0.58	0.48	0.50	0.42	0.45			-0.06	-0.15
6	0.23	0.53	0.43	0.56	0.44	0.73	0.29	0.54	-0.15	-0.06
7	0.48	0.86	0.71	0.78	0.77	0.81	0.49	0.61	0.03	0.20
8	0.56	0.78	0.73	0.83	0.56	0.59	0.41	0.51	0.01	0.08
9	0.53	0.75	0.40	0.47	0.59	0.67	0.55	0.61	-0.12	0.04
10	0.57	0.69	0.47	0.52	0.55	0.77	0.37	0.61	0.09	0.33
11	0.29	0.56	0.30	0.33	0.72	0.80	0.30	0.38	-0.11	0.19
MEAN	0.42	0.65	0.50	0.55	0.60	0.69	0.37	0.49	-0.05	0.02
STANDARD DEVIATION	±0.13	±0.15	±0.13	±0.14	±0.11	±0.14	±0.09	±0.11	±0.08	±0.14

rose after a latent period of about 20 minutes to a new post-cooling value which was about 0.07°C higher than the pre-cooling value. This rise too was statistically significant (P = 0.02).

From table 8, it can be seen that the net effect of the drug was a reduction in the response of the duodenum, ileum, large intestine and rectum to environmental cooling. It appears however that the response of the stomach to environmental cooling was enchanced.

Hepatic Portal Vein

A. Response to the injection of atropine sulphate in the warm environment.

Fig 24 shows the typical course of the reaction of the organ-aorta temperature differentials of the liver and associated vessels to, the injection of atropine sulphate (mean of 8 experiments). Table 6(a) gives figures of the absolute temperatures of the liver and associated vessels during the hour before and immediately after the second hour of the injection of atropine sulphate. Table 6(b) and Fig 25 give the values of the corresponding temperature differentials.

Fig 25 shows that there was no marked change in the value of the portal vein-aorta temperature differential on the injection of atropine sulphate. The difference of 0.01°C between the pre-injection and the post-injection values is not significant at the 5% level.

(B) Response to environmental cooling after atropine sulphate.

Fig 26 shows the typical response of the liver and associated vessels to environmental cooling after atropine sulphate (mean of 8 experiments). Table 9(a) gives values of absolute temperatures of

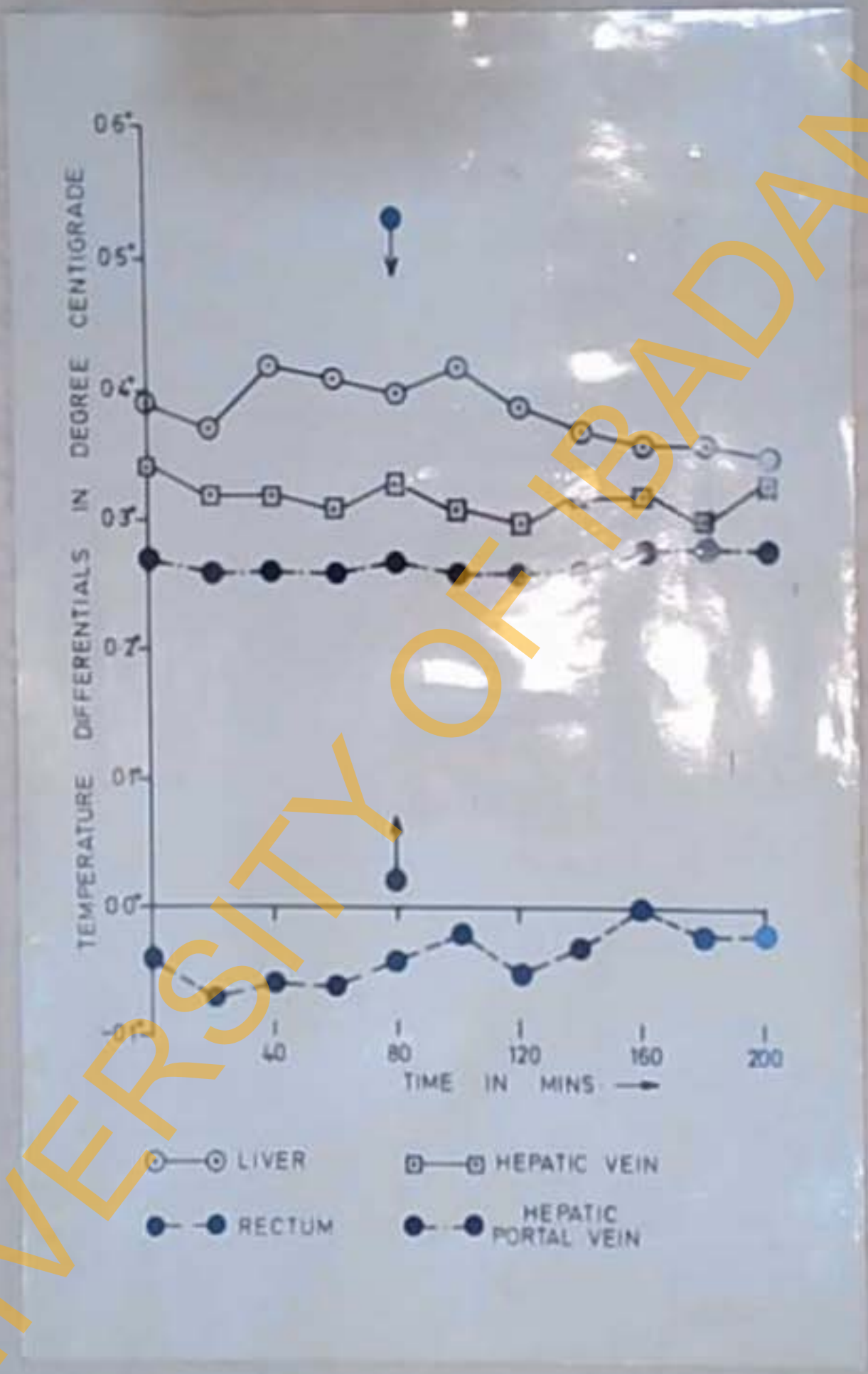

Fig 24. The response of the organ-aorta temperature differentials of the liver and its associated vessels, to the injection of atropine sulphate (1mg/kg body weight). Arrows indicate the time of injection.

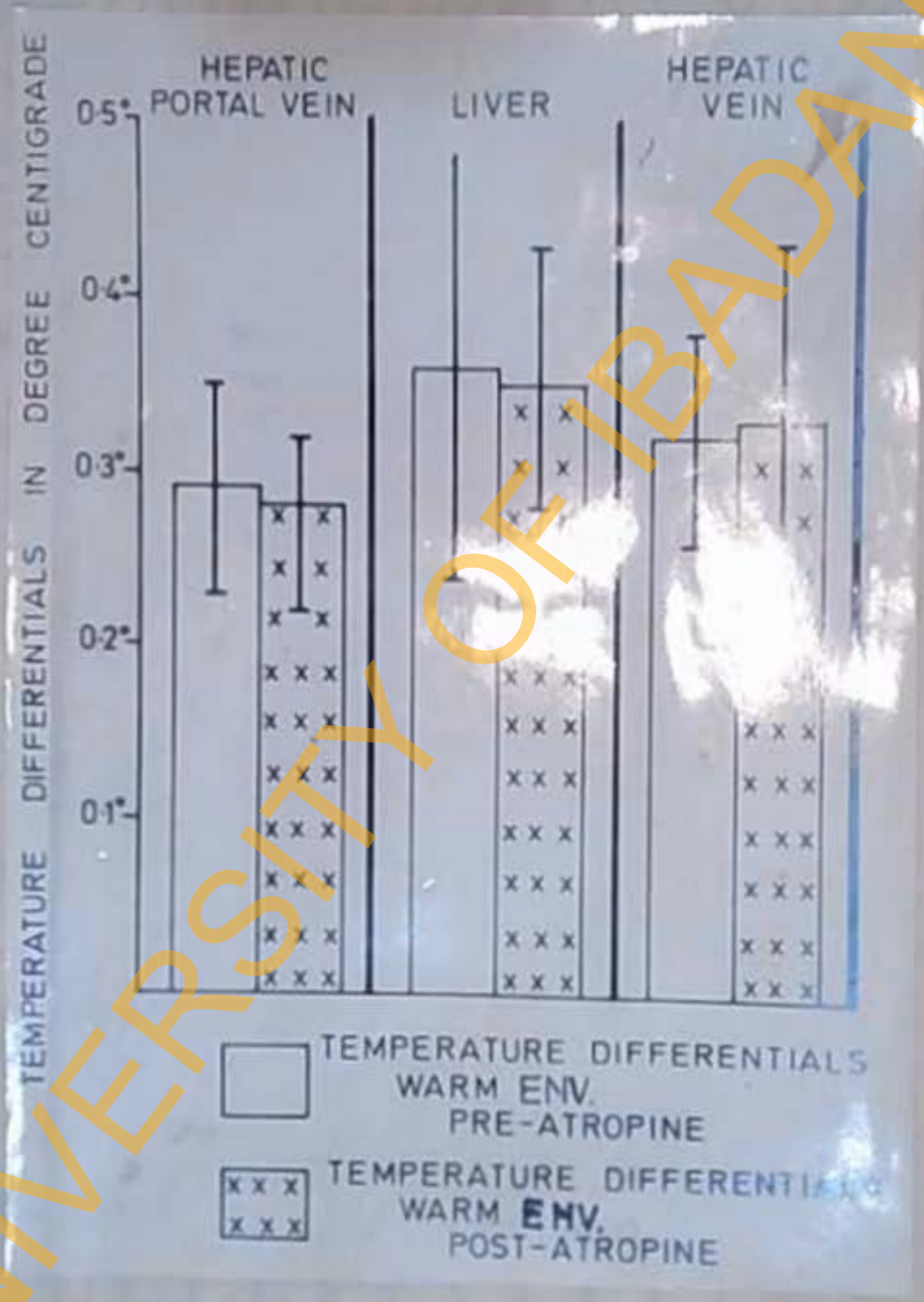

Fig 25. The effect of atropine sulphate (1 mg/kg body weight) on the mean organ-aorta temperature differentials of the liver and its associated vessels (warm environment only).

TABLE 8A.

Absolute temperatures measured in the liver and its associated vessels before and 2 hours after the intravenous injection of (1mg/kg body weight) atropine sulphate. "Warm" environment = 29.2 ± 1.6°°. Relative humidity 72.8 ± 2.0%

EXPT.	AORTA		HEP. PORT. VEIN		LIVER		HEPATIC VEIN	
NOS.	PRE ATR WARM	POST ATR WARM	PRE ATR WARM	POST ATR WARM	PRE ATR WARM	POST ATR WARM	PRE ATR WARM	POST ATR WARM
1	33.96	34.12	34.20	34.37	34.21	34.44	34.41	34.64
2	36.69	37.13	36.93	37.52	36.92	37.45	36.89	37.45
3	34.59	35.55	34.93	35.83	34.92	35.85	34.87	35.70
4	33.96	34.60	34.31	34.93	34.58	35.10	34.34	34.94
5	37.62	39.33	38.03	39.67	37.86	39.60	37.96	39.66
6	36.39	37.07	36.62	37.30	36.78	37.43	36.66	37.40
7	37.11	37.34	37.34	37.55	37.41	37.62	37.37	37.56
8	34.10	34.73	34.28	34.92	34.47	35.04	34.44	35.09
9	35.16	34.26	35.48	34.54	35.62	34.71	35.54	34.59
10	36.71	37.87	37.07	38.20	37.10	38.25	37.04	38.16
MEAN	35.63	36.20	35.92	36.48	35.99	36.55	35.95	36.52

TABLE 8b.

Organ - aorta temperature differentials measured in the liver and its associated vessels before and 2 hours after the intravenous injection of (1mg/kg body weight) atropine sulphate.
"Warm" environment:- Dry bulb temperature 29.2 ± 1.6°c Relative humidity 72.8 ± 2.0%

EXPT.	HEP. PORT. VEIN- AORTA		LIVER- AORTA		HEP. VEIN - AORTA	
NOS.	PRE ATR. WARM	POST ATR. WARM	PRE ATR. WARM	POST ATR. WARM	PRE ATR. WARM	POST ATR. WARM
1.	0.24	0.25	0.25	0.32	0.45	0.52
2.	0.24	0.39	0.23	0.32	0.20	0.32
3.	0.34	0.28	0.33	0.30	0.28	0.25
4.	0.35	0.33	0.62	0.50	0.38	0.34
5.	0.41	0.34	0.24	0.27	0.34	0.33
6.	0.23	0.23	0.39	0.36	0.27	0.33
7.	0.23	0.21	0.30	0.28	0.26	0.22
8.	0.18	0.19	0.37	0.31	0.34	0.36
9.	0.32	0.28	0.46	0.45	0.38	0.33
10.	0.36	0.33	0.39	0.38	0.33	0.29
MEAN	0.29	0.28	0.36	0.35	0.32	0.33
STANDARD DEVIATION	±0.07	±0.06	±0.11	±0.07	±0.07	±0.08

the liver and associated vessels one hour before cooling and 2 hours after the commencement of cooling. Table 9(b) and Fig 27 give values of the corresponding organ-aorta temperature differentials during the same periods. Table 10 compares the changes in the organ-aorta temperature differentials in response to environmental cooling in the control experiment with the post atropine series.

Fig 26 demonstrates the reaction of the portal vein to environmental cooling. There was a rise of about 0.07°C in the value of the portal vein-aorta temperature differential from the pre-cooling to the post cooling value. This rise was significant (P = 0.05 - 0.02). Table 10 shows that the portal venous response to environmental cooling was slightly reduced by atropine sulphate.

Liver

A. Response to the injection of atropine sulphate in the warm environment.

There was a marked but gradual fall in the value of the liver-aorta temperature differential on the injection of atropine (See fig 24). The fall which lasted about 80 minutes, was followed by a recovery which brought the post injection value close to the pre-injection one. The difference between the pre and the post injection values was 0.01°C, which is not significant (See fig 25).

B. Response to environmental cooling after atropine sulphate.

The reaction of the liver to environmental cooling after atropine was erratic (See fig 26). There was an initial rise followed

TABLE 9A.

Effect of environmental cooling on the absolute temperatures measured in the liver and its associated vessels - post atropine sulphate (intravenous injection of 1mg/kg body weight).

"Warm" environment - dry bulb temperature 29.2°° ± 1.6°° relative humidity = 72.8 ± 2.0%

"Cool" environment - dry bulb temperature = 21.8 ± 1.5°° relative humidity = 61.5 ± 1.8%

EXPT.	AORTA		HEP. PORTAL VEIN		LIVER		HEPATIC VEIN	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	34.12	35.98	34.36	34.28	34.43	34.32	34.37	34.32
2	37.13	36.88	37.54	37.33	37.50	37.38	37.49	37.29
3	35.55	36.39	35.85	36.77	36.07	36.93	36.03	36.97
4	34.60	34.56	34.90	34.97	34.84	34.91	34.84	34.89
5	39.33	40.26	39.60	40.62	39.68	40.62	39.60	40.62
6	37.07	36.57	37.34	36.85	37.69	37.15	37.59	37.18
7	37.34	37.18	37.59	37.53	37.56	37.56	37.73	37.64
8	34.73	34.38	34.98	34.74	35.04	34.72	35.09	34.74
9	34.26	32.19	34.49	32.44	34.76	32.71	34.59	32.65
10	37.87	37.34	38.08	37.63	38.19	37.72	38.09	37.67
MEAN	36.20	35.97	36.48	36.32	36.58	36.41	36.54	36.40

TABLE 9B.

The effect of environmental cooling on the organ - aorta "temperature differentials" measured in the liver and its associated vessels - after intravenous injection of (1mg/kg body weight) atropine sulphate.
"Warm" environment:- dry bulb temperature = 29.2 ± 1.0°C
relative humidity = 72.8 ± 2.0%
"Cool" environment:- dry bulb temperature = 21.8 ± 1.5°C
relative humidity = 61.5 ± 1.8%

EXPT.	HEP. PORT. VEIN - AORTA		LIVER - AORTA		HEP. VEIN - AORTA	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL
1	0.24	0.30	0.32	0.34	0.25	0.34
2	0.41	0.45	0.37	0.50	0.36	0.41
3	0.33	0.38	0.52	0.54	0.48	0.58
4	0.30	0.41	0.34	0.45	0.24	0.43
5	0.37	0.36	0.35	0.36	0.27	0.36
6	0.27	0.34	0.52	0.54	0.52	0.57
7	0.25	0.35	0.32	0.38	0.39	0.46
8	0.28	0.36	0.31	0.34	0.36	0.36
9	0.23	0.25	0.50	0.55	0.33	0.46
10	0.22	0.29	0.32	0.38	0.22	0.33
MEAN	0.28	0.35	0.39	0.44	0.34	0.43
STANDARD DEVIATION	±0.06	±0.06	±0.09	±0.08	±0.10	±0.08

TABLE 10

Summary of changes in the mean value of the "organ - aorta" temperature differentials measured in the liver and its associated vessels in response to environmental cooling, in the control experiment as well after atropine - sulphate (1mg/kg body weight given i.v.)

	HEPATIC PORTAL VEIN	LIVER	HEPATIC VEIN.
CONTROL	+ 0.10	+ 0.10	+ 0.14
POST ATROPINE SULPHATE	+ 0.07	+ 0.05	+ 0.09

by a fall and then a rise. The ultimate liver-aorta temperature differential was 0.05°C higher than the pre-cooling value. This was found not to be significant. Table 10 shows that the response of the liver to environmental cooling was reduced after atropine sulphate administration.

Hepatic Vein.

A Response to the injection of atropine sulphate in the warm environment.

From fig 22, it can be seen that the hepatic vein-aorta temperature differential only responded to atropine injection by becoming more oscillatory than ever. After two hours of the injection, the difference between the pre and the post injection values was about 0.01°C, which was not significant.

B. Response to environmental cooling after atropine sulphate.

The hepatic vein-aorta temperature differential was observed to increase with environmental cooling after atropine. The rise of about 0.09°C was found to be significant (P = 0.05). Table 10 however shows it was as lightly reduced response to environmental cooling.

II Vagotomy

When Bisgard and Nye (1940) observed increased motor activities of the stomach on exposing the body to cold stress, they felt it was secondary to an increased production of gastric acid in response to released histamine (Horton and Brown 1932). In his attempt to

study the "modus operandi" of this increased motor activities of the stomach on body chilling, Sato (1935) showed that the reaction was completely reversed after vagotomy. He did not, however, obtain this reversal after the division of the coeliac and superior mesenteric ganglia as well as after spinal transection. Instead what was obtained on body chilling was either increased motor activities or no effect at all respectively. Thus the vagus nerve was implicated in the increased motor activities of the gut, in response to body chilling.

There is yet no general agreement on the role of the vagus nerves in the determination of the levels of temperatures, in the gastro intestinal tract. Tscheschlow (1902) and Freund (1913) observed an increase in rectal temperature after vagotomy. Cacioppo & Bevilotti (1946) and Cilento (1951), on the other hand, reported that vagotomy led to hypothermia in pigeons.

It was therefore decided to study the effect of vagotomy on the pattern of distribution of both the absolute temperatures and organ-aorta temperature differentials, in the 'core area' of the dog in the warm environment as well as during body chilling.

Vagotomy was carried out as described earlier (see page 39)

A <u>The effect of cervical vagotomy on the temperature distribution, in the core area of the dog</u>.

Cervical vagotomy was carried out after recording a constant organ-aorta temperature differential for about 1 hour, in most of the regions of the gastro-intestinal tract and the liver, in the

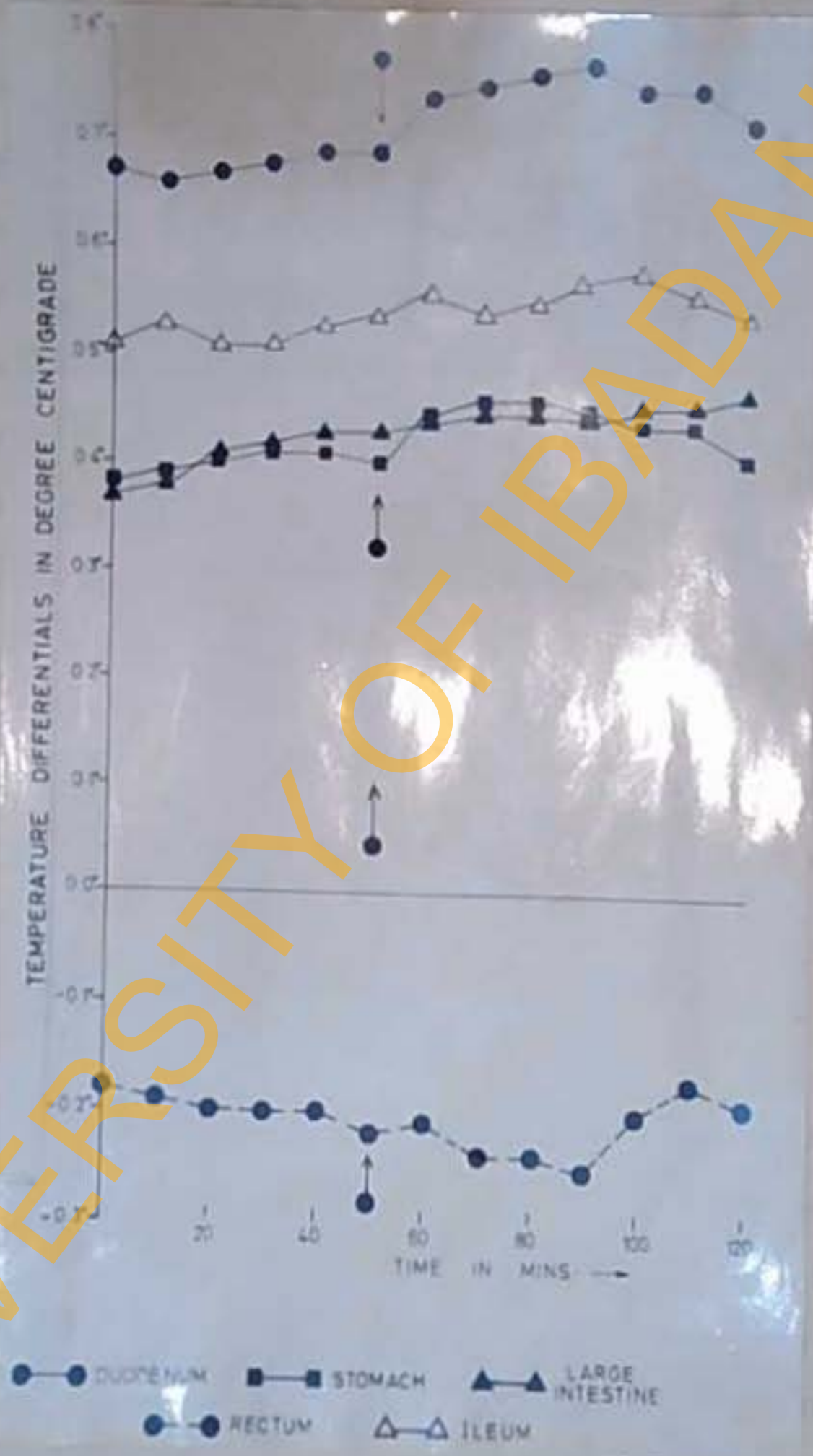

Fig 28. The response of the organ-aorta temperature differentials of various regions of the gastro intestinal tract to cervical vagotomy. Arrows indicate the time of sectioning.

warm environment.

The gastro intestinal tract

Fig 28 shows the effect of cervical vagotomy on the absolute temperatures of and the temperature differentials between various regions of the gastro intestinal tract and the aorta.

There was an immediate rise in the value of the stomach-aorta temperature differentials when the vagi were sectioned. This rise lasted 50 minutes before it started to reduce towards the pre-sectioning value.

The rise in the duodenum-aorta temperature differential was rapid and was, in fact, more than the rise in any other region of the gastro-intestinal tract. It also lasted about 50 minutes and was later followed by a fall to the pre sectioning value.

The ileum did not react as well as either the duodenum or the stomach. It rose but the rise was delayed and slight.

The large intestine was also not much affected by cervical vagotomy. The rise was very gradual and did not show the subsequent characteristic fall seen in the others.

There was not much change in the rectum-aorta temperature differential during the first 40 minutes. This "latent period" was followed by a rise, which corresponded in time to the fall of both the stomach and the duodenum.

The Hepatic Portal Vein

Fig 29 shows that there was no marked alteration in the values of the portal vein-aorta temperature differential in response to

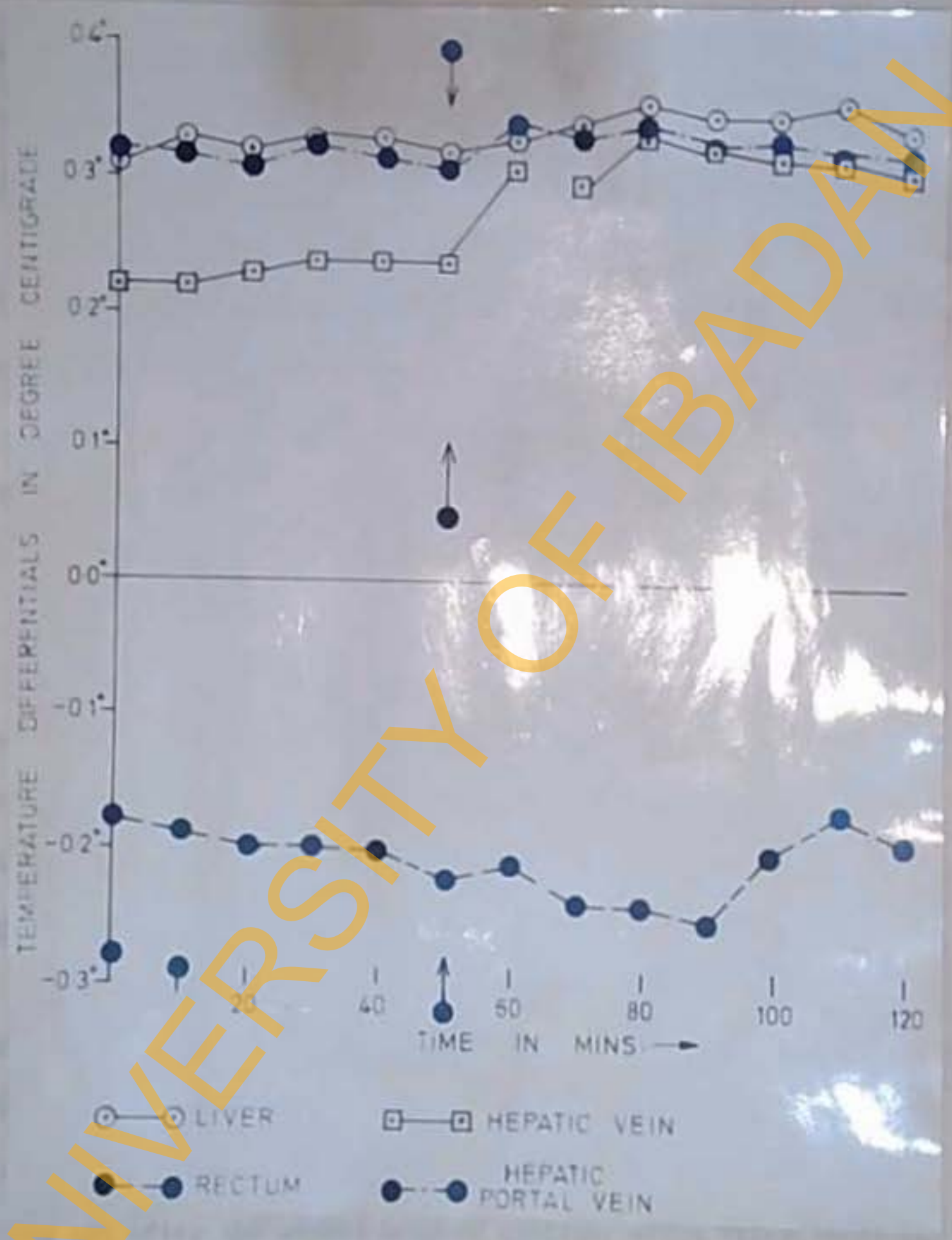

Fig 29. The response of the organ-aorta temperature differentials of the liver and its associated vessels to cervical vagotomy. Arrows indicate the time of sectioning.

cervical vagotomy. The slight rise obtained was not significant at the 5% level.

Liver and Hepatic Vein

There was a gradual rise in the value of liver-aorta temperature differential after sectioning the vagi (See fig 29). This rise was however not marked.

On the other hand, the hepatic vein-aorta temperature differentials rose quite markedly after sectioning the vagi.

B The response of the core area to environmental cooling after abdominal vagotomy

The process of abdominal vagotomy has already been described (See page 39). Environmental cooling did not commence until after obtaining steady organ-aorta temperature differentials in most of the regions of the gastro - intestinal tract for upwards of 1 hour.

The gastro intestinal tract.

Fig 30 describes the reaction of the organ-aorta temperature differentials of the gastro intestinal tract to environmental cooling after vagotomy. Table 11(a) gives the mean values of the absolute temperatures recorded in the gastro intestinal tract one hour before and after the second hour of cooling, while Table 11(b) and Fig 31 give values of the corresponding organ-aorta temperature differentials during the same periods.

The stomach and the rectum were the most responsive of the regions of the gastro intestinal tract, to environmental cooling after the vagotomy. The stomach-aorta temperature differential rose

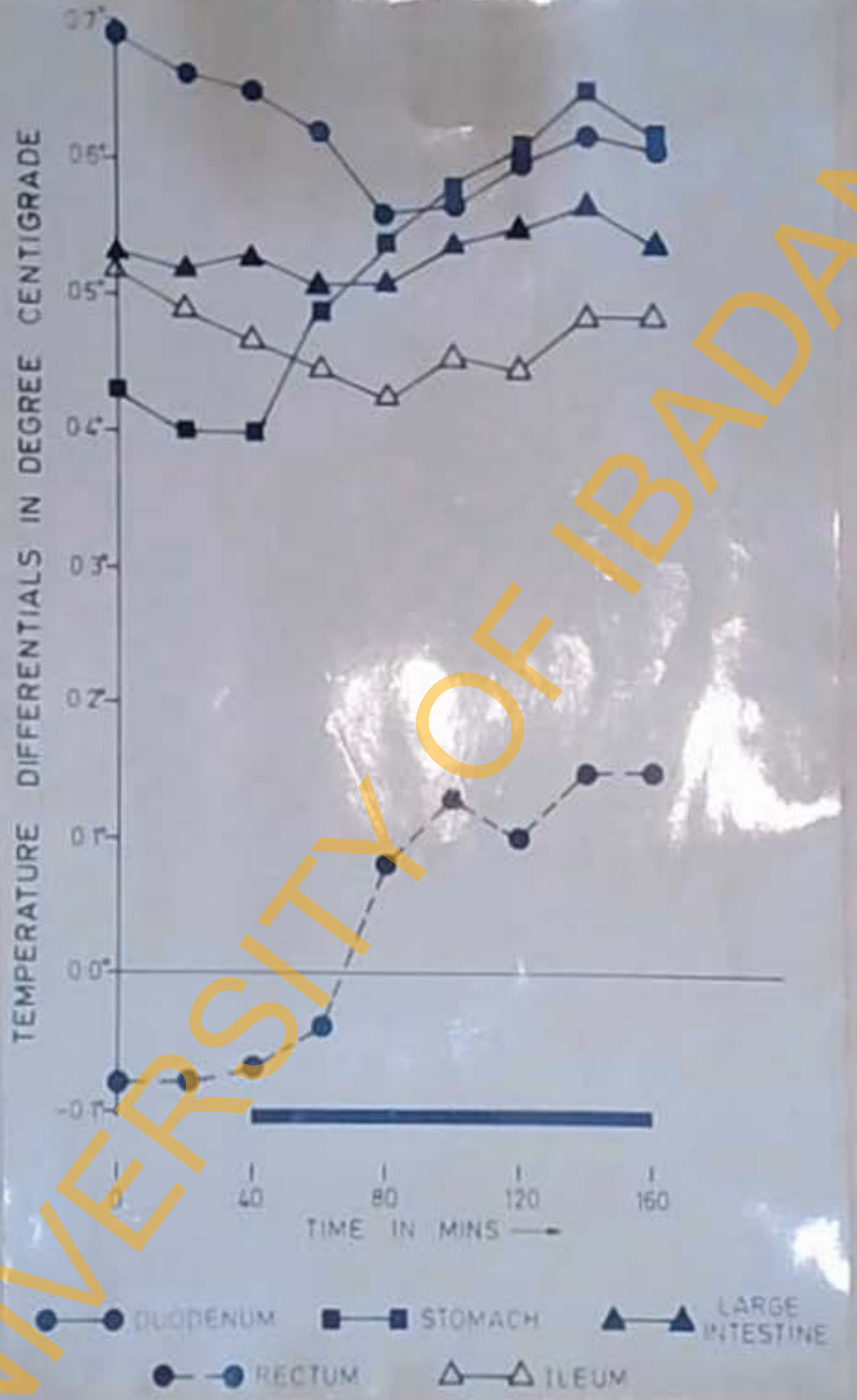

Fig 30. The response of the organ-aorta temperature differentials of various regions of the gastro intestinal tract to environmental cooling, after abdominal vagotomy. Thick horizontal line indicates the period of cooling.

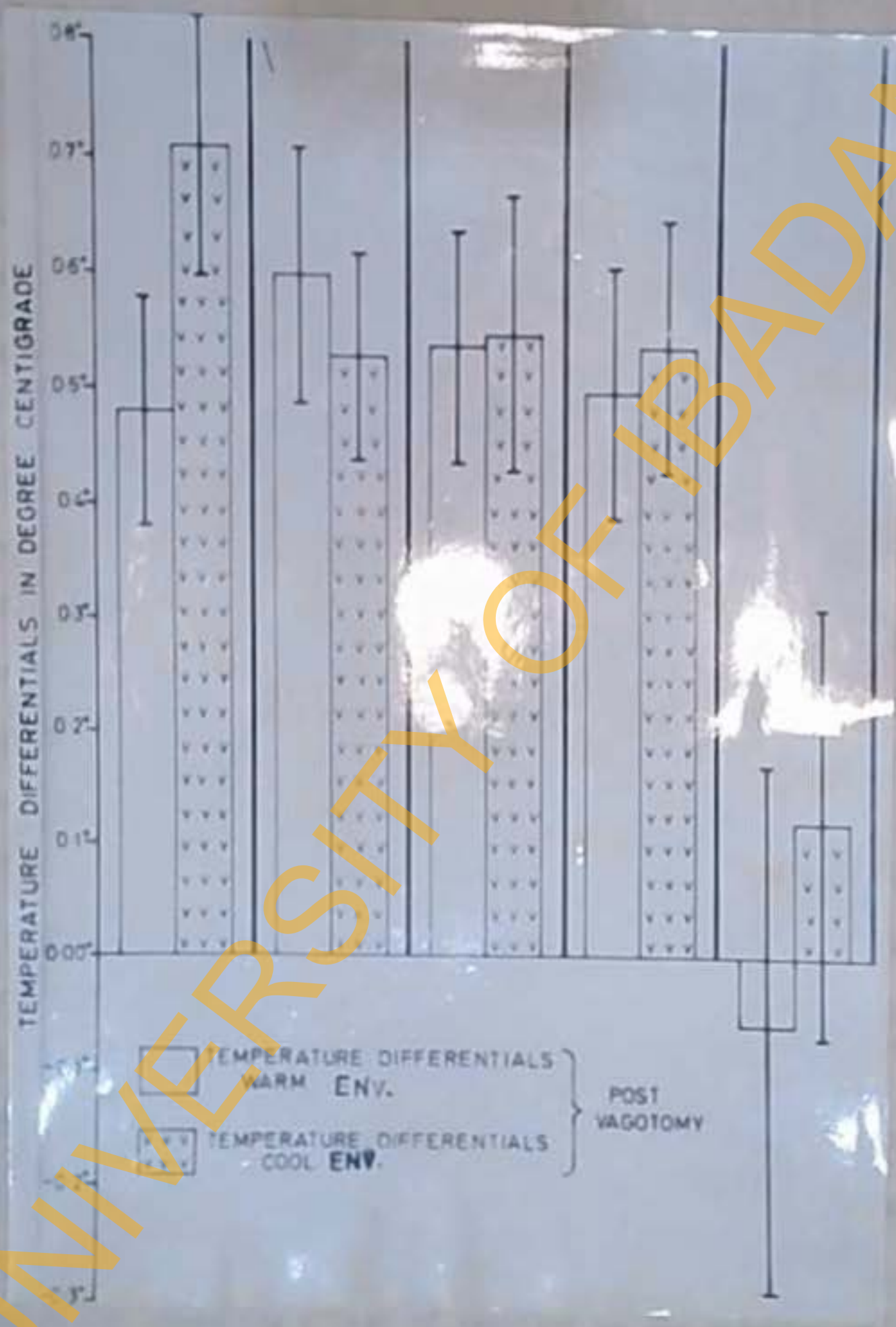

Fig 31. The effect of environmental cooling on the organ-aorta temperature differentials of various regions of the gastro intestinal tract - after abdominal vagotomy.

steeply and after 2 hours became the hottest region in the gastro intestinal tract. The 0.23°C rise in the temperature differential from the pre to the post-cooling value was highly significant (P = 0.01).

The duodenum-aorta temperature differential declined in value during the first 40 minutes of cooling. Thereafter, it began to rise. The post cooling stable level was 0.07°C less than the mean temperature differential of the pre-cooling condition. The reduction in the value was significant (P = 0.05).

The ileum reacted like the duodenum in that its temperature with reference to the aorta fell during the first 40 minutes of cooling. It recovered too, stabilising at a level 0.01°C less than the pre-cooling value.

The large intestine on the other hand responded with a gradual rise. The difference between the mean values of the pre and the post-cooling large intestine-aorta temperature differentials was 0.04°C. This is just significant (P = 0.05).

The rectum-aorta temperature differential rose during environmental cooling. The difference between the pre and the post cooling values was 0.18°C, which was quite significant.

Table 12, shows the effect of vagotomy on the response of the various regions of the gastro intestinal tract to environmental cooling. It shows that there was a marked reduction in the response of the ileum and large intestine, while, the response of the stomach and rectum were enhanced. The response of the duodenum was actually

TABLE 11A.

The effect of environmental cooling on the absolute temperature distribution along the gastro - intestinal tract after abdominal vagotomy.
"Warm" environment dry bulb temperature = 29.2 ± 1.6°c relative humidity = 72.8 ± 2.0%
"Cool" environment dry bulb temperature = 1.8 ± 1.5°c relative humidity = 61.5 ± 1.8%

EXPT.	AORTA		STOMACH		DUODENUM		ILEUM		LARGE INTESTINE		RECTUM	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	34.60	34.23	35.02	34.80	35.13	34.69	35.29	34.96	35.28	34.93	34.54	34.48
2	36.14	36.07	36.49	36.66	37.02	36.88	36.60	36.53	36.86	36.82	35.73	35.93
3	36.48	36.08	36.91	36.76	37.04	36.66	37.06	36.67	36.81	36.43	36.03	36.07
4	35.64	36.04	36.07	36.76	36.05	36.54	36.22	36.82	36.07	36.65	35.31	35.95
5	35.95	36.09	36.43	36.77	36.62	36.69	36.44	36.47	36.35	36.62	36.13	36.46
6	33.98	32.87	34.28	33.50	34.45	33.32	34.40	33.31	34.38	33.09		
7	36.35	35.74	36.83	36.52	37.15	36.35	36.85	36.14	36.97	36.41	36.59	36.18
8	35.75	35.89	36.37	36.83	36.36	36.26	36.45	36.62	36.36	36.45	35.96	36.07
9	35.48	35.08	36.09	36.01	35.94	35.48	35.91	35.56	35.81	35.56	35.56	35.19
MEAN	35.60	35.34	36.08	36.05	36.20	35.87	36.14	35.89	36.10	35.88	35.54	35.46

TABLE 11B.

The effect of environmental cooling on the "organ - aorta""temperature differentials distribution along the gastro intestinal tract - after abdominal vagotomy.
"Warm" environment - dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%
"Cool" environment - dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT.	STOMACH-AORTA		DUODENUM-AORTA		ILEUM-AORTA		LARGE INTEST-INE AORTA		RECTUM-AORTA	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	0.42	0.57	0.53	0.46	0.69	0.73	0.68	0.70	-0.06	0.25
2	0.35	0.59	0.80	0.71	0.46	0.46	0.62	0.65	-0.41	-0.14
3	0.43	0.68	0.56	0.58	0.58	0.59	0.41	0.45	-0.45	-0.01
4	0.43	0.72	0.49	0.60	0.58	0.68	0.43	0.61	-0.33	-0.09
5	0.48	0.68	0.67	0.60	0.49	0.98	0.40	0.53	0.18	0.37
6	0.40	0.73	0.47	0.45	0.42	0.44	0.40	0.42		
7	0.48	0.68	0.70	0.51	0.50	0.40	0.62	0.67	0.24	0.44
8	0.62	0.94	0.67	0.47	0.70	0.73	0.61	0.56	0.21	0.18
9	0.70	0.83	0.46	0.40	0.43	0.48	0.33	0.38	0.08	0.09
MEAN	0.48	0.71	0.60	0.53	0.54	0.55	0.50	0.54	-0.06	0.12
STANDARD DEVIATION	±0.12	±0.12	±0.11	±0.10	±0.09	±0.11	±0.09	±0.10	±0.23	±0.19

TABLE 12.

Summary of changes in the mean values of the organ - aorta "temperature differentials" distributed along the gastro - intestinal tract, in response to environmental cooling - in the control experiment as well as after abdominal vagotomy.

	STOMACH	DUODENUM	ILEUM	LARGE INTESTINE	RECTUM
CONTROL	+ 0.18°C	+ 0.09°C	+ 0.16°C	+ 0.19°C	+ 0.15°C
POST VAGOTOMY	+ 0.25°C	- 0.07°C	+ 0.1°C	+ 0.04°C	+ 0.18°C

reversed after abdominal vagotomy.

Hepatic Portal Vein.

Fig 32 shows the response of the liver and its associated vessels to environmental cooling after abdominal vagotomy. Table 13(a) gives values of the absolute temperatures of the liver and associated during the last hour before and the second hour of environmental cooling, while 13(b) and Fig 33 give values of the corresponding organ-aorta temperature differentials.

There was a rise in the portal vein-aorta temperature differentials during environmental cooling. The post-cooling value was 0.05°C higher than the pre-cooling value. Table 14 shows that the response of the hepatic portal vein to environmental cooling was reduced to half by abdominal vagotomy.

Liver and Hepatic Vein

There was no substantial response from the liver on cooling the environment after abdominal vagotomy. The 0.02°C difference between the pre-cooling and the post cooling values was not significant. Table 14 shows that the response of the liver to environmental cooling has almost been abolished.

The hepatic vein-aorta temperature differential increased sharply on the commencement of environmental cooling. The difference between the pre-cooling and the post cooling values was 0.11°C which was quite significant.

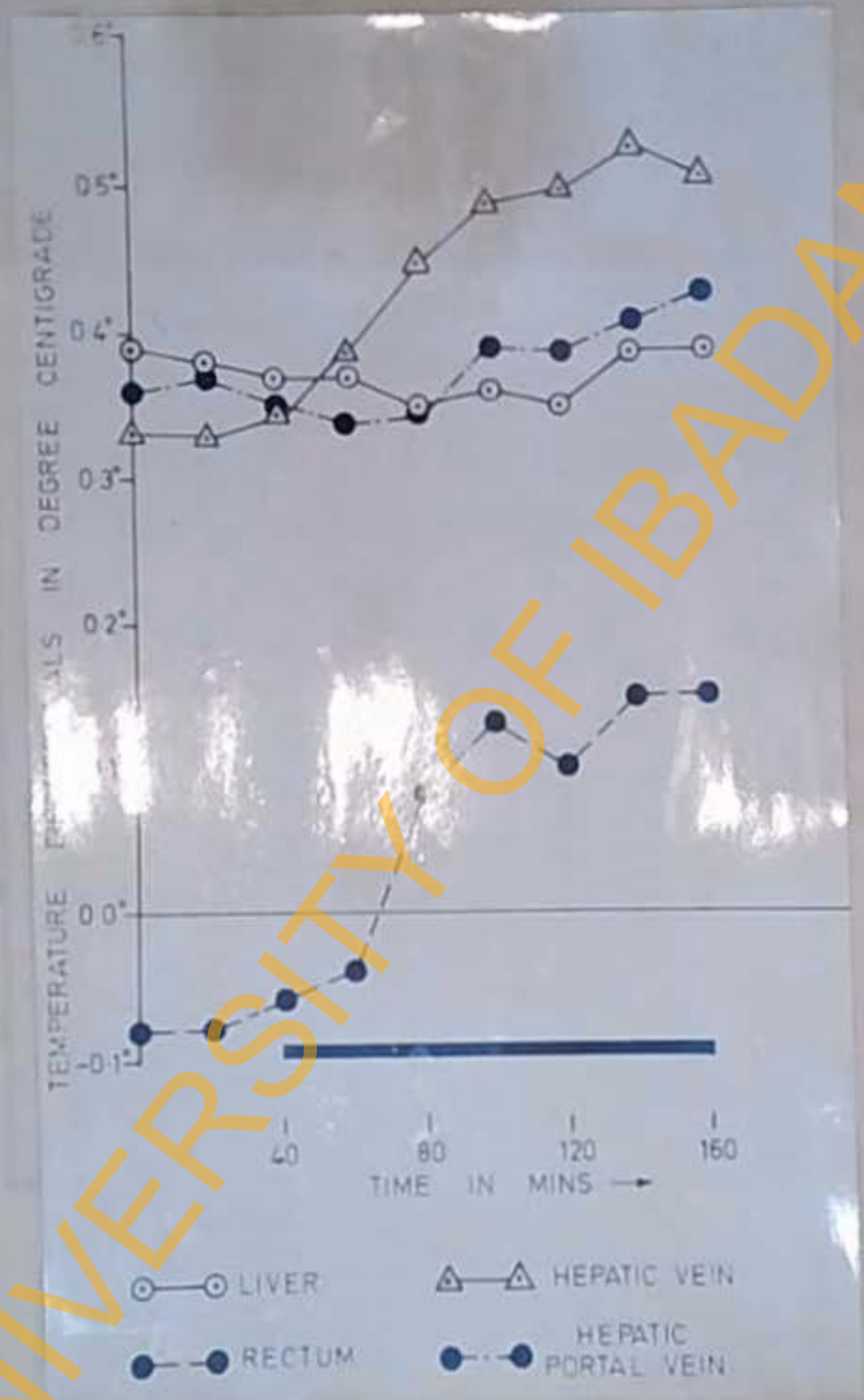

Fig 12. The response of the organ-aorta temperature differentials of the liver and its associated vessels to environmental cooling after abdominal vagotomy. Thick horizontal line indicates the period of cooling.

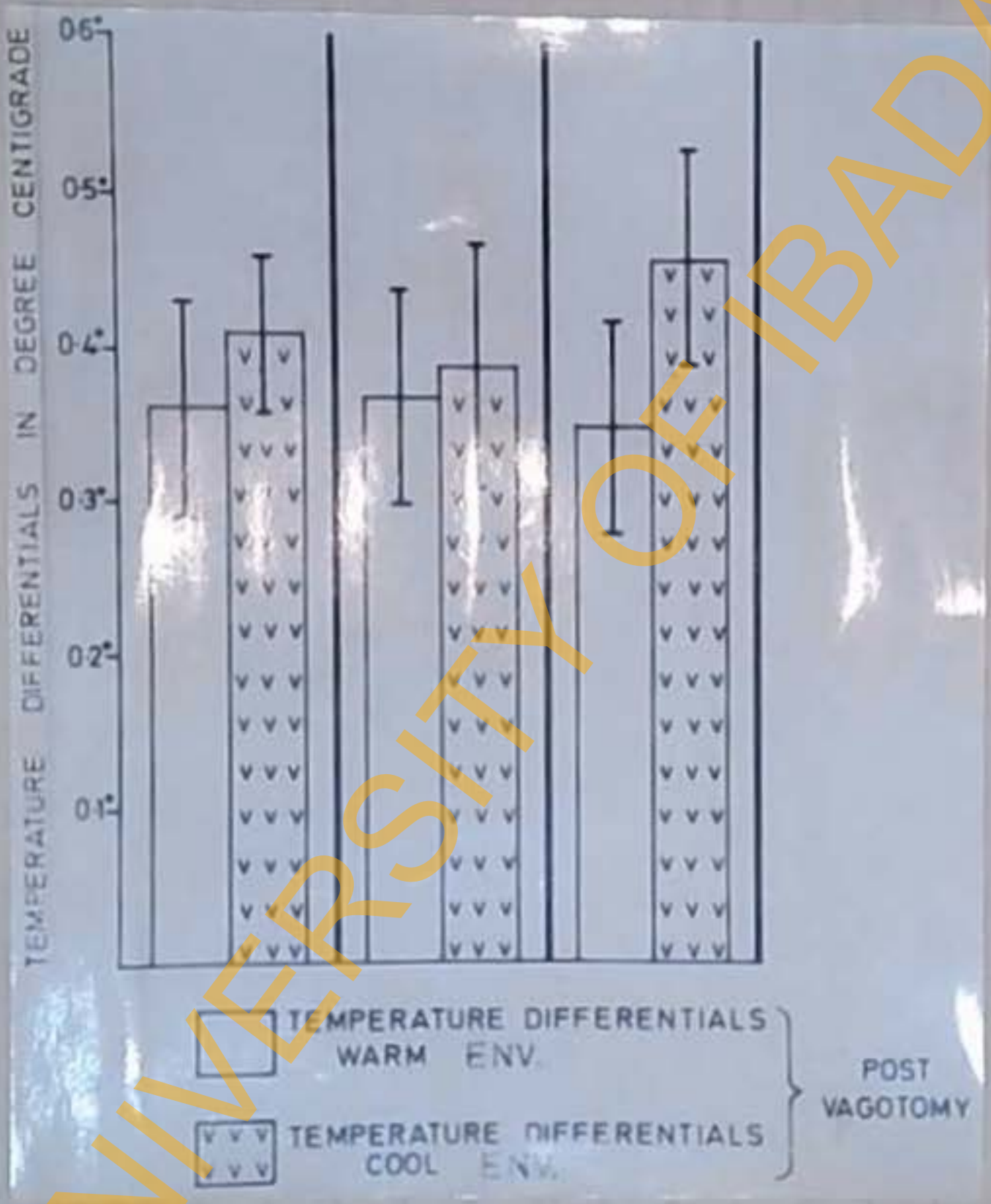

Fig 33. The effect of environmental cooling on the organ - aorta temperature differentials of the liver and its associated vessels after abdominal vagotomy.

TABLE 13A.

The effect of environmental cooling on the absolute temperatures measured in the liver and its associated vessels after abdominal vagotomy.
"Warm" environment - dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%
"Cool" environment - dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.3 ± 1.8%

EXPT.	AORTA		HEP. PORT VEIN		LIVER		HEP. VEIN	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	34.60	34.23	34.90	34.53	34.90	34.51	34.92	34.66
2	36.14	36.07	36.30	36.31	36.49	36.50	36.44	36.51
3	36.48	36.08	36.96	36.57	36.71	36.28	36.81	36.52
4	35.64	36.04	35.93	36.48	35.91	36.38	35.92	36.48
5	35.95	36.09	36.22	36.47	36.29	36.43	36.24	36.43
6	33.98	32.87	34.30	33.29	34.36	33.25	34.36	33.43
7	36.35	33.74	36.98	36.14	36.98	36.34	36.84	36.33
8	35.75	35.89	36.14	36.33	36.21	36.35	36.09	36.36
9	35.48	35.08	35.91	35.52	35.85	35.52	35.90	35.51
MEAN	35.60	35.34	35.96	35.75	35.97	35.73	35.95	35.80

TABLE 13B.

The effect of environmental cooling on the organ-aorta temperature differentials measured in the liver and its associated vessels after abdominal vagotomy.
"Warm" environment dry bulb temperature = 29.2 ± 1.6°C
relative humidity = 72.3 ± 2.0%
"Cool" environment dry bulb temperature = 21.6 ± 1.5°C
relative humidity = 61.5 ± 1.8%

EXPT. NOS.	HEP. PORT. VEIN-AORTA		LIVER-AORTA		HEP. VEIN-AORTA	
	WARM	COOL	WARM	COOL	WARM	COOL
1	0.30	0.30	0.30	0.28	0.32	0.43
2	0.36	0.44	0.35	0.43	0.30	0.44
3	0.48	0.49	0.23	0.30	0.33	0.44
4	0.29	0.44	0.27	0.34	0.28	0.44
5	0.27	0.38	0.34	0.34	0.29	0.34
6	0.32	0.42	0.38	0.38	0.38	0.56
7	0.43	0.40	0.53	0.50	0.49	0.59
8	0.34	0.44	0.46	0.46	0.34	0.47
9	0.43	0.44	0.37	0.44	0.42	0.43
MEAN	0.36	0.42	0.37	0.39	0.35	0.46
S. D.	±0.05	±0.06	±0.09	±0.07	±0.07	±0.08

TABLE 14.

Summary of changes in the mean values of the organ-aorta "temperature differentials" - measured in the liver and hepatic vessels - in response to environmental cooling in the control experiments as well as after abdominal vagotomy.

	HEPATIC PORTAL VEIN.	LIVER	HEPATIC VEIN.
CONTROL	+ 0.10	+ 0.10	+ 0.14
POST VAGOTOMY	+ 0.05	+ 0.02	+ 0.11

'Core' Temperatures and Adrenergic Influences.

Grayson et al 1966 suggested that the rise in the temperature differential of the gut with respect to the aorta, which occurs on cold exposure, might be due to intestinal vasoconstriction. Gastrointestinal vasoconstriction had earlier been shown to follow cold exposure (Wolf and Wolff 1943 and Grayson 1951).

If this be so, sympathetic blockade might then help to unfold the role of vasoconstriction in the determination of the resting gastro intestinal temperatures as well as their response to environmental cooling.

The pharmacological tool chosen for the present experiments was Bretylium tosylate. Bretylium (darenthin; N-o-bromobenzy l-N-ethyl-N, N-dimethyl ammonium), is one of the congeners of T.M. 10, or choline 2, 6-xylyl ether, which was the first of the strongly basic compounds shown to inhibit responses to adrenergic nerve stimulation, without impairing responses to exogenous catbecholamines (Nickerson 1965). Bretylium in large doses is known to act by accumulating in adrenergic nerve endings. Although the relationship between drug accumulation and effect is highly complex (Boura et al 1961), it is known that the antiadrenergic action roughly parallels the amount of the drug thus accumulated (Nickerson 1965). This antiadrenergic effect lasts between 6 and 24 hours (Boura and Green 1959; Green 1960).

Bretylium was given in doses of 10mg/kg body weight (i.v. injection). On giving the drug the first noticeable effect was on the blood pressure. The response was either an immediate fall if the

Fig 34 (a). The effect of slow intravenous injection of bretylium tosylate (10 mg/kg body weight). on the blood pressure.

Fig 34 (b). The effect of rapid intravenous injection of bretylium tosylate (10 mg/kg body weight) on the blood pressure.

the drug was injected rapidly or an immediate rise, if the drug was injected slowly (See Fig 34 (a&b). The fall in blood pressure was the commoner effect observed. The rise might have been due to a transient sympathomimetic effect, possibly due to local release of cathechol amines (Boura and Green 1959, Green 1960). Rise or fall, the blood pressure stabilized at a lower level, after a mean period of about 8 minutes.

Results

The drug was injected after obtaining constant organ-aorta temperature differentials in most regions of the gastro intestinal tract, for more than 1 hour.

The Gastro Intestinal Tract

A. Response to bretylium tosylate injection in the warm environment.

Fig 35 shows the typical response of the gastro intestinal tract (means of 7 experiments) to the injection of bretylium tosylate in the "warm environment". Table 15(a) gives the distribution of absolute temperatures along the gut, during the last hour before and after the second hour of bretylium administration. Table 15(b) and Fig 36 give the corresponding values of organ-aorta temperature differentials (Means of 10 experiments).

Fig 35 shows that the temperature differentials of the duodenum, ileum, stomach and large intestine were reduced by the injection of bretylium while that of the rectum was increased. The stomach and ileum showed the greatest response to bretylium. Shortly after the second hour of injection, the ileum-aorta, and the stomach-aorta

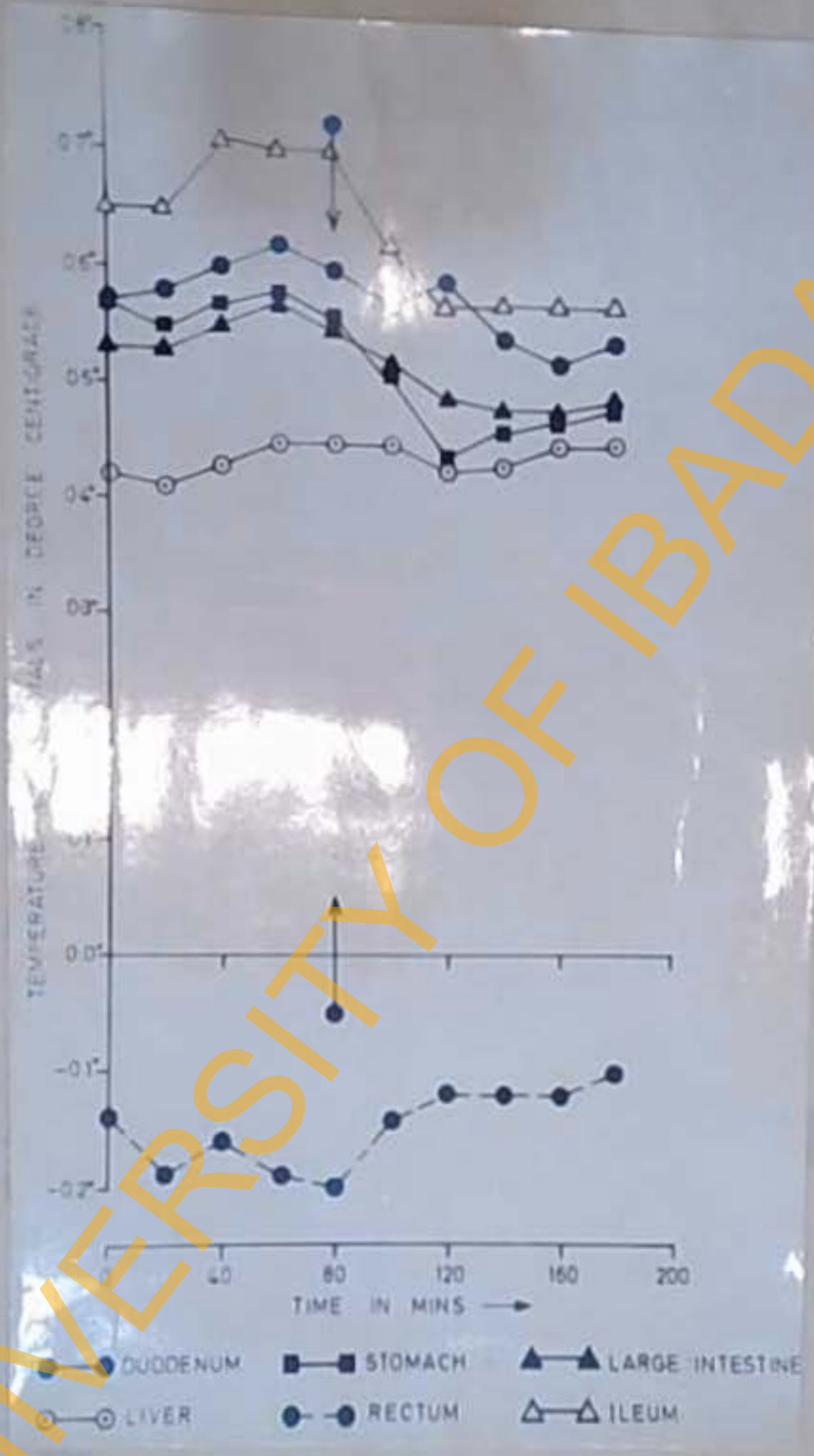

Fig 35. The response of the organ-aorta temperature differentials of various regions of the gastro intestinal tract - to the injection of bretylium tosylate (10 mg/kg body weight). Arrows indicate the time of injection.

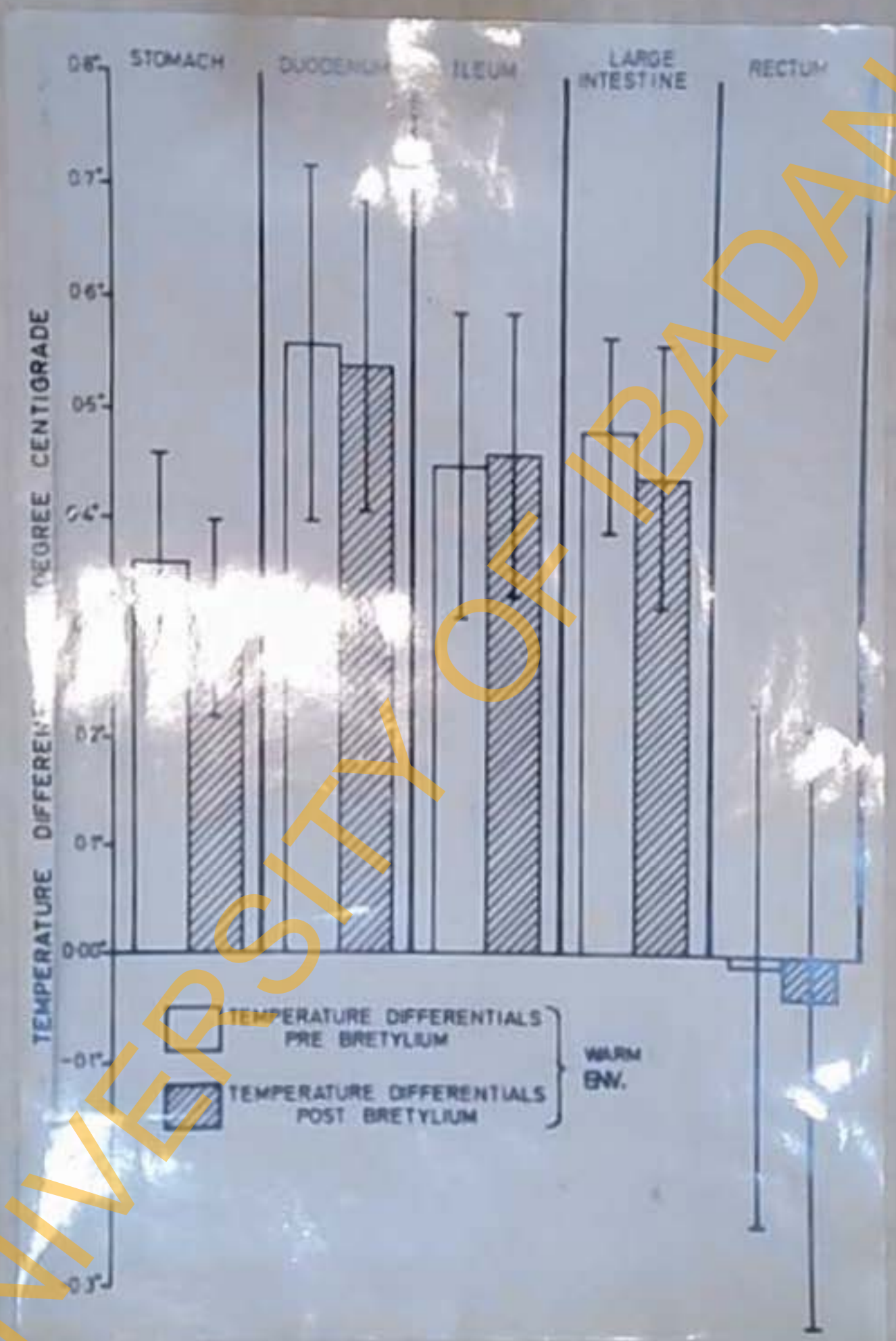

Fig 36. The effect of bretylium tosylate (10 mg/kg body weight) on the organ-aorta temperature differentials of various regions of the gastro intestinal tract (warm environment only).

TABLE 15A.

The effect of intravenous injection of Bretylium tosylate (10mg/kg body weight) on the absolute temperature distribution along the gastro intestinal tract.
"Warm" environment dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

EXPT. NOS.	AORTA		STOMACH		DUODENUM		ILEUM		LARGE INTESTINE		RECTUM	
	PRE BRET WARM	POST BRET WARM	PRE BRET WARM	POST BRET WARM	PRE BRET WARM	POST BRET WARM	PRE BRET WARM	POST BRET WARM	PRE BRET WARM	POST BRET WARM	PRE BRET WARM	POST BRET WARM
1	33.97	34.34	34.59	34.80	34.24	34.64	34.37	34.73	34.33	34.61		
2	34.90	35.61	35.20	35.90	35.34	36.[illegible]	35.24	35.93	35.40	36.07	34.81	35.71
3	34.34	35.12	34.70	35.43	34.57	35.46	34.67	35.53	34.82	35.62	34.35	35.37
4	34.95	35.56	35.25	35.96	35.62	36.28	35.40	36.18	35.39	36.04	35.15	35.68
5	35.98	35.81	36.33	36.00	36.57	36.34	36.55	36.33	36.39	36.15		
6	33.63	34.43	34.07	34.79	34.33	35.02	34.30	35.08	34.29	35.08	33.81	34.59
7	36.03	37.26	36.53	37.50	36.65	37.81	36.60	37.78	36.58	37.63	36.29	37.47
8	32.45	32.64	32.80	32.93	33.15	33.22	32.75	32.87	32.95	32.98	32.30	32.21
9	33.06	33.35	33.29	33.56	33.79	34.05	33.31	33.62	33.45	33.75	32.91	32.96
10	35.92	35.75	36.13	38.01	36.61	36.57	36.60	36.40	36.50	36.34	35.42	35.49
MEAN	34.53	34.99	34.89	35.30	35.09	35.53	35.98	35.45	35.01	35.43	34.92	34.95

TABLE 15B.

The effect of intravenous injection of Bretylium, tosylate (10mg/kg body weight) on the organ - aorta "temperature differential" distribution along the gastro intestinal tract.
"Warm" environment: dry bulb temperature = 29.2 ± 1.6° relative humidity = 72.8 ± 2.0%

EXPT. NOS.	STOMACH-AORTA		DUODENUM-AORTA		ILEUM-AORTA		LARGE INTESTINE AORTA		RECTUM-AORTA	
	PRE BRET	POST BRET	PRE BRET	POST BRET	PRE BRET	POST BRET	PRE BRET	POST BRET	PRE BRET	POST BRET
1	0.62	0.46	0.27	0.30	0.40	0.39	0.36	0.27		
2	0.30	0.29	0.44	0.43	0.34	0.32	0.50	0.46	0.09	0.10
3	0.36	0.31	0.23	0.34	0.33	0.41	0.48	0.50	0.01	0.25
4	0.30	0.40	0.67	0.72	0.45	0.62	0.44	0.48	0.20	0.12
5	0.35	0.19	0.59	0.53	0.57	0.52	0.39	0.34		
6	0.42	0.36	0.68	0.59	0.65	0.65	0.64	0.65	0.16	0.16
7	0.50	0.30	0.62	0.55	0.57	0.52	0.33	0.37	0.26	0.21
8	0.35	0.29	0.70	0.58	0.30	0.23	0.50	0.34	-0.15	-0.43
9	0.23	0.21	0.73	0.70	0.25	0.27	0.40	0.40	-0.15	-0.39
10	0.21	0.26	0.69	0.76	0.68	0.65	0.58	0.59	-0.50	-0.35
MEAN	0.36	0.31	0.56	0.54	0.45	0.46	0.48	0.44	-0.01	-0.04
STANDARD DEVIATION	+0.12	+0.08	+0.17	+0.15	+0.15	+0.15	+0.08	+0.11	+0.23	+0.27

temperature differentials rose towards the pre injection value. The result was that the difference between the pre injection and post injection values for these two regions were 0.05°C and 0.01°C respectively. None of these was found significant at the 5% level. The response of the duodenum was slower than the response of both the stomach and the ileum, taking about 80 minutes to reach completion. After two hours it also recovered and the post-injection value was only 0.01°C different from the pre-injection value. The reaction of the large intestine too was slow but it eventually became the second most affected region. The difference between the post and the pre-injection values was 0.04°C. The rectum-aorta temperature differentials were increased during the first 2 hours after the injection of bretylium. It later reduced to a value lower than the pre-injection value by 0.03°C.

B. Response to environmental cooling after bretylium tosylate.

Fig 37 shows the typical response (Mean of 7 experiments) of the gastro-intestinal tract to environmental cooling after bretylium tosylate. Table 16(a) gives values of the mean absolute temperatures during the last hour before and the second hour of cooling while table 16(b) and fig 38 give values of the corresponding temperature differentials during the same periods.

The most responsive regions of the gastro intestinal tract to environmental cooling, were the large intestine and the rectum, followed by the stomach. The response of both the duodenum and the ileum were not as much as the others but they were definitely

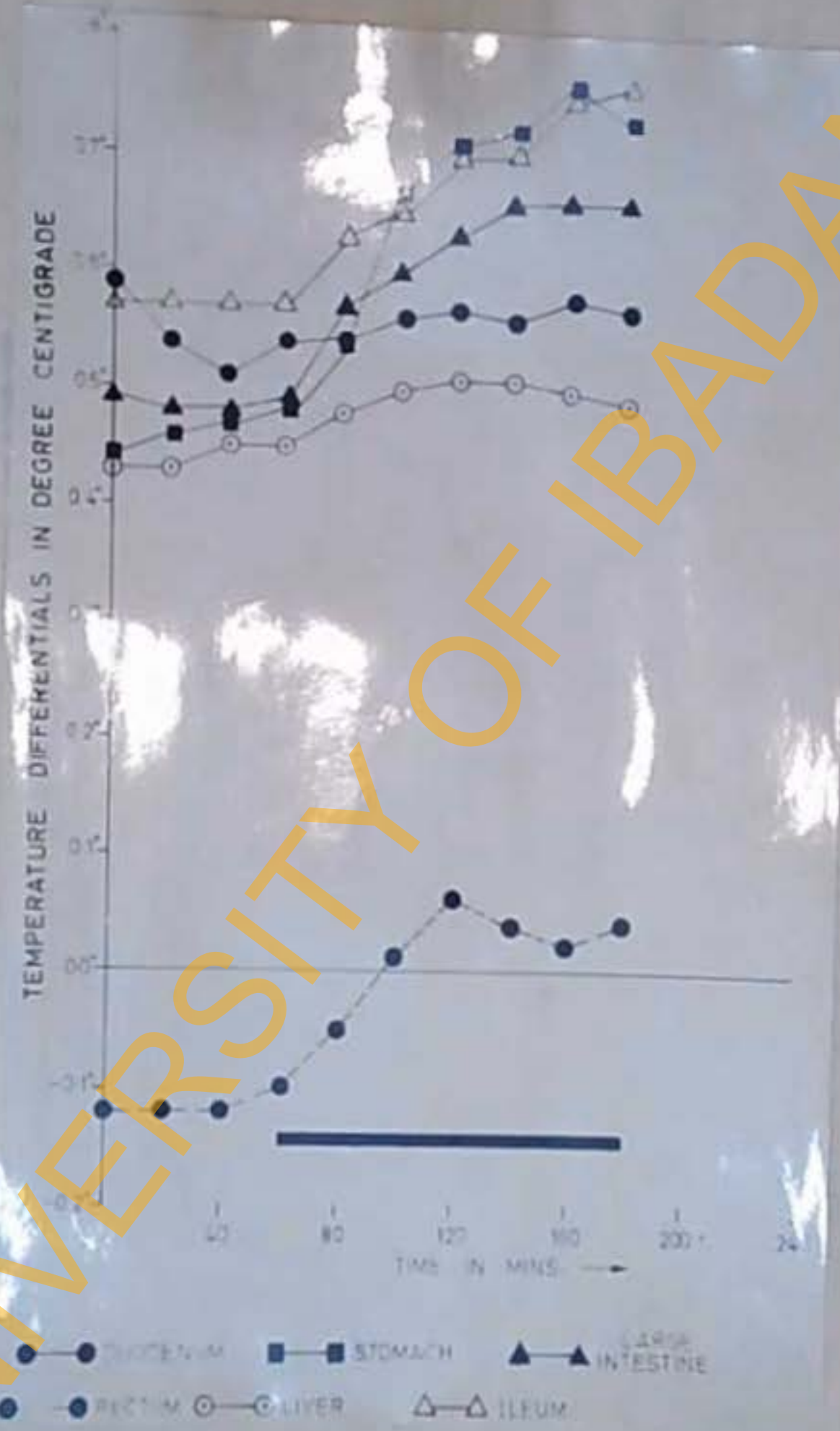

Fig 37. The response of the organ-aorta temperature differentials of various regions of the gastro-intestinal tract to environmental cooling - after bretylium tosylate (10 mg/kg body weight). Thick horizontal line indicates period of cooling.

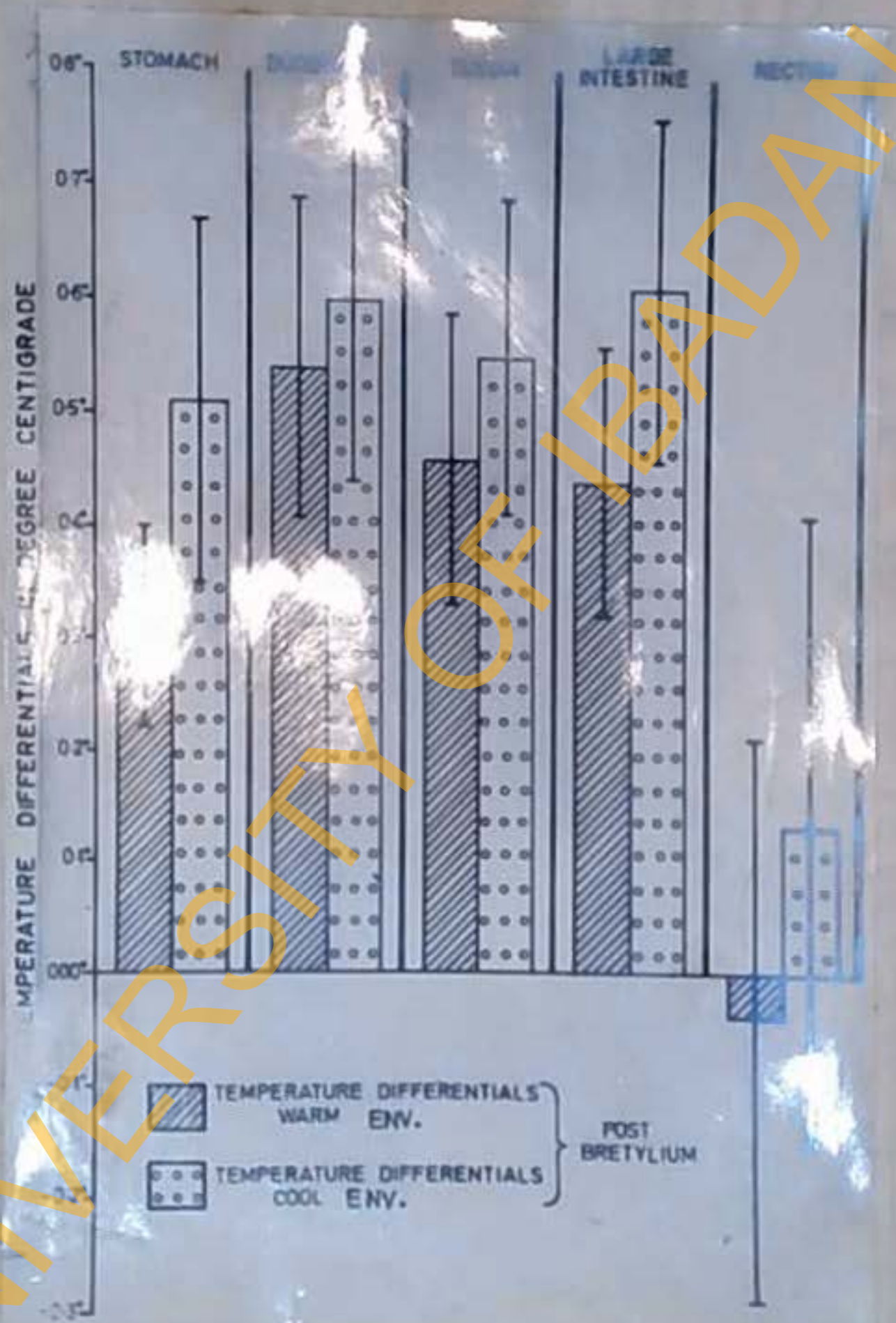

Fig 38. The effect of environmental cooling on the organ-aorta temperature differentials of various regions of the gastro intestinal tract, after bretylium tosylate (10 mg/kg body weight).

TABLE 16A.

The effect of **environmental** cooling on the absolute temperature distribution along the gastro intestinal tract after Bretylium Tosylate. (10mg/kg body weight i.v.).
"Warm" **environment** :- dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%
"Cool" **environment** :- dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT. NOS.	AORTA		STOMACH		DUODENUM		ILEUM		LARGE INTESTINE		RECTUM	
	POST BRET WARM	POST BRET COOL	POST BRET WARM	POST BRET COOL	POST BRET WARM	POST BRET COOL	POST BRET WARM	POST BRET COOL	POST BRET WARM	POST BRET COOL	POST BRET WARM	POST BRET COOL
1	35.61	34.66	36.07	35.48	35.91	35.02	36.00	35.12	35.91	34.98		
2	34.34	34.19	34.63	43.60	34.77	34.85	34.66	34.79	34.80	34.83	34.44	34.46
3	35.56	34.81	35.87	35.19	35.90	35.18	35.97	35.23	35.06	35.45	35.81	34.99
4	35.12	34.85	35.52	35.46	35.84	35.58	35.74	35.58	35.60	35.47	35.24	35.17
5	34.43	33.91	34.62	34.11	34.96	34.34	34.95	34.35	34.77	34.28		
6	37.26	38.08	37.62	38.80	37.85	38.52	37.91	38.72	37.91	38.75	37.42	38.37
7	32.64	31.60	32.94	32.39	33.19	32.26	33.16	32.23	33.01	32.38	32.85	32.12
8	33.35	31.90	33.64	32.89	33.93	32.65	33.58	32.45	33.69	32.55	32.72	31.92
9	35.76	34.78	35.97	35.31	36.46	35.62	36.03	35.14	36.16	35.45	35.57	34.50
10	35.81	34.84	36.07	35.13	36.57	35.69	36.46	35.63	36.40	35.61	35.46	34.59
MEAN	34.99	34.36	35.30	34.87	35.53	34.96	34.45	34.91	35.43	34.97	34.95	34.49

TABLE 16B.

The effect of environmental cooling on the organ - aorta "temperature differential" distribution along the gastro-intestinal tract - after intravenous injection of Bretylium tosylate (10mg/kg body weight.

"Warm" environment dry bulb temperature = 29.2 ± 1.6°° relative humidity = 72.8 ± 2.0%

"Cool" environment dry bulb temperature = 21.8 ± 1.5°° relative humidity = 61.5 ± 1.8%

EXPT. NOS.	STOMACH-AORTA		DUODENUM-AORTA		ILEUM-AORTA		LARGE INTESTINE AORTA		RECTUM - AORTA	
	PRE BRET	POST BRET	PRE BRET	POST BRET	PRE BRET	POST BRET	PRE BRET	POST BRET	PRE BRET	POST BRET
	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	0.46	0.82	0.30	0.36	0.39	0.46	0.27	0.32		
2	0.29	0.41	0.43	0.66	0.[illegible]	0.60	0.46	0.64	0.10	0.27
3	0.31	0.38	0.34	0.37	0.41	0.42	0.50	0.64	0.25	0.14
4	0.40	0.61	0.72	0.77	0.62	0.73	0.48	0.62	0.12	0.32
5	0.19	0.20	0.53	0.[illegible]3	0.52	0.44	0.34	0.37		
6	0.36	0.72	0.59	0.[illegible]	0.65	0.64	0.65	0.67	0.16	0.29
7	0.30	0.79	0.55	0.[illegible]	0.52	0.63	0.37	0.78	0.21	0.52
8	0.29	0.39	0.[illegible]	0.75	0.23	0.55	0.34	0.65	-0.63	+0.02
9	0.21	0.53	0.70	0.84	0.27	0.36	0.40	0.67	-0.19	-0.28
10	0.26	0.29	0.[illegible]	0.85	0.65	0.79	0.59	0.77	-0.35	-0.25
MEAN	0.31	0.51	0.54	0.60	0.46	0.55	0.44	0.61	-0.04	+0.13
STANDARD DEVIATION	±0.09	±0.20	±0.15	±0.18	±0.15	±0.13	±0.11	±0.14	±0.29	±0.26

TABLE 17

Summary of changes in the mean values of the organ-aorta "temperature differentials" distributed along the gastro intestinal tract, in response to environmental cooling - in the control experiments as well as after Bretylium Tosylate (10mg/kg body weight).

	STOMACH	DUODENUM	ILEUM	LARGE INTESTINE	RECTUM
CONTROL	+ 0.18	+ 0.09	+ 0.16	+ 0.19	+ 0.15
POST BRETYLIUM	+ 0.15	+ 0.06	+ 0.09	+ 0.17	+ 0.17

significant. The difference between the post-cooling and pre-cooling values of stomach-aorta temperature differentials was 0.15°C. This though significant (P=0.01) was shown in table 17 to be a reduced response to environmental cooling. The difference between the Post-cooling and pre-cooling values of the duodenum-aorta temperature differentials was 0.06°C. This was not significant (P=0.4) This was shown in table 17 to be a reduced response. The 0.09°C difference between the post-cooling pre-cooling ileum-aorta temperature differentials was not significant (P=0.1). It was also seen to be a much reduced response to environmental cooling (See table 17). Table 17 shows the response of the large intestine was not affected by bretylium tosylate. The large intestine-aorta temperature differential rose by 0.17°C on environmental cooling. This was found significant (P=0.01). The rectum showed a rise of about 0.17°C in its temperature with respect to the aorta on cooling. This rise was significant at the 5% and was infact an enhanced response to environmental cooling.

Hepatic Portal Vein.

A Response to bretylium tosylate injection.

Fig 39 shows the typical response (Mean of 7 experiments) its of the liver and its associated vessels to the injection of bretylium tosylate in the warm environment. Table 18(a) gives values (Mean of 10 experiments) of the absolute temperatures of the liver and its associated vessels during the last hour before and the second hour after injection. Table 18(b) and Fig 40 give the corresponding

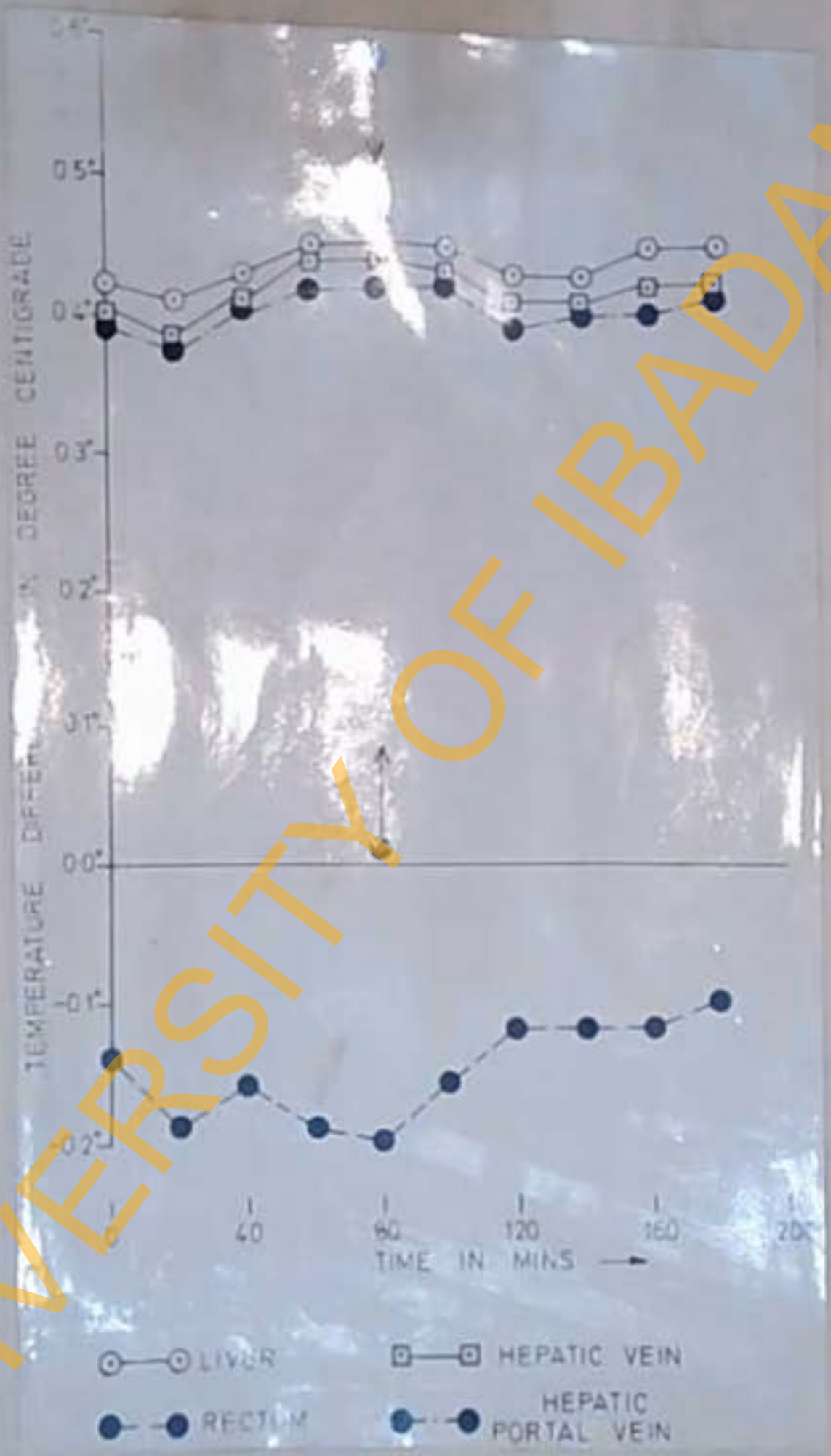

Fig 39. The response of the organ-aorta temperature differentials of the liver and its associated vessels to the injection of bretylium tosylate (10 mg/kg body weight). Arrows indicate the time of injection.

Fig 40. The effect of bretylium tosylate (10 mg/kg body weight) on the organ-aorta temperature differentials of the liver and its associated vessels. (Warm environment only).

TABLE 18A.

The effect of Bretylium tosylate (10mg/kg body weight) given intravenously on the absolute temperatures measured in the liver and its associated vessels - in the "warm" environment.
"Warm" environment. - Dry bulb temperature = 29.2 ± 1.6°C relative humidity= 72.8 ± 2.0%

EXPT. NOS.	AORTA		HEP. PORT VEIN		LIVER		HEPATIC VEIN	
	PRE BRET WARM	POST BRET WARM	PRE BRET WARM	POST BRET WARM	PRE BRET WARM	POST BRET WARM	PRE BRET WARM	POST BRET WARM
1	33.97	34.34	34.37	34.73	34.29	34.69	34.42	34.70
2	34.90	35.61	35.40	36.07	35.44	36.10	35.43	36.10
3	34.34	35.12	34.61	35.35	34.61	35.37	34.59	35.36
4	34.95	35.56	35.27	35.83	35.19	35.81	35.21	35.76
5	35.98	35.81	36.20	36.05	36.64	36.46	36.48	36.24
6	33.65	34.34	34.01	34.78	34.12	34.88	34.08	34.82
7	36.03	37.26	36.29	37.53	36.36	37.55	36.32	37.57
8	32.45	32.64	32.74	32.87	32.87	33.05	32.79	32.99
9	33.06	33.35	33.28	33.56	33.41	33.79	33.29	33.57
10	35.92	35.75	36.14	35.99	36.44	36.19	36.21	36.10
MEAN	34.52	34.99	34.83	35.28	34.94	35.39	34.88	35.32

TABLE 16D.

The effect of intravenous injection of Bretylium tosylate (10mg/kg body weight) on the organ - aorta "temperature differentials" measured in the liver and its associated vessels - in the "warm" environment.

"Warm" environment - dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

EXPT. NOS	HEP. PORT. VEIN - AORTA		LIVER - AORTA		HEP. VEIN - AORTA	
	PRE BRET WARM	POST BRET WARM	PRE BRET WARM	POST BRET WARM	PRE BRET WARM	POST BRET WARM
1	0.40	0.39	0.32	0.35	0.45	0.36
2	0.50	0.46	0.54	0.49	0.53	0.49
3	0.27	0.23	0.27	0.25	0.25	0.24
4	0.32	0.27	0.34	0.35	0.26	0.20
5	0.22	0.24	0.56	0.55	0.50	0.43
6	0.36	0.35	0.47	0.45	0.43	0.39
7	0.26	0.27	0.33	0.29	0.29	0.31
8	0.29	0.23	0.42	0.41	0.34	0.35
9	0.22	0.21	0.35	0.33	0.23	0.22
10	0.22	0.24	0.52	0.44	0.29	0.35
MEAN	0.31	0.29	0.41	0.40	0.36	0.33
STANDARD DEVIATION	±0.09	±0.08	±0.10	±0.09	±0.11	±0.09

values of organ-aorta temperature differentials.

There was no marked change in the value of the portal vein-aorta temperature differential on the injection of bretylium. The difference between the pre-injection and the post-injection values was 0.02°C. This was not statistically significant (P = 0.7).

B Response to environmental cooling after bretylium

Fig 41 shows the typical response (Mean of 7 experiments) of the portal vein-aorta temperature differentials to environmental cooling. Table 19(a) gives values of absolute temperatures during the last hour before and the second hour of environmental cooling. Table 19(b) and Fig 42 give the corresponding values of organ-aorta temperature differentials.

It is seen from the above tables and graphs that there was a gradual increase in the values of the hepatic portal vein-aorta temperature differentials during environmental cooling. The rise of about 0.08°C in the value of the mean temperature differentials during cooling was significant (P=0.02). Table 20 shows that bretylium reduced the response of the hepatic portal vein by about 20%.

The Liver and Hepatic Vein

A. Response to Bretylium tosylate injection.

From Fig 39 it can be seen that the effect of bretylium injection on the temperature differential between both the liver and hepatic vein with respect to the aorta, was very slight. Fig 40 and table 18(b) show that the difference in the value produced in the liver and hepatic vein respectively are 0.01°C and 0.03°C. These are by no means significant.

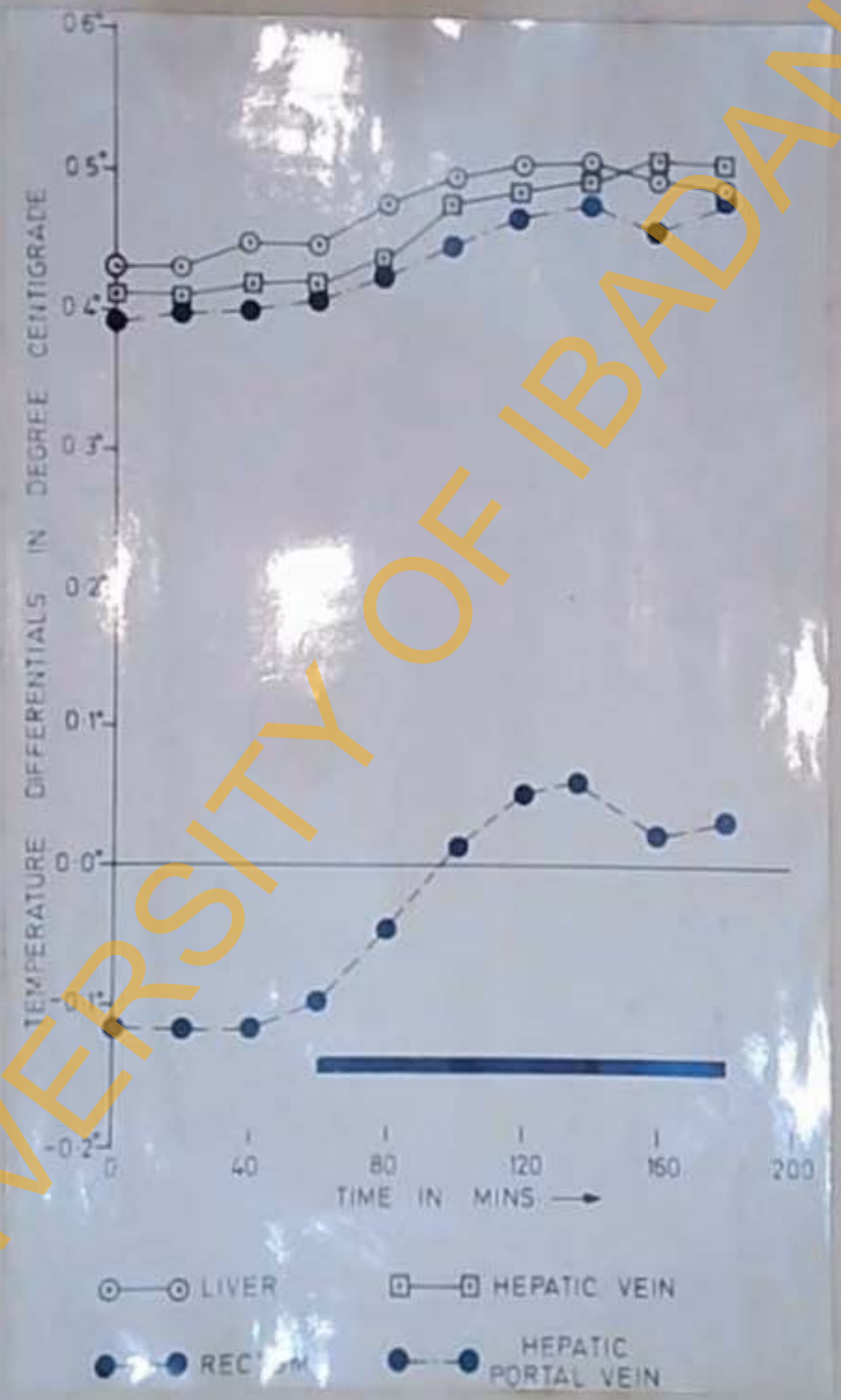

Fig 41. The response of the organ-aorta temperature differentials of the liver and its associated vessels to environmental cooling after bretylium tosylate (10 mg/kg body weight) Thick horizontal line indicates period of cooling.

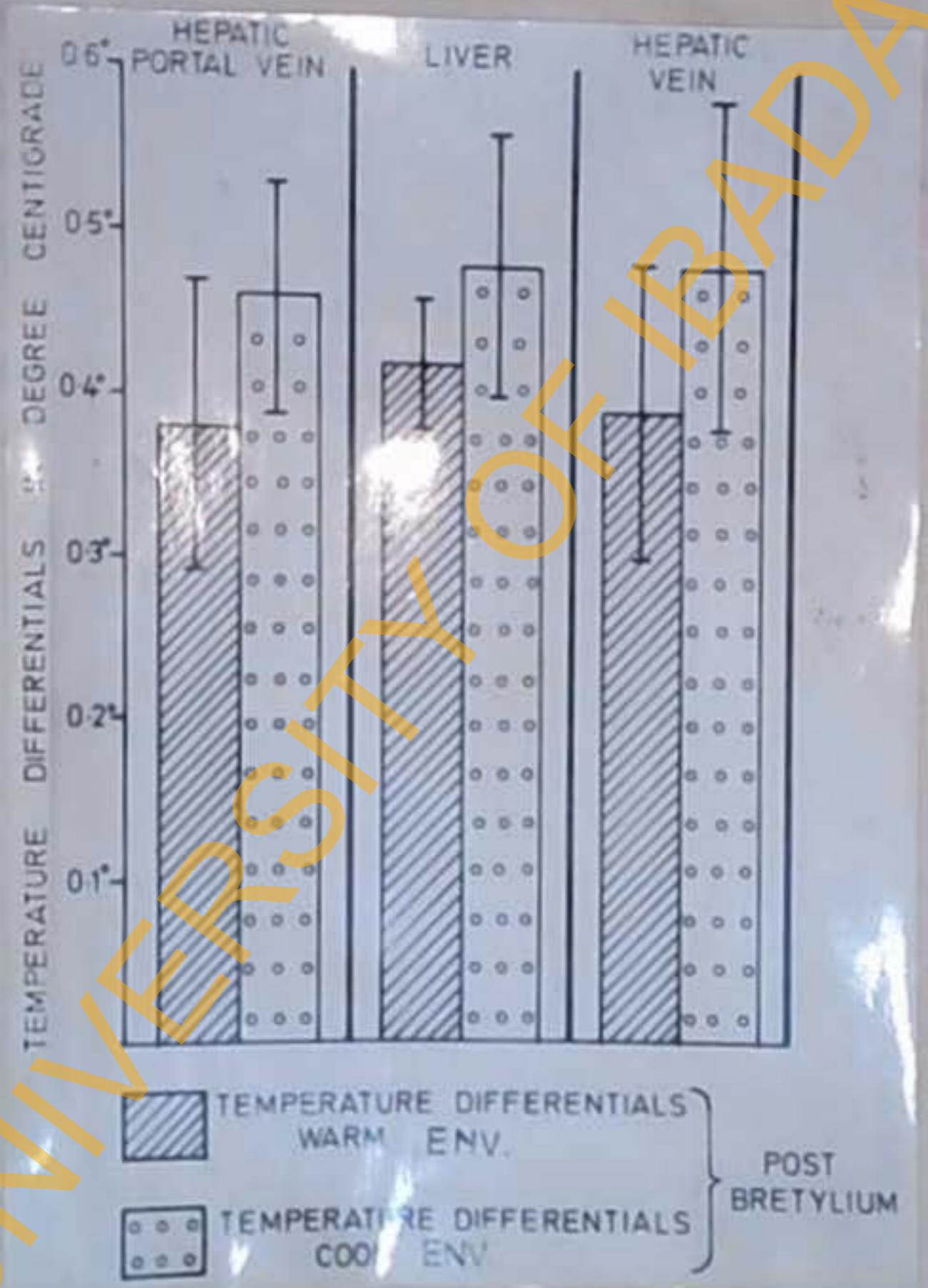

Fig 42. The effect of environmental cooling on the organ-aorta temperature differentials of the liver and its associated vessels after bretylium tosylate (10 mg/kg body weight).

Response of Liver and Hepatic Vein to environmental cooling after bretylium

From fig 41 it can be seen that both the liver and hepatic vein responded to environmental cooling. The liver-aorta temperature differentials increased by about 0.06°C, it was not significant (P=0.1). There was a rise of 0.11°C in the hepatic vein - aorta temperature differential on cooling. This was found significant (P=0.05). Table 20 shows that the effect of bretylium in reducing the response of both the liver and hepatic vein to cooling was only slightly more than the effect on the portal vein.

TABLE 19A.

The effect of environmental cooling on the absolute temperatures measured in the liver and its associated vessels - after intravenous injection of Bretylium tosylate (10mg/kg body weight).

"Warm" environment - dry bulb temperature = 29.2 ± 1.6°° relative humidity = 72.8 ± 2.0%

"Cool" environment - dry bulb temperature = 21.8 ± 1.5°° relative humidity = 61.5 ± 1.8%

EXPT.	AORTA		HEP. PORT. VEIN		LIVER		HEPATIC VEIN	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	35.61	34.66	35.97	35.16	36.00	35.12	35.99	35.61
2	34.34	34.19	34.74	34.68	34.84	34.79	34.85	34.79
3	35.56	34.81	36.06	35.32	36.13	35.43	36.10	35.46
4	35.12	34.85	35.47	35.23	35.47	35.22	35.36	35.18
5	35.81	34.84	36.17	35.31	36.27	35.25	36.16	35.25
6	34.43	33.91	34.73	34.41	34.86	34.37	34.82	34.45
7	37.26	38.08	37.65	38.58	37.68	38.58	37.69	38.62
8	32.64	31.60	33.10	32.17	33.00	32.09	33.00	32.08
9	33.35	31.90	33.58	32.19	33.76	32.28	33.71	32.33
10	35.76	34.78	36.17	35.27	36.10	35.21	36.06	35.23
MEAN	34.99	34.36	35.36	34.83	35.41	34.85	35.37	34.85

TABLE 19B.

The effect of environmental cooling on the organ - aorta "temperature differentials" measured in the liver and its associated vessels after intravenous injection of bretylium tosylate (10mg/kg body weight).

"Warm" environment - dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

"Cool" environment - dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT. NOS	HEP. PORT VEIN-AORTA		LIVER - AORTA		HEP. VEIN-AORTA	
	WARM	COOL	WARM	COOL	WARM	COOL
1	0.36	0.50	0.39	0.46	0.38	0.42
2	0.40	0.49	0.50	0.60	0.51	0.60
3	0.50	0.51	0.57	0.62	0.54	0.65
4	0.35	0.38	0.35	0.37	0.24	0.33
5	0.36	0.47	0.46	0.41	0.35	0.41
6	0.30	0.40	0.43	0.46	0.39	0.54
7	0.39	0.50	0.42	0.50	0.43	0.54
8	0.46	0.57	0.36	0.49	0.36	0.48
9	0.23	0.29	0.41	0.38	0.36	0.43
10	0.41	0.49	0.34	0.43	0.30	0.45
MEAN	0.38	0.46	0.42	0.48	0.39	0.48
S. D.	±0.07	±0.08	±0.07	±0.08	±0.09	±0.09

TABLE 20

Summary of changes in the mean value of the organ - aorta "temperature differentials" measured in the liver and its associated vessels - in response to environmental cooling - during the control experiments and after Bretylium tosylate (10mg/kg body weight).

	HEPATIC PORTAL VEIN	LIVER	HEPATIC VEIN
CONTROL	+ 0.10	+ 0.10	+ 0.14
POST BRETYLIUM TOSYLATE	+ 0.08	+ 0.06	+ 0.11

EFFECT OF ADRENERGIC AND CHOLINERGIC BLOCKADE ON TEMPERATURE DISTRIBUTION IN THE CORE AREA OF THE DOG.

The effect of atropine sulphate and bretylium tosylate on the temperature distribution as well as the response to environmental cooling have already been shown separately. The present series was designed to show the effect of combined adrenergic and cholinergic blockade on the absolute temperature distribution as well as the level of the organ-sorta temperature distribution in each region of the gastro intestinal tract and the liver with its associated vessels. The effect of these drugs on the response of the above mentioned regions of the core area to environmental cooling was also studied. Bretylium tosylate was given in doses of 10mg/kg body weight (i.v. slow injection), about twenty minutes before the injection or 1mg/kg body weight atropine sulphate. Fig 43 shows the reaction of the blood pressure to the administration of both drugs. The fall in b.p. recorded always lasted about five to seven minutes on the average. After this it stabilised on a lower level.

The Gastro Intestinal Tract

A. Response to the simultaneous injections of bretylium tosylate and atropine sulphate in the warm environment.

Fig 44 shows the reaction of the gastro intestinal tract to the injection of both bretylium and atropine. Table 21(a) gives values of absolute temperatures in the various regions of the gastro intestinal tract, one hour before and after the second hour of the

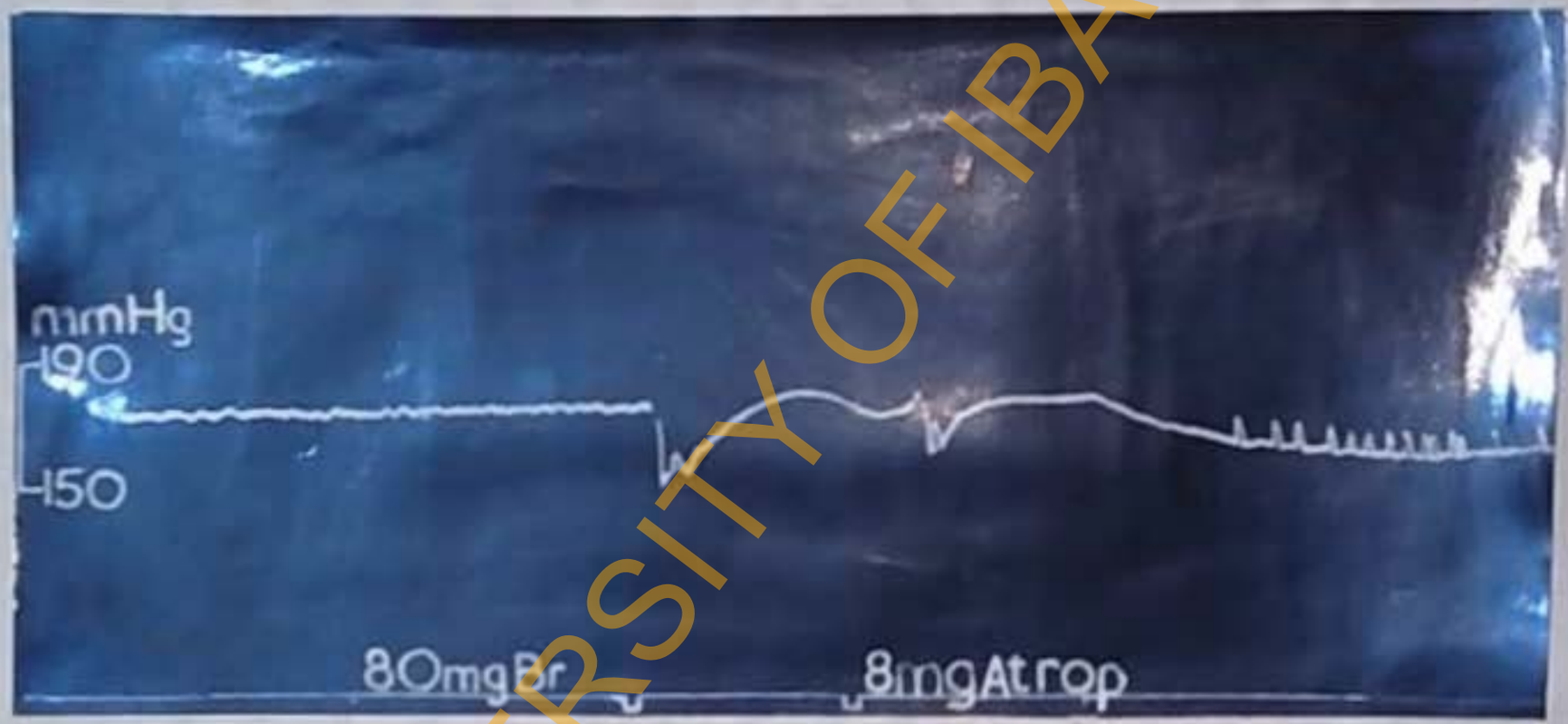

Fig 43. The effect of simultaneous injection of bretylium tosylate (10 mg/kg body weight) and atropine sulphate (1 mg/kg body weight) on the blood pressure.

injection of both drugs. Table 21(b) and fig 45 give the corresponding values of the organ-aorta temperature differentials during the same periods of time.

The injection of both drugs had a marked effect on the temperature differentials of the stomach. The difference between the post administration and the pre-administration values was - 0.11°C (P = 0.1). The duodenal-aorta temperature differential was reduced by 0.12°C after the injection of both drugs. The reduction in the ileum - aorta temperature differential after the injection of both drugs was 0.07°C. The large intestine-aorta temperature differentials got reduced by 0.04°C. The reaction of the rectum to both drugs was quite unique, in that, it was the only region which displayed an increase in temperature differential with reference to the aorta. The rise was 0.14°C and it was significant (P=0.05). Table 21(c) shows a comparison between the effect of atropine sulphate, bretylium tosylate and a combination of both drugs on the levels of temperature differentials. It can be seen from this that the effect of the simultaneous inject of both drugs was greater than any single one of them. There was a bigger reduction in the temperature differentials of the stomach, duodenum, ileum, and large intestine but there was an increase in that of the rectum.

B. Response to environmental cooling after both bretylium and atropine.

Fig 46 gives the response of the gastro intestinal tract to environ-

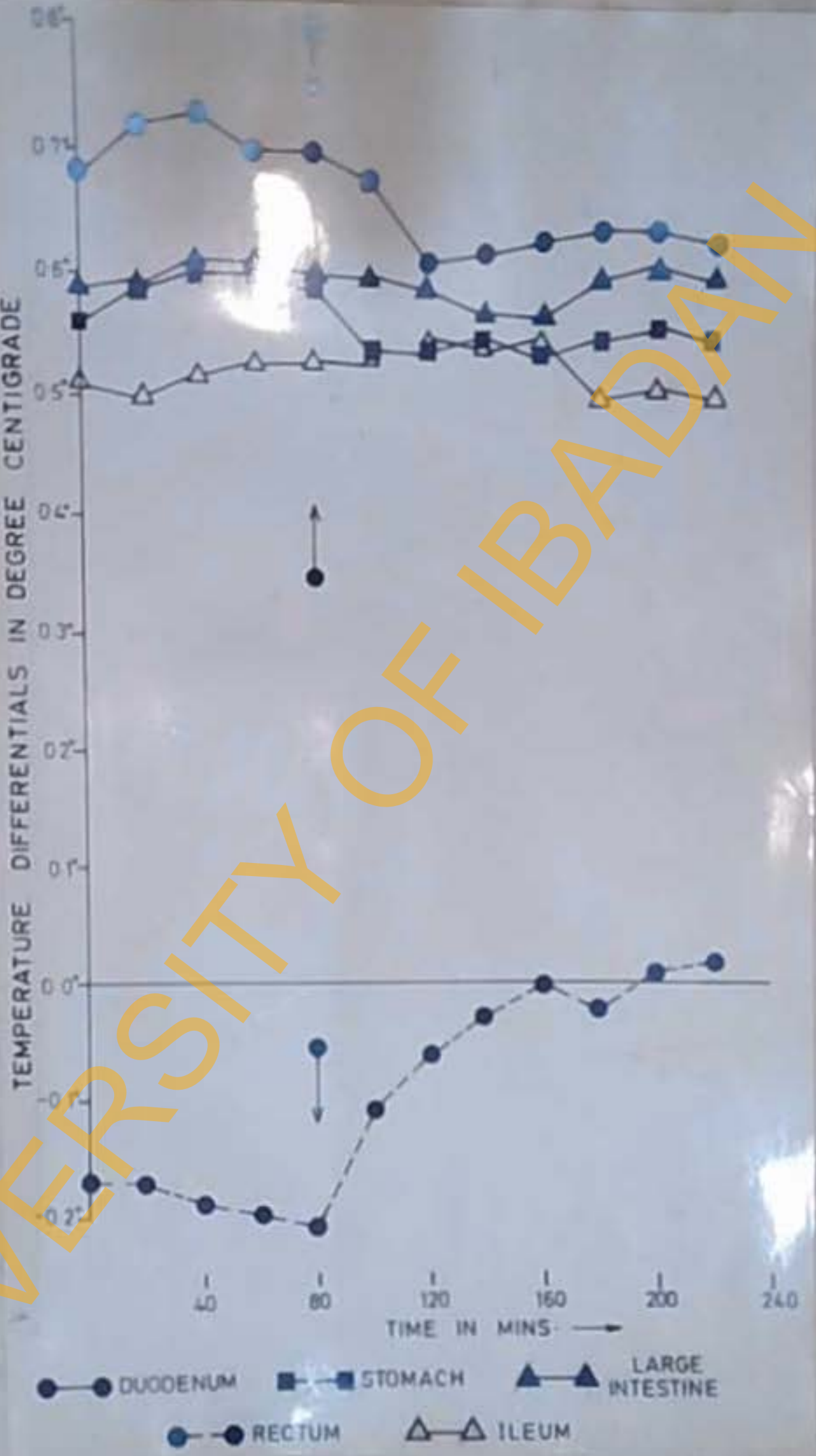

Fig 44. The response of the organ-aorta temperature differential of various regions of the gastro intestinal tract to simultaneous injections of bretylium tosylate (10 mg/kg body weight) and atropine sulphate (1mg/kg body weight). Warm enviroment only. Arrows indicate the time of injections.

Fig 45. The effect of simultaneous administration of bretylium tosylate (10 mg/kg body weight) and atropine sulphate (1 mg/kg body weight) on the organ-aorta temperature differentials of various regions of the gastro intestinal tract. Warm environment.

TABLE 21A.

The effect of intravenous injection of both Bretylium tosylate (10mg/kg body weight) and atropine sulphate (1mg/kg body weight) on the absolute temperature distribution along the gastro intestinal tract - in the "warm" environment.

"Warm" environment = dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

EXPT. NOS.	AORTA		STOMACH		DUODENUM		ILEUM		LARGE INTEST-INE		RECTUM	
	PRE BOTH WARM	POST WARM	PRE BOTH WARM	POST BOTH WARM	PRE BOTH WARM	POST BOTH WARM	PRE BOTH WARM	POST BOTH WARM	PRE BOTH WARM	POST BOTH WARM	PRE BOTH WARM	POST BOTH WARM
1	33.81	33.81	34.31	34.08	34.57	34.51	34.21	34.18	34.41	34.04	33.65	33.96
2	34.73	35.07	35.26	35.52	35.37	35.48	35.23	35.49	35.13	35.53	34.60	35.14
3	35.41	35.44	35.87	35.94	36.20	36.11	35.71	35.69	35.95	35.94	35.18	35.28
4	36.33	37.03	36.75	37.41	36.93	37.60	37.10	37.75	36.94	37.69	36.28	37.06
5	35.95	37.99	36.52	38.21	36.41	38.32	36.38	38.21	36.51	38.53	35.76	37.95
6	36.46	37.93	37.01	38.41	37.31	38.68	36.96	38.29	37.07	38.50	36.44	37.90
7	33.66	33.62	34.47	34.38	34.37	34.25	33.92	33.91	34.49	34.37	33.82	33.40
8	33.84	34.93	34.44	35.21	34.34	35.26	34.31	35.18	34.40	35.49	33.97	34.86
9	37.08	38.72	37.61	39.29	37.71	39.41	37.81	39.52	37.48	39.21	36.72	38.60
MEAN	35.25	36.03	35.80	36.47	35.91	36.57	35.73	36.44	35.82	36.56	35.16	36.04

TABLE 21B.

The effect of intravenous injections of both Bretylium tosylate (10mg/kg body weight) and atropine sulphate (1mg/kg body weight) on the organ-aorta "temperature differential" distribution along the gastro intestinal tract in the warm environment.

"Warm" environment = dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

EXPT. NOS	STOMACH-AORTA		DUODENUM-AORTA		ILEUM-AORTA		LARGE INTES-TINE AORTA		RECTUM - AORTA	
	PRE ADMIN	POST ADMIN	PRE ADMIN	POST ADMIN	PRE ADMIN	POST ADMIN	PRE ADMIN	POST ADMIN	PRE ADMIN	POST ADMIN
	WARM	WARM	WARM	WARM	WARM	WARM	WARM	WARM	WARM	WARM
1	0.50	0.27	0.76	0.50	0.40	0.37	0.60	0.23	-0.16	+0.15
2	0.53	0.45	0.64	0.41	0.50	0.42	0.40	0.46	-0.13	+0.07
3	0.46	0.50	0.79	0.67	0.30	0.25	0.54	0.50	-0.23	-0.16
4	0.42	0.38	0.60	0.57	0.77	0.72	0.61	0.66	-0.05	+0.03
5	0.57	0.25	0.46	0.33	0.43	0.25	0.56	0.54	-0.19	-0.04
6	0.55	0.48	0.85	0.75	0.50	0.36	0.61	0.57	-0.02	-0.03
7	0.81	0.76	0.71	0.63	0.26	0.29	0.83	0.75	+0.16	0.22
8	0.60	0.28	0.50	0.33	0.47	0.25	0.56	0.54	0.13	-0.07
9	0.53	0.57	0.63	0.69	0.73	0.80	0.40	0.49	-0.36	-0.12
MEAN	0.55	0.44	0.66	0.54	0.48	0.41	0.57	0.53	-0.09	00.05
S. D.	±0.10	±0.16	±0.12	±0.15	±0.16	±0.19	±0.12	±0.14	±0.15	±0.12

TABLE 21C.

Summary of the changes in the mean values of the organ - aorta temperature differentials distributed along the gastro intestinal tract in response to the injection of atropine sulphate, Bretylium tosylate and a combination of both of them.

	STOMACH	DUODENUM	ILEUM	LARGE INTESTINE	RECTUM
ATROPINE	- 0.03	- 0.08	- 0.06	+ 0.1	- 0.02
BRETYLIUM	- 0.05	- 0.02	+ 0.01	- 0.04	- 0.03
BRETYLIUM AND ATROPINE	- 0.11	- 0.12	- 0.07	- 0.04	+ 0.14

mental cooling after the injection of both bretylium and atropine. Table 22(a) gives the mean values of the absolute temperatures of various regions of mean values of the gastro intestinal tract during the hour before and the second hour of environmental cooling. Table 22(b) give the corresponding organ temperature differentials during the same periods.

There was an increase in the value of the stomach-aorta temperature differentials during environmental cooling. The rise of 0.15°C was still significant (P=0.05). The duodenum-aorta temperature differentials did not increase sustantially during environmental cooling. The rise was only 0.01°C. The ileum-aorta temperature differentials increased by 0.06°C during environmental cooling. The large intestine-aorta temperature differentials increased by 0.09°C during cooling. The increase in the temperature differentials of the rectum with respect to the aorta was 0.21°C. This was found significant at the 5% level. Table 23 shows that the response of the stomach to environmental cooling was only slightly reduced while that of the duodenum was virtually knocked off completely. The response of both the ileum and large intestine to environmental cooling were heavily reduced. The response of the rectum on the other hand, was enhanced by both drugs.

THE HEPATIC PORTAL VEIN

A. Response to the simultaneous injection of both bretylium tosylate and atropine sulphate in the warm environment.

Fig 48 gives the reaction of the liver and its associated vessels to the injection of both bretylium and atropine. Table 24(a) gives

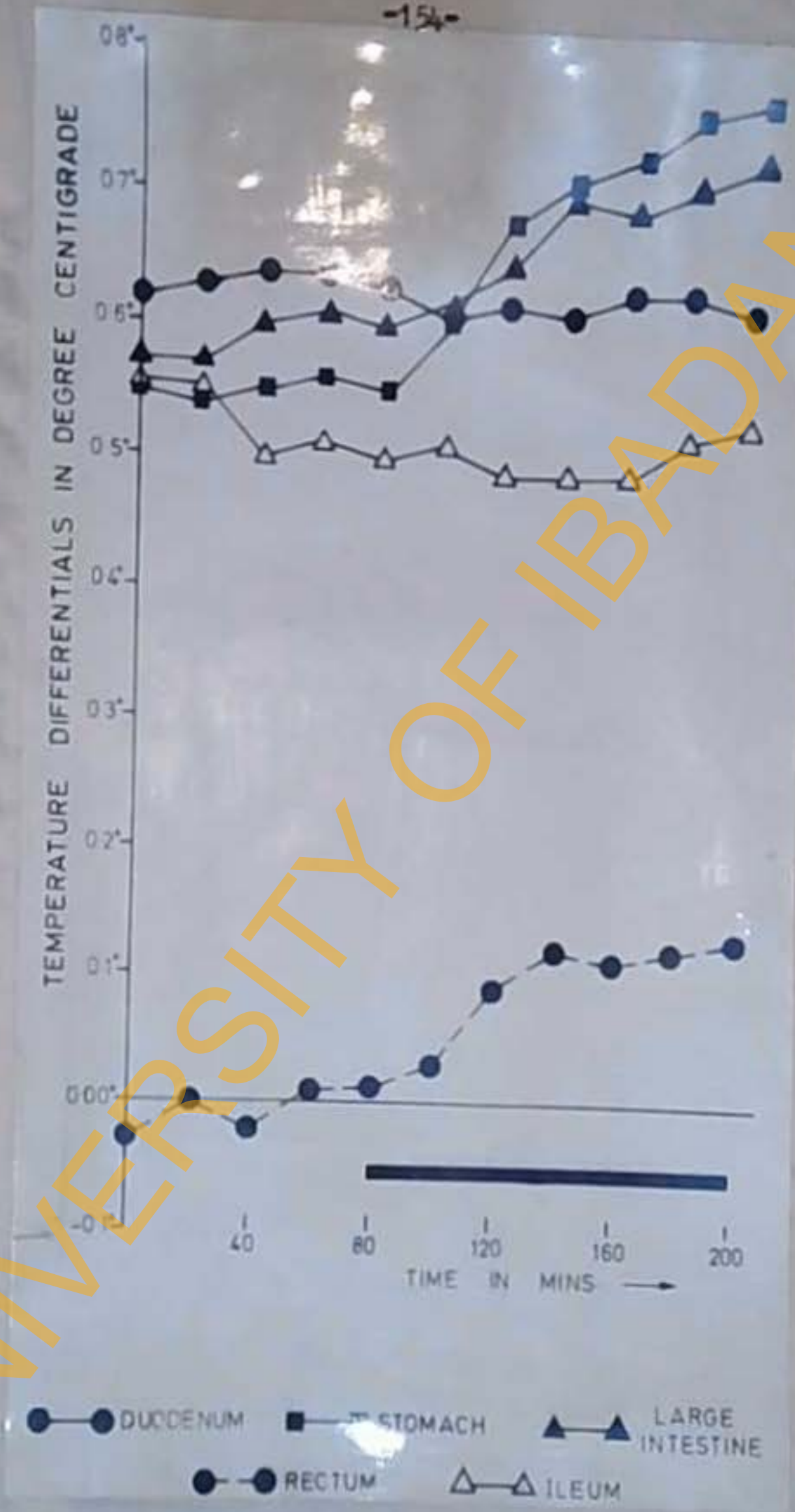

Fig 46. The response of the organ-aorta temperature differentials of various regions of the gastro intestinal tract to environmental cooling after bretylium tosylate (10 mg/kg body weight) and atropine sulphate (1 mg/kg body weight). Thick horisontal line indicates the period of cooling.

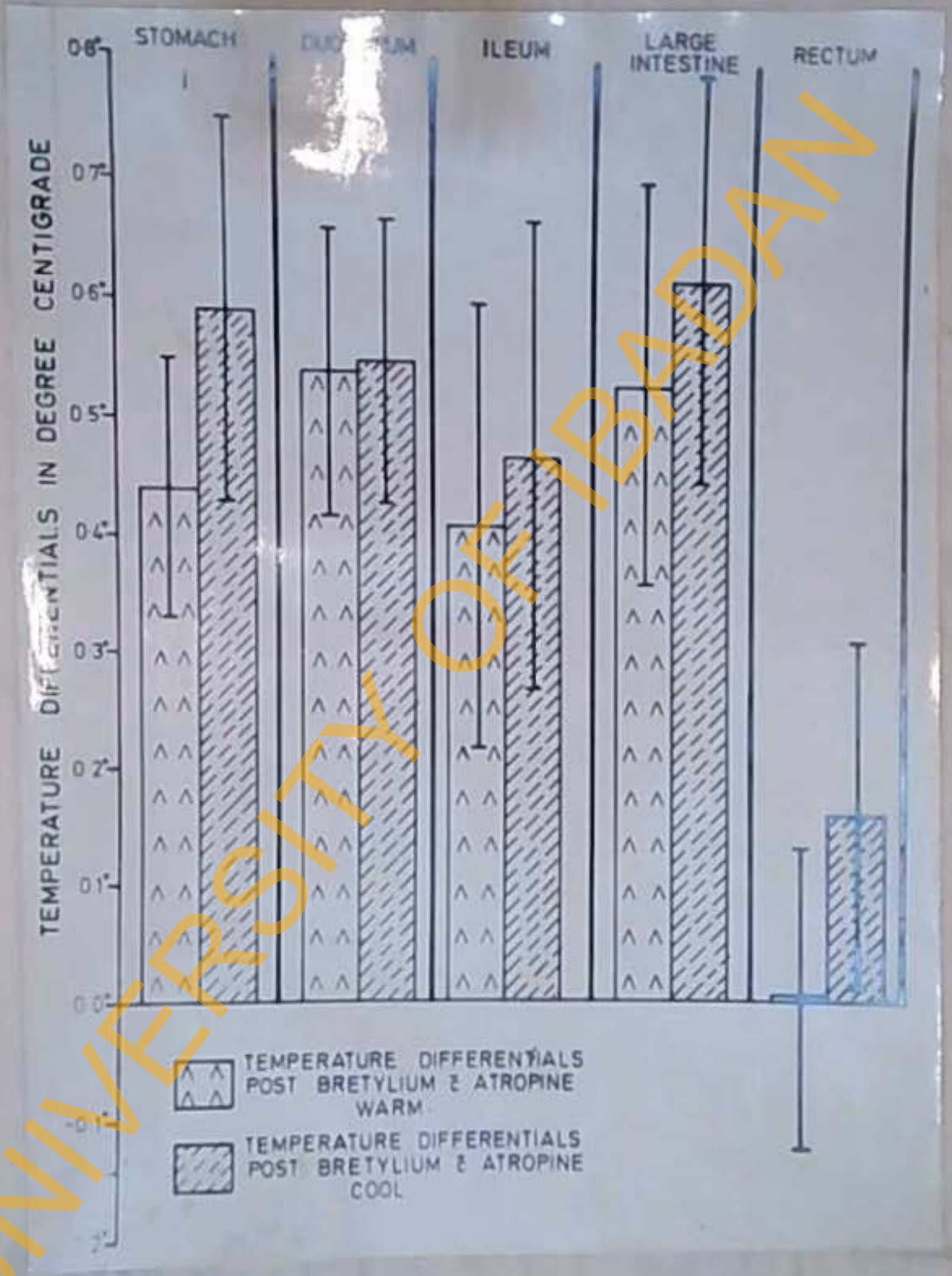

Fig 47. The effect of environmental cooling on the organ-aorta temperature differentials of various regions of the gastro-intestinal tract, after bretylium tosylate (10 mg/kg body weight) and atropine sulphate (1 mg/kg body weight).

TABLE 22A.

The effect of **environmental** cooling on the absolute temperature distribution along the gastro intestinal tract after intravenous injections of Bretylium tosylate (10mg/kg body weight) - atropine sulphate (1mg/kg body weight).

"Warm" **environment** = dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

"Cool" **environment** = dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT. NOS.	AORTA		STOMACH		DUODENUM		ILEUM		LARGE INTESTINE		RECTUM	
	POST WARM	ADMIN COOL	POST WARM	ADMIN COOL	POST WARM	ADMIN COOL	POST WARM	ADMIN COOL	POST WARM	ADMIN COOL	POST WARM	ADMIN COOL
1	33.81	32.93	34.08	33.37	34.31	33.45	34.18	33.26	34.04	33.23	33.96	33.16
2	35.07	34.33	35.52	34.89	35.48	34.76	35.49	34.86	35.53	34.89	35.14	34.48
3	35.44	34.34	35.94	34.97	36.11	35.05	35.69	34.59	35.94	34.94	35.28	38.28
4	37.03	36.81	37.41	37.31	37.60	37.45	34.75	37.59	37.69	37.62	37.06	37.20
5	37.99	38.30	38.24	38.75	38.32	38.64	38.24	38.73	38.53	38.94	37.95	38.21
6	37.93	38.00	38.41	38.97	38.68	38.69	38.29	38.32	38.50	38.65	37.90	38.23
7	33.62	33.32	34.38	34.21	34.25	33.90	33.91	33.63	34.37	32.51	33.40	33.67
8	34.93	34.36	35.21	34.78	35.26	34.70	35.18	34.79	35.49	33.73	34.86	34.54
9	38.72	37.20	38.29	38.06	39.41	37.87	39.52	38.06	39.21	36.63	38.60	37.18
MEAN	36.03	35.51	36.47	36.10	36.57	36.06	36.44	35.98	36.56	36.13	36.04	35.67

TABLE 22B.

The effect of environmental cooling on the organ - aorta temperature differential distribution along the gastro intestinal tract after intravenous injection of Bretylium tosylate (10mg/kg body weight) and atropine sulphate (1mg/kg body weight).
"Warm" environment - dry bulb temperature = 29.2 ± 1.5°C relative humidity = 72.8 ± 2.0%
"Cool" environment - dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT. NOS.	STOMACH		DUODENUM - AORTA		ILEUM - AORTA		LARGE INTESTINE AORTA		RECTUM - AORTA	
	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	0.27	0.44	0.50	0.52	0.27	0.33	0.23	0.30	0.15	0.23
2	0.45	0.56	0.41	0.43	0.42	0.53	0.46	0.56	0.07	0.15
3	0.50	0.63	0.67	0.71	0.25	0.25	0.50	0.60	-0.16	-0.06
4	0.38	0.50	0.57	0.64	0.72	0.78	0.66	0.81	0.03	0.39
5	0.25	0.43	0.33	0.34	0.25	0.43	0.54	0.64	-0.04	-0.09
6	0.48	0.57	0.75	0.89	0.36	0.32	0.57	0.65	-0.03	0.23
7	0.76	0.89	0.65	0.58	0.29	0.31	0.75	0.81	0.22	0.39
8	0.28	0.42	0.33	0.34	0.25	0.43	0.54	0.63	-0.07	0.18
9	0.57	0.86	0.69	0.67	0.80	0.86	0.49	0.57	-0.12	-0.02
MEAN	0.44	0.59	0.54	0.55	0.41	0.47	0.53	0.62	-00.49	+0.16
STANDARD DEVIATION	±0.15	±0.17	±0.15	±0.17	±0.20	±0.20	±0.14	±0.14	±0.12	±0.17

TABLE 23

Summary of changes in the mean values of the organ - sorte "temperature differentials distributed along the gastro intestinal tract - in response to cooling - in the control experiments as well as after combined administration of Bretylium tosylate (10mg/kg body weight) and atropine sulphate (1mg/kg body weight).

	STOMACH	DUODENUM	ILEUM	LARGE INTESTINE	RECTUM
CONTROL	+ 0.18	+ 0.09	+ 0.16	+ 0.19	+ 0.15
POST COMBINED BRETYLIUM AND ATROPINE	+ 0.15	+ 0.01	+ 0.06	+ 0.09	+ 0.21

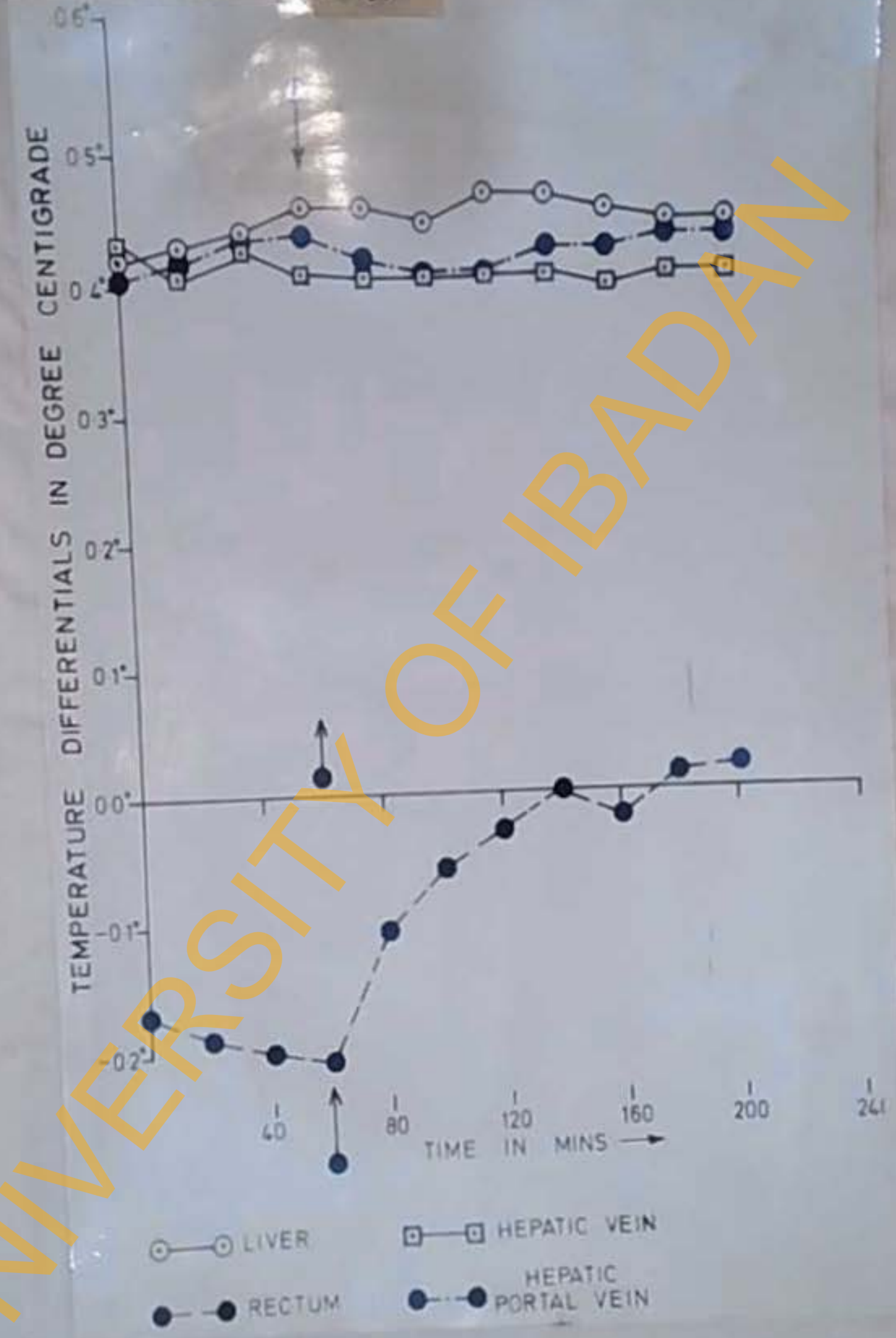

Fig 48. The response of the organ-aorta temperature differentials of the liver and its associated vessels to the simultaneous injections of bretylium tosylate (10 mg/kg body weight) and atropine sulphate (1 mg/kg body weight). Warm environment only. Arrows indicate the time of injections.

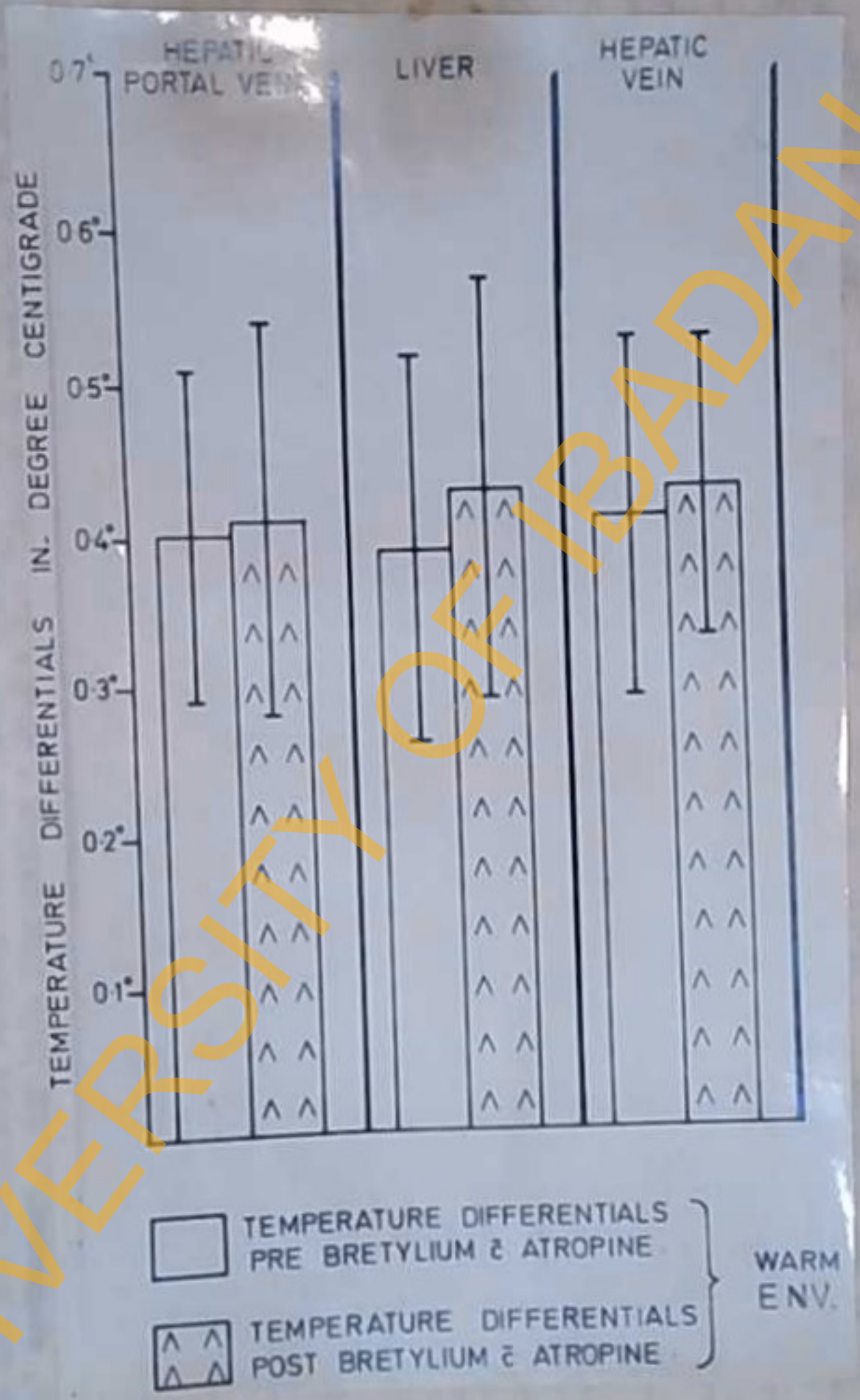

Fig 49. The effect of simultaneous injections of bretylium tosylate (10 mg/kg body weight) atropine sulphate (1 mg/kg body weight) on the organ-aorta temperature differentials of the liver and its associated vessels. (Warm environment only).

TABLE 24A.

The effect of intravenous injections of Bretylium tosylate (10mg/kg body weight) and atropine sulphate (1mg/kg body weight) on the absolute temperatures measured in the liver and its associated vessels - in the "warm" environment.

"Warm" environment - dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

EXPT.	AORTA		HEP. PORT. VEIN		LIVER		HEP. VEIN	
NOS.	PRE ADM WARM	POST ADM WARM	PRE ADM WARM	POST ADM WARM	PRE ADM WARM	POST ADM WARM	PRE ADM WARM	POST ADM WARM
1	33.81	33.81	34.07	34.07	34.04	34.05	34.32	34.38
2	34.73	35.07	35.35	35.74	35.28	35.65	36.17	35.65
3	35.41	35.44	35.81	35.84	35.81	35.90	35.89	35.92
4	36.33	37.03	36.68	37.35	36.68	37.41	36.70	37.38
5	35.95	37.99	36.30	38.37	36.38	38.39	36.36	38.38
6	36.46	37.93	36.76	38.19	36.77	38.33	36.75	38.29
7	33.66	33.62	34.04	34.04	33.94	33.94	33.89	33.88
8	33.84	34.93	34.24	34.36	34.17	35.31	34.22	35.27
9	37.08	38.72	37.61	39.28	37.72	39.39	37.59	39.28
MEAN	35.25	36.03	35.65	36.44	35.64	36.46	35.66	36.46

TABLE 2.B.

The effect of intravenous injections of Bretylium tosylate (10mg/kg body weight) and atropine sulphate (1mg/kg body weight) on the organ - aorta "temperature differentials" measured in the liver and its associated vessels in the warm environment.

"Warm" environment - dry bulb temperature = 29.2 ± 1.[illegible] relative humidity = 72.8 ± 2.0%

EXPT. NOS.	HEP. PORT. VEIN AORTA		LIVER - AORTA		HEPATIC VEIN - AORTA	
	PRE ADM WARM	POST ADM WARM	PRE ADM WARM	POST ADM WARM	PRE ADM WARM	POST ADM WARM
1	0.26	0.26	0.23	0.24	0.51	0.57
2	0.62	0.67	0.57	0.58	0.52	0.58
3	0.40	0.40	0.40	0.46	0.48	0.48
4	0.35	0.32	0.35	0.38	0.37	0.35
5	0.35	0.38	0.43	0.40	0.41	0.39
6	0.30	0.26	0.31	0.40	0.29	0.36
7	0.38	0.42	0.28	0.32	0.23	0.26
8	0.40	0.43	0.33	0.38	0.38	0.34
9	0.53	0.56	0.64	0.67	0.51	0.56
MEAN	0.40	0.41	0.39	0.43	0.41	0.43
STANDARD DEVIATION	±0.11	±0.13	±0.13	±0.12	±0.10	±0.11

values of the absolute temperatures of the liver and its associated vessels during the last hour before and after the second hour of the administration of both drugs. Table 24(b) and Fig 49, on the other hand give the corresponding organ aorta temperature differentials during the same period.

The reduction in the value of the temperature differentials of the hepatic portal vein with respect to the aorta was short lived, lasting only about 60 minutes. It rose again and at the end of two hours it was only 0.01°C less than the pre-injection value. This difference was not significant (P > 0.1).

B. Response to cooling after bretylium tosylate and atropine sulphate.

Fig 50 shows the response of the liver and its associated vessels to environmental cooling after bretylium tosylate and atropine sulphate. Table 25(a) gives values of the absolute temperatures while table 25(b) and fig 51 give the corresponding mean organ-aorta temperature differentials of the liver and its associated vessels during the above named periods.

There was an instant increase in the hepatic portal vein temperature differentials with respect to the aorta, during environmental cooling. In fact the temperature of the hepatic portal vein rose above the liver and hepatic vein during cooling. The difference between the temperature differentials before and after cooling was 0.09°C. This was significant at the 5% level.

The Liver and Hepatic Vein

A. Response to the simultaneous injection of bretylium tosylate and atropine sulphate.

From the above mentioned tables and figures, it can be seen that the effect of both drugs on the liver-aorta temperature differentials as well as on the hepatic vein-aorta temperature differentials was negligible. The liver aorta temperature differentials rose by 0.04°C. This was not significant (P = 0.07) that of the hepatic vein-aorta temperature differentials rose by 0.02°C. This too not significant (P = 0.9).

B. Response to environmental cooling after bretylium and atropine.

From figs 50 & 57 it could be seen that the liver-aorta temperature differential rose in response to environmental cooling. The difference between the pre and post cooling values was 0.03°C. This rise was not significant at the 5% level (P = 0.6).

The hepatic vein on the other hand responded more than did the liver. The hepatic vein-aorta temperature differentials rose by about 0.10°C which was significant (P = 0.05). Table 26 shows a comparison between the response of the liver, portal vein and the hepatic vein to environmental cooling in the control series and after combined bretylium and atropine. From here it can be seen that there was a reduction in the response of the liver and hepatic vein while there was no significant reduction in the response of the portal vein.

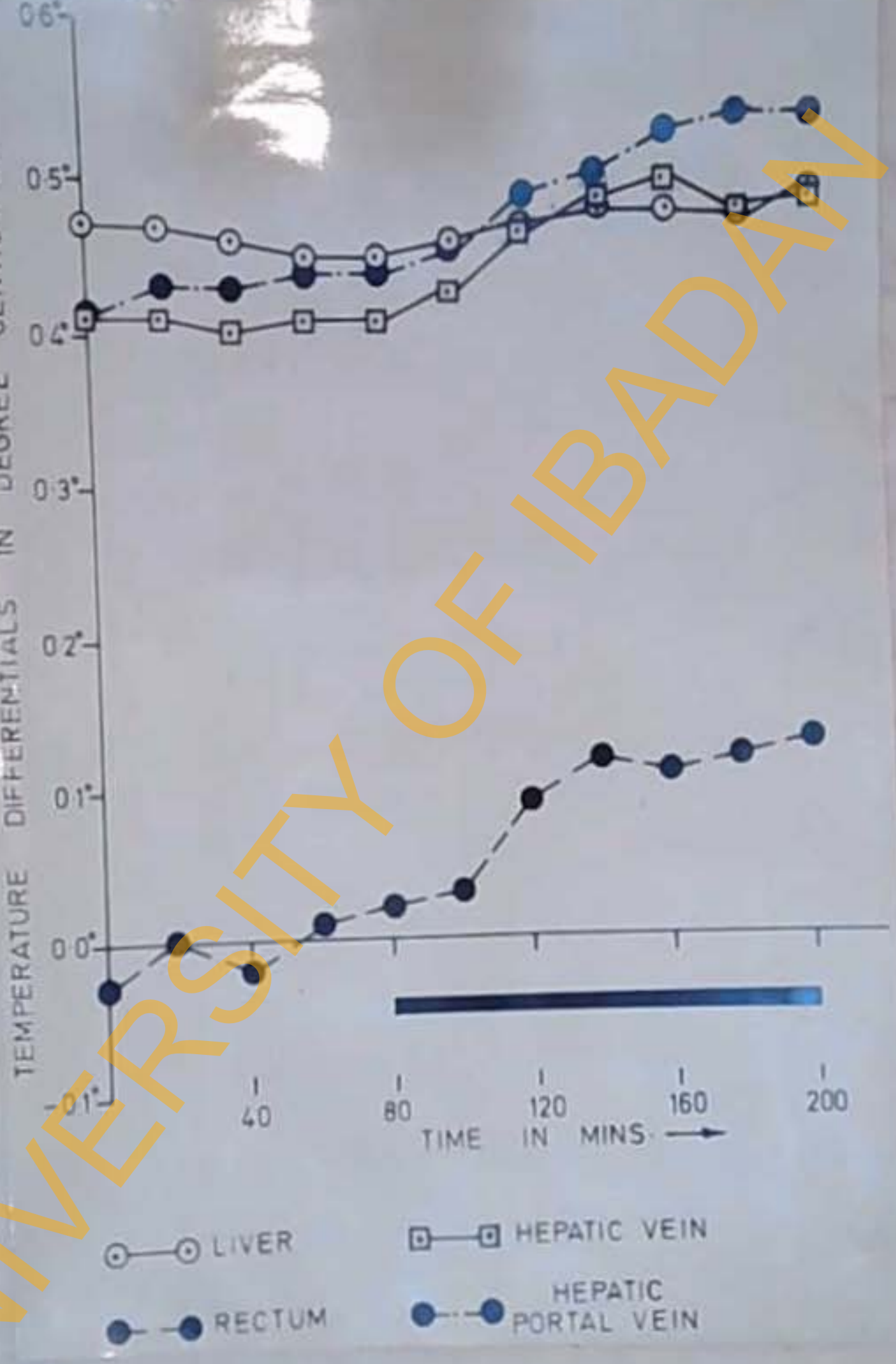

Fig 50. The response of the organ-aorta temperature differentials of the liver and its associated vessels to environmental cooling after bretylium tosylate (10 mg/kg body weight) and atropine sulphate (1 mg/kg body weight). Thick horizontal line indicates the period of cooling.

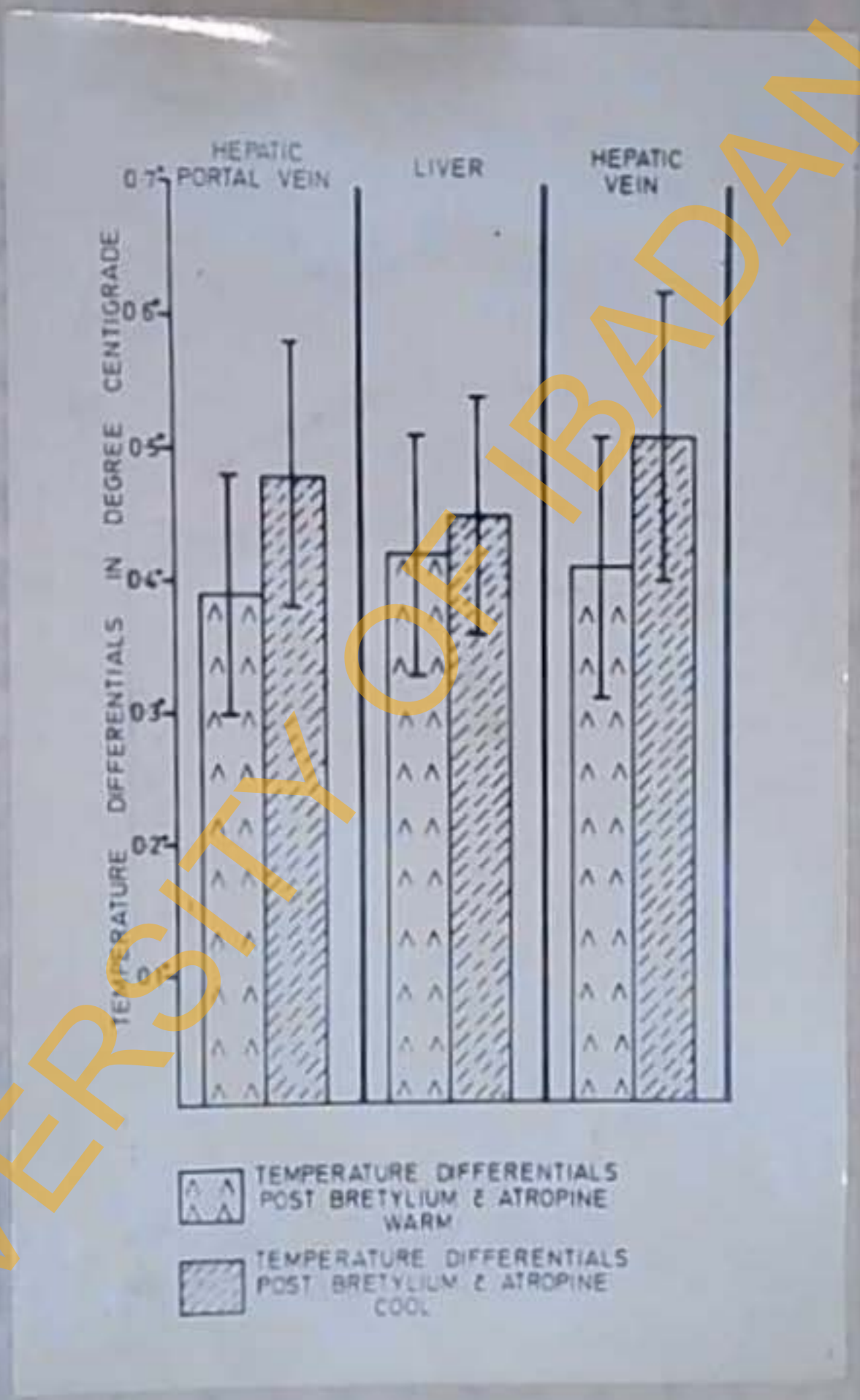

Fig 51. The effect of environmental cooling on the organ-aorta temperature differentials of the liver and its associated vessels after bretylium tosylate (10 mg/kg body weight) and atropine sulphate (1 mg/kg body weight).

TABLE 25A

The effect of environmental cooling on the absolute temperature measured in the liver and its associated vessels after the administration of both Bretylium tosylate (10mg/kg body weight) atropine sulphate (1mg/kg body weight) intravenously.
"Warm" environment - dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%
"Cool" environment - dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.0%

EXPT.	AORTA		HEP. PORTAL VEIN		LIVER		HEPATIC VEIN	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	33.81	32.93	34.10	33.27	34.13	33.30	34.16	33.33
2	35.07	34.35	35.33	34.67	35.57	34.78	35.33	34.81
3	35.44	34.34	35.83	34.88	35.82	34.70	35.79	34.79
4	37.03	36.81	37.41	37.30	37.49	37.35	37.51	37.38
5	37.99	38.30	38.41	38.85	38.31	38.72	37.57	38.98
6	37.93	38.00	38.39	38.51	38.37	38.44	38.32	38.46
7	33.62	33.32	34.09	33.93	34.21	33.86	34.19	33.92
8	34.93	34.36	35.47	35.01	35.50	34.96	35.39	34.99
9	38.72	37.20	39.09	37.54	39.06	37.58	39.08	37.52
MEAN	36.03	35.51	36.42	35.99	36.45	35.96	36.44	36.02

TABLE 25B.

The effect of **environmental** cooling on the organ-aorta "temperature differentials" measured in the liver and its associated vessels after the administration of both Bretylium tosylate (10mg/kg body weight) and atropine sulphate, (1mg/kg body weight) intravenously.

"Warm" **environment** - dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

"Cool" **environment** - dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.6%

EXPT.	HEP. PORT. VEIN-AORTA		LIVER-AORTA		HEP. VEIN - AORTA	
NOS	WARM	COOL	WARM	COOL	WARM	COOL
1	0.29	0.34	0.32	0.37	0.35	0.40
2	0.26	0.34	0.50	0.45	0.26	0.48
3	0.39	0.54	0.38	0.36	0.36	0.45
4	0.38	0.49	0.46	0.54	0.48	0.57
5	0.42	0.55	0.32	0.42	0.58	0.68
6	0.46	0.53	0.40	0.44	0.39	0.46
7	0.47	0.61	0.59	0.66	0.57	0.60
8	0.56	0.65	0.57	0.60	0.46	0.63
9	0.34	0.34	0.34	0.38	0.26	0.32
MEAN	0.39	0.48	0.42	0.45	0.41	0.51
STANDARD DEVIATION	±0.09	±0.11	±0.10	±0.10	±0.11	±0.11

TABLE 26

Summary of changes in the mean values of the organ-aorta temperature differentials measured in the liver and its associated vessels in response to environmental cooling in the control experiments as well as after administration of both Bretylium tosylate (10mg/kg body weight) and atropine sulphate (1mg/kg body weight).

	HEPATIC PORTAL VEIN.	LIVER	HEPATIC VEIN.
CONTROL	+ 0.10	+ 0.10	+ 0.14
POST COMBINED BRETYLIUM AND ATROPINE	+ 0.09	+ 0.03	+ 0.10

ROLE OF BACTERIAL MECHANISMS IN THE DETERMINATION OF GASTRO INTESTINAL TEMPERATURE.

The existence of bacterial flora in the gastro intestinal tract has been well established. Their activities have been invoked to explain the high rectal heat on several occassions. (Barott 1951). Rubin, Horvath and Mellette 1951, measured temperature in the rectum of patients treated in such a way as to reduce the bacteria in their bowel and found no difference between the rectal temperature of these patients and normal ones.

In this section it was intended to reduce the bacterial flora in the gastro intestinal tract to see what effect this had on the pattern of temperature distribution in these animals as opposed to that of the control and also to study the effect of gut sterilization on the response to environmental cooling.

Animals used in this group of experiments were housed for three days and fed on a regular diet of mixed carbohydrates and low proteins. They were given 86 mg/kg body weight Neomycin sulphate per day. This was administered orally twice in the day. This does corresponds with the suggested dose for human gut sterilization which is 4gm-8gm/day given orally (Weinstein 1965).

The drug was administered for three days and the animals were used on the fourth day.

Result.

The Gastro intestinal tract

Fig 52 shows the response of the gastro intestinal tract to environ-

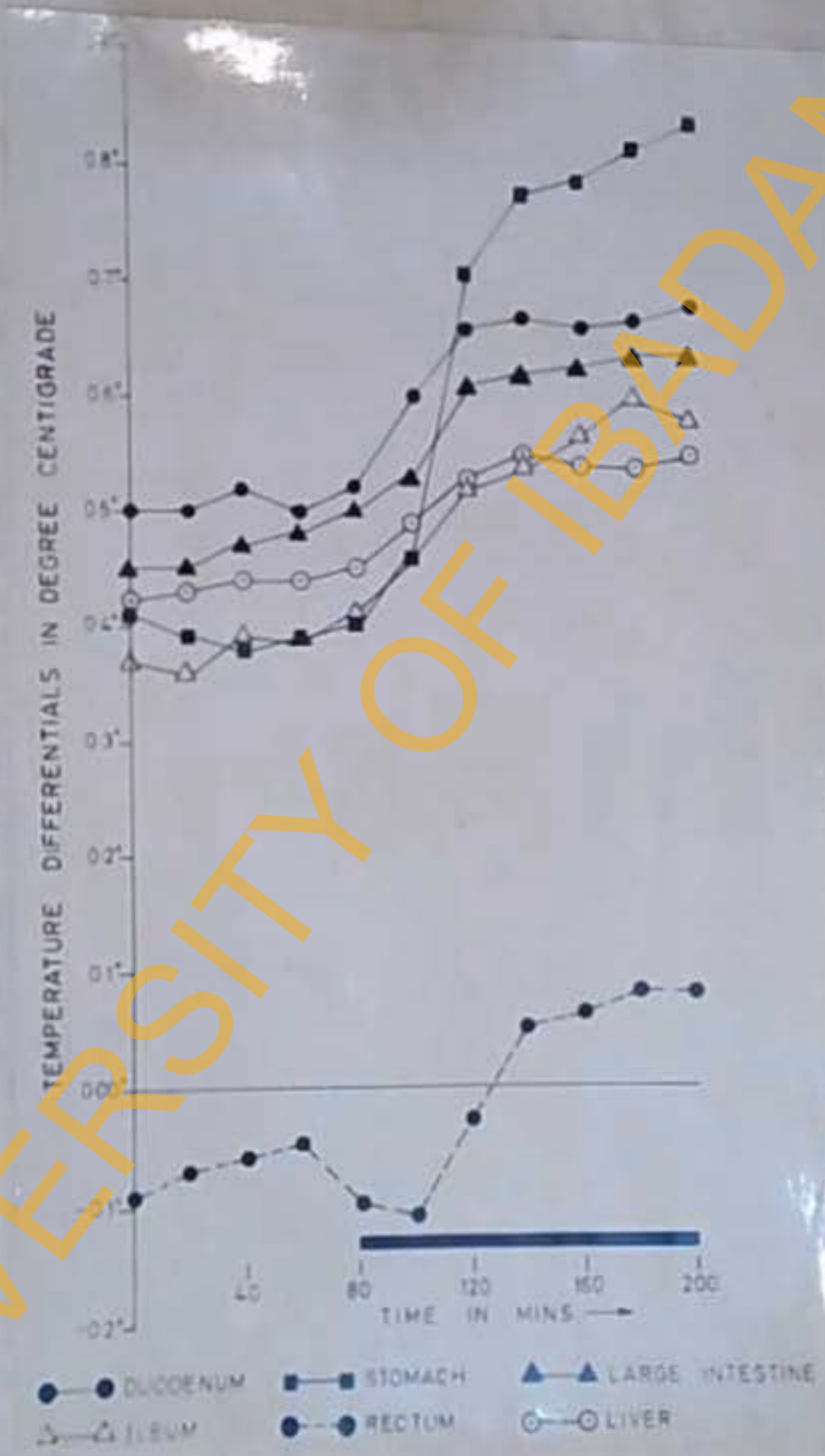

Fig 52. The response of the organ-aorta temperature differentials of various regions of the gastro intestinal tract to environmental cooling-after gut sterilization with neomycin sulphate (86 mg/kg body weight/day). Thick horizontal line indicates the period of cooling.

Fig 53. The effect of environmental cooling on the organ-aorta temperature differentials of various regions of the gastro intestinal tract after gut sterilization with neocycin sulphate (86 mg/kg body weight/day).

TABLE 27A.

The effect of environmental cooling on the absolute temperature distribution along the gastro intestinal tract after gut sterilisation with neomycin sulphate 86mg/kg body weight/day - administered orally for a period of 3 days.

"Warm" environment = dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

"Cool" environment - dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT.	AORTA		STOMACH		DUODENUM		ILEUM		LARGE INTESTINE		RECTUM	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	36.40	37.10	36.67	37.57	36.89	37.56	36.80	37.55	36.91	37.84	36.27	36.93
2	37.11	36.88	37.53	37.76	37.74	37.62	37.62	37.40	37.64	37.45	36.87	36.69
3	31.87	32.06	32.29	32.93	32.38	32.61	31.38	32.63	32.29	32.65	31.68	32.12
4	35.01	34.12	35.36	35.03	35.53	34.93	35.39	34.96	35.40	34.65	34.90	34.20
5	35.70	35.97	36.13	36.85	36.16	36.62	36.12	36.72	36.11	36.68	35.87	36.32
6	35.12	34.89	35.40	35.37	35.65	35.52	35.50	35.52	35.53	35.42	35.28	35.01
7	35.13	35.04	35.45	35.59	35.63	35.67	35.49	35.61	35.50	35.59	35.17	35.05
8	37.51	36.43	37.80	36.90	37.98	36.93	37.90	36.99	37.85	37.02	37.30	36.52
9	34.67	35.01	34.91	35.51	35.09	35.50	35.10	35.49	35.17	35.71	34.57	34.87
10	35.34	35.84	35.70	36.49	35.84	36.57	35.72	36.42	35.75	36.44	35.36	35.93

TABLE 27B.

The effect of environmental cooling on the organ-aorta "temperature differential" distribution along the gastro intestinal tract - after gut sterilization with neomycin sulphate 86mg/kg body weight/day - administered orally for a period of 3 days.
"Warm" environment - dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%
"Cool" environment - dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT.	STOMACH - AORTA		DUODENUM - AORTA		ILEUM - AORTA		LARGE INTESTINE AORTA		RECTUM - AORTA	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	0.27	0.47	0.49	0.46	0.40	0.45	0.51	0.74	-0.13	-0.17
2	0.42	0.88	0.63	0.74	0.51	0.52	0.53	0.57	-0.24	-0.19
3	0.42	0.87	0.51	0.55	0.51	0.57	0.42	0.59	-0.19	+0.06
4	0.34	0.91	0.52	0.81	0.38	0.84	0.39	0.53	-0.11	+0.08
5	0.43	0.88	0.46	0.65	0.42	0.75	0.41	0.71	0.17	0.35
6	0.28	0.48	0.53	0.63	0.38	0.63	0.41	0.53	0.16	0.12
7	0.32	0.55	0.50	0.63	0.36	0.57	0.37	0.55	0.04	0.01
8	0.29	0.47	0.47	0.50	0.39	0.56	0.34	0.59	-0.21	0.09
9	0.24	0.50	0.42	0.49	0.43	0.48	0.50	0.70	-0.10	-0.14
10	0.36	0.65	0.50	0.73	0.38	0.58	0.41	0.60	0.02	0.09
MEAN	0.34	0.67	0.50	0.62	0.42	0.60	0.43	0.61	-0.06	0.03
STANDARD DEVIATION	±0.07	±0.19	±0.04	±0.11	±0.05	±0.11	±0.06	±0.07	±0.14	±0.15

TABLE 28.

Summary of changes in the mean values of the organ - aorta "temperature differential" distribution along the gastro intestinal tract - in response to environmental cooling after gut sterilization with 86mg/kg body weight/day Neomycin sulphate given orally for 3 days.

	STOMACH	DUODENUM	ILEUM	LARGE INTESTINE	RECTUM
CONTROL	+ 0.18	+ 0.09	+ 0.16	+ 0.19	+ 0.15
POST GUT STERILIZATION	+ 0.29	+ 0.11	+ 0.18	+ 0.18	+ 0.09

mental cooling after gut sterilization. Fig 53 gives values of the organ-aorta temperature differentials along the gastro intestinal tract one hour before cooling and during the second hour of cooling. Tables 27 (a) and (b) give values of absolute temperatures and organ-aorta temperature differentials respectively of the gastro intestinal tract during the same period.

From fig 52 it can be seen that the most reactive portion of the gastro intestinal tract was the stomach. It responded instantly and steeply on cooling. The difference between the pre-cooling and the post-cooling values was 0.29°C. The duodenum too responded by increasing its temperature with respect to the aorta, by about 0.11°C, which is significant. The ileum and the large intestine too showed similar rises in organ-aorta temperature differentials. This time the rise was 0.10°C in both cases. The rectum too showed a rise in its temperature differential with respect to the aorta.

Table 28 showed that the response of the stomach to cooling appeared to have been enhanced. Those of the duodenum and ileum too appear to be enhanced but this was less so than in the stomach. The rectal response was significantly reduced while that of the large intestine was reduced only slightly.

Hepatic Portal Vein

Fig 54 shows the response of the liver and associated vessels to environmental cooling after gut sterilization. Fig 55 gives values

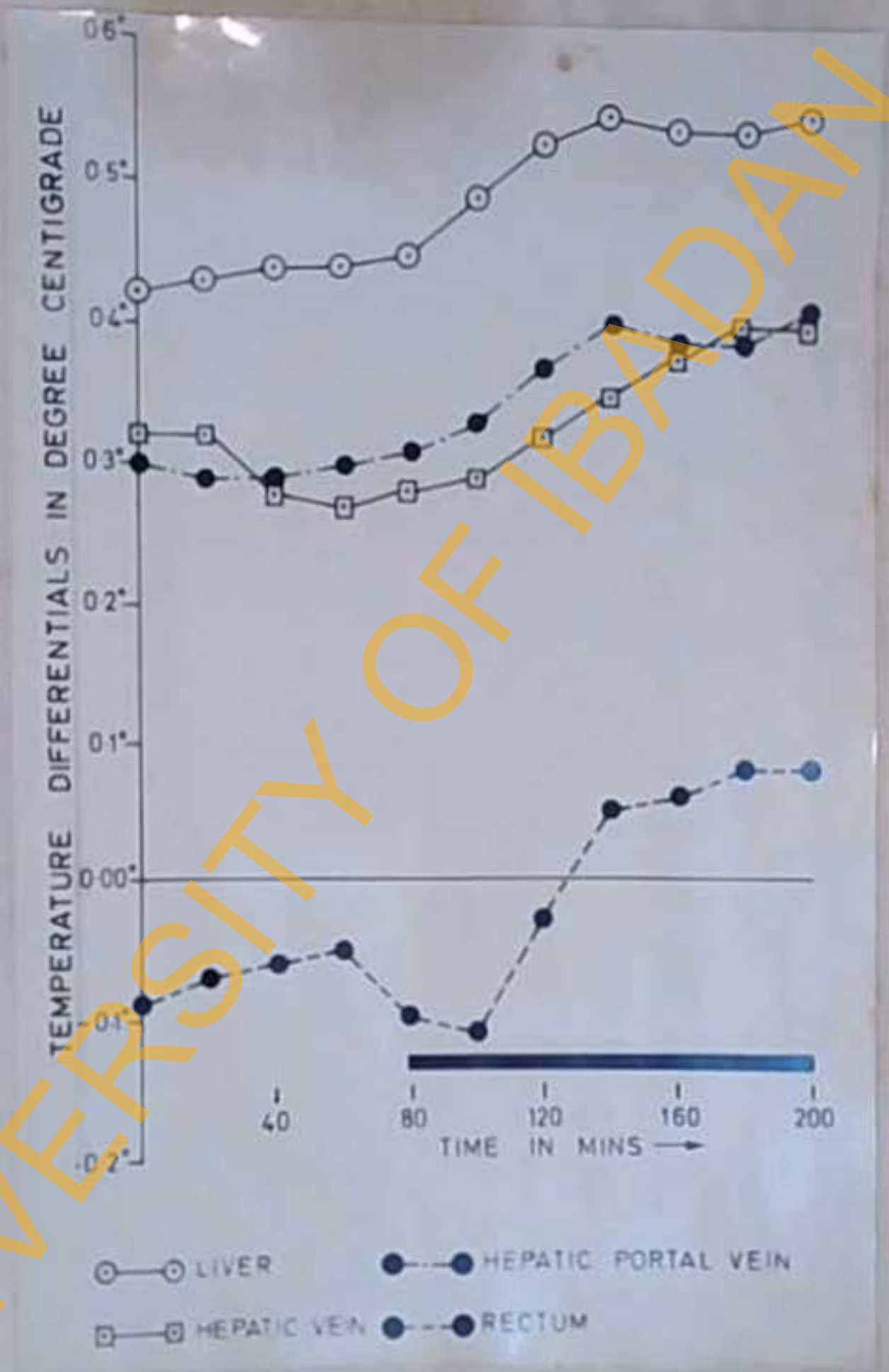

Fig 54. The response of the organ-aorta temperature differentials of the liver and its associated vessels to environmental cooling after gut sterilisation with neomycin sulphate (36 mg/kg body weight/day). Thick horizontal line indicates the period of cooling.

Fig 55. The effect of environmental cooling on the organ-aorta temperature differentials of the liver and its associated vessels after gutsterilisation with neomycin sulphate (86 mg/kg body weight/day).

TABLE 29A.

The effect of environmental cooling on the absolute temperatures measured in the liver and its associated vessels, after gut sterilization with Neomycin sulphate. (66mg/kg body weight/ day.) given orally for 3 days.

"Warm" environment - dry bulb temperature = 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

"Cool" environment - dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT.	AORTA		HEP. PORTAL VEIN		LIVER		HEPATIC VEIN	
NOS.	WARM	COOL	WARM	COOL	WARM	COOL	WARM	COOL
1	36.40	37.10	36.61	37.43	36.87	37.67	37.66	37.44
2	37.11	36.88	37.36	37.17	37.63	37.54	37.37	37.23
3	31.87	32.06	37.14	32.42	32.19	32.53	32.07	32.41
4	35.12	34.89	35.45	35.31	35.55	35.45	35.45	35.41
5	35.01	34.12	35.38	34.62	35.45	34.65	35.43	34.65
6	35.70	35.97	36.00	36.47	36.18	36.47	36.00	36.46
7	35.13	35.04	35.39	35.36	35.51	35.53	35.45	35.49
8	37.51	36.43	37.74	36.77	37.90	36.99	37.86	36.92
9	34.67	35.01	34.89	35.52	35.15	35.56	34.99	35.42
10	35.34	35.84	35.55	36.18	35.77	36.36	35.60	36.30
MEAN	35.34	35.33	35.66	35.70	35.82	35.87	35.69	35.77

TABLE 29B.

The effect of environmental cooling on the organ-aorta "temperature differentials" measured in the liver and its associated vessels - after gut sterilisation with Neomycin sulphate (86mg/kg body weight/day) - given orally for 3 days.

"Warm" environment - dry bulb temperature 29.2 ± 1.6°C relative humidity = 72.8 ± 2.0%

"Cool" environment - dry bulb temperature = 21.8 ± 1.5°C relative humidity = 61.5 ± 1.8%

EXPT. NOS.	HEP. PORT VEIN-AORTA		LIVER-AORTA		HEP. VEIN AORTA	
	WARM	COOL	WARM	COOL	WARM	COOL
1	0.21	0.33	0.47	0.57	0.26	0.34
2	0.25	0.29	0.52	0.66	0.26	0.35
3	0.27	0.36	0.32	0.47	0.20	0.35
4	0.33	0.42	0.43	0.56	0.33	0.52
5	0.37	0.50	0.44	0.53	0.42	0.53
6	0.30	0.50	0.48	0.50	0.30	0.49
7	0.26	0.32	0.38	0.49	0.32	0.45
8	0.23	0.34	0.39	0.56	0.35	0.49
9	0.22	0.31	0.48	0.55	0.32	0.41
10	0.21	0.34	0.43	0.51	0.26	0.46
MEAN	0.27	0.37	0.43	0.54	0.30	0.44
STANDARD DEVIATION	±0.05	±0.07	±0.06	±0.05	±0.06	±0.07

TABLE 30

Summary of changes in the mean values of the organ - aorta "temperature differentials" measured in the liver and its associated vessels in response to environmental cooling - after gut sterilization with Neomycin sulphate (86mg/kg body weight/day) given orally for 3 days.

	HEPATIC PORTAL VEIN.	LIVER	HEPATIC VEIN.
CONTROL	+ 0.10	+ 0.10	+ 0.14
POST GUT STERILIZATION	+ 0.10	+ 0.11	+ 0.14

of the organ-aorta temperature differentials in the liver and hepatic vessels during the hour preceeding and during the second hour of cooling. Tables 29(a) and (b) give values of absolute temperature and values of the organ-aorta temperature differentials in the liver and associated vessels during the same periods. Table 30 gives the summary of temperature changes in the liver and hepatic vessels in response to cooling after gut sterilization as compared to the changes in the control experiments.

The hepatic portal vein-aorta temperature differentials increased significantly on cooling the environment. The rise in the temperature differential amounted to $0.10^{\circ}C$. From table 30 it can be seen that there was no alteration in the response of the hepatic portal vein due to gut sterilization.

Liver and Hepatic Vein.

The liver increased its temperature differential in respect to the aorta by $0.11^{\circ}C$ in response to environmental cooling. Table 30 demonstrates the fact that gut sterilization had no effect on the response of the liver to environmental cooling. The hepatic vein too responded by increasing its temperature differential by $0.14^{\circ}C$ which was not in anyway different from the control response. This therefore shows that gut sterilization had no effect on the response of the hepatic vein to environmental cooling.

GENERAL DISCUSSION

TEMPERATURE DISTRIBUTION WITHIN THE CORE AREA OF THE DOG

On the basis of the fact that the term "body temperature" neither defines average body temperature nor gives the temperature of "the critical" organ in the body - other than the site from which it has been measured, Bazzett (1949) considered the term a misnomer.

The concept of "core" and "shell", which appears to be more acceptable to physiologists, is fast being exposed as being over-simplified (Bregelman & Brown 1965). For one thing, this concept seeks to portray the body as being composed on "an internal mass of tissues maintained at 37°C, surrounded by a thin layer with a steep temperature gradient, such that the surface temperature is 33°C" (Bazzett 1949). While this approach is common, it is inaccurate and may therefore be considered crude (Bazzett 1949; Burton & Edholm 1955; Leithead & Lind 1964). It's inaccuracy lies in the fact that even within the 'core area' there is no constancy of temperatures. Evidence abounds to show definite thermal gradients within the deep tissues of most animals. This has been known as far back as the beginning of the 19th century when Davy (1839) demonstrated the differences between the temperatures of the liver, left ventricle and rectum.

Although the existence of thermal gradients is well documented, it has not been shown in any systematic way by the various workers

in this field. The present work therefore seeks to give a comprehensive systematic study of the temperature distribution within the 'core area' of pentobarbitone anaesthetized dogs.

The relationship between the aorta and temperatures in the gastro - intestinal tract

Table 1, shows that, with the exception of the rectum, most regions of the gastro-intestinal tract, the liver, hepatic vein and the portal vein, were more than 0.3°C in excess of the aorta.

The duodenum was found, not only to be the hottest region of the gastro intestinal tract, but also the hottest structure in the 'core area'. This accords well with the report of H. Ito (1899) who observed that duodenal temperature was higher than both liver and rectal temperatures in the rabbit. The duodenum-aorta temperature differential of 0.57°C found in the present work, agrees with the report of Revutaki (1955), who noted that the upper portion of the intestine, presumably the duodenum, was about 0.5°C hotter than oesophageal temperatures; which has since been shown to be similar to aortic blood temperature (Cooper and Kenyon 1957; Stupfel and Severinghaus 1956). This figure does not agree with the observation of Nedzel (1954), who found that duodenal temperatures in anaesthetized dogs were about 0.5°C cooler than aortic blood temperatures. However, it is difficult to evaluate this work as it is not clear from the report, whether the abdomen of the animal was exposed or closed.

Batinkov (1939) also reported duodenal temperature to be 0.05°C - 0.4°C lower than oesophageal.

The ileum was found to be about 0.49°C hotter than the aortic blood. This is about twice the value of the temperature differential reported by Grayson et al (1966) for the jejunum in pentobarbitone anaesthetized monkey. The jejunum-aorta temperature differential was given by these workers as 0.20°C.

The large intestine was found to be about 0.44°C hotter than the aortic blood.

Gastric temperature recorded from the hottest region of the empty stomach was found to be an average of 0.41°C hotter than the aortic blood. Accepting that oesophageal and aortic blood temperatures are similar, this figure conflicts with the findings of Batinkov (1939) who found gastric temperature similar to oesophageal temperature (except in conditions of gastritis). Nedzel (1934) also observed that the gastric temperature in anaesthetized dog was 0.1°C cooler than abdominal aortic blood; a finding which accords with that of Rewutski (1955), who found gastric temperature to be lower than oesophageal.

A definite thermal gradient was noted in the stomach; cardiac end temperature being about 0.05°- 0.08°C lower than that of the corpus. This confirms earlier observations of thermal gradients in the human stomach between the cardiac and corpus ends as well as between the cardiac and fundic ends (Foged 1933; Masek 1946).

The gradient might be explained in part by the possible presence of air bubbles in the cardiac end as suggested by Masek (1946). Another explanation for this might be found in the possibility of direct heat loss, by conduction across the wall of the stomach, to a slightly cooler liver which lies in contact with this part of it. The contribution of this to the gradient was however not studied in the present work.

Rectal temperature was found to be about 0.02°C cooler than the aorta, in spite of the fact that temperatures were consistently recorded from the hottest region of the rectum. A similar situation to this has been observed in human subjects (Harner and Harris 1920), as well as in anaesthetized monkeys (Grayson et al 1966). The latter authors reported rectal temperature 0.3°C cooler than aortic blood temperature. Working on pentobarbitone anaesthetized dogs Horvath, et al (1950) observed rectal temperature 0.2°C higher than femoral arterial blood temperature; a figure similar to that found by Eichna et al (1949) as the difference between the rectum and the right ventricle of the same animal. The temperature differential found in the same animal by Horvath et al (1949) was 0.44°C.

There are many factors that might account for the intra-species variations noted above. One of the most important factors is the variation in the depth of insertion of the rectal "thermometer". Most authors give values of rectal temperature without giving the depth of insertion (Lomax 1966). This makes comparison between

these figures difficult, in view of the well established thermal gradient in the rectum. Benedict and Slack (1911) observed that human rectal temperatures increased from the anal orifice up to a depth of about 2½ inches, and thereafter fell. Mead and Bonmarito (1949), using five thermocouples arranged in such a way as to measure temperatures at various levels within the rectum, were able to show that the highest rectal temperatures in human subjects was at a depth of between 3 and 4 inches.

Similar thermal gradients were found in the dogs used in these experiments. Temperatures increased from the anal orifice up to a depth of 2½ to 3 inches. Whenever the probe was moved further up, the temperature fell sharply. This might be accounted for by the cooling effect of blood in the rectal venous plexus which, though poorly developed in the dog (Miller et al 1964) could influence the rectal temperature. This has already been suggested by Mead and Bonmarito (1949) as being one of the reasons why the 8 in. thermocouple, which curved backwards and lay in close proximity to the posterior wall of the rectum, gave the lowest value. They attributed this to the cooling effect of blood returning from the hind limbs, external genitalia and the skin of the buttocks which flows in this network of hypogastric veins.

The differences noted between readings observed in animals and human subjects, might probably be due in part to the presence of a tail circulation, as well as the possibility of lower metabolic

activities in the animal rectal mucosa as opposed to that of man.

The values obtained in the present work differ from those of Horvath, Rubin and Foltz (1950), as well as Eichna et al (1949). This perhaps is due in part, to the fact that arterial temperatures were measured from sites different from the one chosen by the author. They measured from unspecified points in the femoral artery. Temperature in the femoral artery is known to be considerably influenced by blood flowing in the femoral vein (Bazzett et al 1948; Horvath et al 1950). Bazzett suggested that, by a process of counter current heat exchange between the arteries and the adjacent veins - blood in most arteries is cooled progressively as it flows towards the periphery. The result of this sort of cooling, is perhaps the thermal gradient which is known to exist in the femoral artery. Horvath et al (1950) observed a well defined thermal gradient of about 0.4°F within 5 cms inside the femoral artery. It might be expected therefore, that blood in the abdominal aorta, at a point near the origin of the coeliac artery is warmer than blood in the femoral artery. This might contribute to the differences in values of the rectum - aorta temperature differential obtained in the present work and those obtained by Horvath et al (1949); Eichna et al (1949).

The thermal gradient along the gastro-intestinal tract.

The existence of a thermal gradient along the length of the gastro intestinal tract has been known for some time. Revutaki (1955) noted

a gradient between the oesophagus and the upper portion of the intestine.

The present work confirms the existence of such thermal gradient; temperatures increasing from the mouth and anal orifice until a peak is reached in the duodenum. The magnitude of the gradient is not stable in so far as it changes with environmental temperature. This can be seen in the control experiment on environmental cooling, in the present work. Duodenal temperature in the present work, was found to be 0.08°C hotter than the ileal, 0.13°C hotter than the large intestinal, 0.16°C hotter than the gastric and 0.59°C hotter than rectal temperatures. This gastric - duodenal relationship conflicts with earlier findings of Hepburn et al (1932); Nedzel (1934) and Batinkov (1939). These authors found gastric temperature hotter than the duodenal temperature with a differential ranging from 0.05°to 0.5°C. Batinkov even pointed out that duodenal temperatures were only higher during such conditions as duodenitis.

Although rectal temperatures have been commonly found higher than the gastric temperature, in human subjects (Foged 1933; Masek 1946; Hochrein and Schleicher 1948; Graf 1959), the situation in animals appears to be quite different.

THE TEMPERATURE OF THE LIVER AND ITS ASSOCIATED VESSELS

The relation of liver temperature to aortic temperature

The liver temperature was found to be 0.39°C hotter than the aortic blood. This agrees directionally with the findings of Davy (1839);

Cavazine, Hirch, Mueller and Rolly (1894); Nedzel (1933); & Grayson et al (1966). The exact values obtained by these authors were however conflicting. Davy found a 0.5°C differential between the liver and left ventricular blood temperatures of the lamb. Nedzel found the liver-aorta differential in the dog to be 0.2°C while Grayson's group recorded a 0.1°C differential in the monkey.

A well defined species variation is quite clearly demonstrated in the above group of figures.

This species variation has been explained on the basis of the differences in the metabolic rates of the liver in various animals. Kleiber (1941) and Waymount, Field Kleiber (1942) claim that the liver metabolism bears an inverse relationship to the body size of animals. They suggest that the liver oxygen consumption amounts to $5.28^{W^{0.228}}$.

The portal and hepatic venous temperatures

The portal vein-aorta temperature differential recorded in the present work is 0.32°C. This figure which reflects the heat production of the entire gastro-intestinal tract, is a little lower than the calculated average temperature of the gut. This perhaps can be explained on two grounds. The first is the composition of the blood in the hepatic portal vein. Blood here being a mixture coming from both the inferior and superior mesenteric veins, as well as the splenic vein. Since the blood in the splenic vein is cooler than blood from the superior or inferior mesenteric vein - it might cons-

titute a cooling factor. This may explain why the value of portal venous aorta temperature differential in table 3(b) is lower than the one under consideration (splenic vein in the control experiment being left intact). Another likely reason is the possible heat loss by counter current mechanism from the portal vein to the hepatic artery which lies in close contact with it. This counter current heat exchange mechanism has already been demonstrated for the descending aorta and the inferior vena cava as well as for the femoral vein and femoral artery (Bazzett et al 1948).

The 0·32°C obtained in the present work is higher than values obtained by Federov & Shur (1942) and Grayson & Mendel (1956). Their values were 0.23°C in the dog and 0.2°C in the rat respectively. The animals in both cases were, however, unanaesthetized. The hepatic vein was found to be, on the average, 0.34°C hotter than the aorta. The values showed some oscillatory variations of about 0.15°C. The oscillation corresponded quite closely to the respiratory cycle; values rising at expiration and falling at inspiration. There are about three main factors which could readily explain the variations. The first is the possible oscillatory alteration in the relative depth of the applicator inside the hepatic vein. A thermal gradient of about the same magnitude as the variations observed, has been reported found in the hepatic vein (Kiehna et al 1951). If therefore, during inspiration the applicator was moved outwards but

further inwards during expiration, there could be the observed variations in the values recorded. A second factor is a possible admixture of a cooler inferior vena caval blood with blood at the entry of the hepatic vein. If the admixture increases during inspiration and reduces during expiration, this could also account for the observed variations. The third factor might be a possible phasic pattern of outflow of the hepatic venous blood into the inferior vena cava. This might tend to reduce during expiration, thus allowing for a greater warming up of blood in the hepatic vein. If during inspiration the outflow increases, as it might, then there is the possibility of the lower value. Of these three factors, the first and the third appear to be more responsible for the variation. The second if it happens must be playing a very minor role.

The hepatic vein in the present work is about 0.02°C hotter than the portal vein. This figure is just less than the 0.05 - 1.0°C observed by Federov and Shur (1942) in anaesthetized dog. It is substantially lower than the figures of Bernard (1856) and Kozaka (1930) who got values ranging from 0.25 to 0.5°C in anaesthetized rabbits and dogs. Claude Bernard noted that the differential rose with digestion to values between 0.6 and 1.6°C.

The above values conflict directionally with the observations of Miller, Schastnaya and Jukevich (1940) as well as some individual experiments reported by Federov and Shur (1942) in which the portal vein was hotter than the hepatic vein. The value of the hepatic

vein as recorded in this experiments cannot be taken as being completely valid in view of the possibility of the applicator being pushed out of the hepatic vein into the inferior vena cava.

The relation of liver temperature to gastro intestinal tract temperatures.

Contrary to the findings of Chimvies and Fishbas, Grayson & Mendel (1956) and Lomax (1966), the liver did not give the highest intra abdominal temperature. It was found to be 0.18°C cooler than the duodenum, 0.10°C cooler than ileum, 0.05°C cooler than the large intestine and 0.02°C cooler than the stomach. It was however 0.41°C hotter than the rectum.

In an attempt to explain the higher temperature recorded in the rectum of human subjects as opposed to its liver, Graf (1959) suggested the insulating role played by the low rectal mucosal blood flow. Results from the present work show that this is not likely to be the only reason for this relationship. The duodenum has been shown to have a higher blood flow than the other regions of the gastro intestinal tract. (Burton - Opitz (1910); Steiner and Mueller (1911); and Gober (1960). There is therefore every possibility that the duodenal mucosa may be more richly supplied with blood than the rectal mucosa. If Graf's explanation were correct, the relationship should be such that the differential between the duodenum and the liver should less than that between the rectum and the liver. Since this is not so, it only means that there may be more to the higher values of temperatures recorded the gastro intestinal lumen than heat

insulation due to low mucosal blood flow. It therefore suggests a possibility of very high heat production in the gastro intestinal tract.

The Gastro-Intestinal Tract As A Potential Heat Producer

Following up a previous observation by Claude Bernard (1856 - 1876), Federov and Shur (1942) showed evidence that the gastro intestinal tract is a potent heat producer. In 1966 Grayson and his group, basing their calculations on the temperature differential between the bowel of human subjects and the aorta, observed that the gastro-intestinal tract might be responsible for about 40% of the total body heat production at rest. This figure is large when compared to the 7.6% calculated by Lehman 1953.

The author however believes that a better approach to the calculation of gut heat production is to base it on the temperature differential between the portal vein and the aorta. This gives a more general picture of the heat production of the entire gastro-intestinal tract.

The portal vein-aorta temperature differential in the present work is 0.32°C. Average portal venous flow can be taken as 270 ml/min, a figure calculated from values given by Burton - Opitz (1911); Grab et al (1929); Blalock and Mason (1936); Grindlay et al (1941) and Green et al (1959).

The heat production from the above figures gives 864 cals/min which is 5.184 Cals/hr. This is the value for the dogs used in these

experiments whose average weight was 10kgs. Comparing the above values with the 1.60 Cals/kg/hr found for tropical dogs of a weight range between 7 and 14 kgms, by Galvao (1947), it is found that the gastro-intestinal tract accounts for about 32.4% of the total basal heat production in the dog. This value is lower than one based on the value of the temperature differential of any one region of the gastro-intestinal tract. It however remains far higher than had been previously suspected.

The question now is, what exactly are the mechanisms involved in the heat production? Has this anything to do with muscular or secretory activities? Or has it to do with mucosal metabolic activities or transport mechanisms? What are the parts played by cholinergic and adrenergic influences in the determination of the heat production and temperature levels in the gastro-intestinal tract?

Factors maintaining canine core temperature distribution in the warm environment

The temperature of a given organ depends upon the heat producing activities of its tissues, as well as upon the temperature, volume and flow rate of the blood supplying this organ. At any one time therefore, the temperature measured in the tissues of an organ reflects a state of thermal equilibrium between the heat produced within, and the heat conducted away from the tissues of this organ.

If the blood flow to any actively metabolising organ is reduced, it is to be expected that the temperature would rise, while if it is

increased a fall in the temperature ensues. Increasing the heat production of an organ in the face of either no alteration or a slight change in the blood flow, raises the temperature of this organ.

The gastro-intestinal tract and the liver have already been shown to have higher temperatures than the aortic blood. The role of vasoconstrictor tone in the determination of temperature levels found in these structures will be discussed presently.

Effects of blood flow changes on the temperature of the 'core area.'

Up till now, there is no general agreement on the interpretations of the effects of blood flow changes on the temperature of internal organs. Masuda et al (1953) attributed the rise in gastric temperature observed on cooling the body surface of human subjects, to gastric hyperaemia. This hyperaemia on the other hand has been suggested by other authors to explain the falls in gastric temperature. Henning, Demling and Kinzlmeier (1951) for example, attributed the fall in gastric temperature, observed on injecting histamine into human subjects to gastric hyperaemia.

What must have been responsible for these conflicting interpretations given to observations is perhaps the failure of some authors to measure aortic or arterial blood temperature. Thus it has not been possible for these authors to realise fully that most of the time, the aortic or arterial blood constitutes a cooling influence to most, but by no means all, the internal organs. An increase in blood flow to organs with a higher temperature than the aortic blood,

can only mean a greater removal of heat from these organs, and hence a fall in the temperature. The converse holds for vasoconstriction.

In the present work, the effect of blood flow changes on the temperature levels and distribution in the core area, was demonstrated in two ways. First the animals were bled sufficiently enough, to obtain a 10-20 mm Hg drop in blood pressure. Secondly, tonic sympathetic discharges to peripheral vessels, including those of the splanchnic area was blocked by pharmacological sympathectomy using bretylium tosylate.

The response to haemorrhage

Haemorrhage in the present work was shown to cause a slight but distinct rise in the temperature of the stomach, duodenum, ileum, and large intestine but a fall in the temperature of the rectum, relative to the aorta (see fig 12). There was however no significant response in the temperature differentials of the liver, portal vein and hepatic vein.

The rise in the gastro-intestinal tract-aorta temperature differentials is due in all probabilities to vasoconstriction.

It has long been established that one of the vascular adjustments to haemorrhage is blood redistribution. This has been shown to involve, amongst others, vasoconstriction to the gastro intestinal tract, leading to a reduction in mesenteric blood flow (Malcolm (1910); Mann (1915); Selkurt, Alexander and Patterson (1947); Selkurt and Brecher (1956); Gregg 1962).

Since the upper regions of the gastro-intestinal tract was found distinctly hotter than aortic blood,a reduction in the blood supply to these structures could only lead to a reduction in the amount of heat conducted away by blood and hence a rise in temperature. The situation in the case of the rectum is different. The rectum has been pointed out to be cooler than aortic blood and its arterial supply may probably warm it up. A reduction in the supply of arterial blood to it therefore could only lead to the observed fall in rectal temperature.

The extent of bleeding in this work was perhaps just enough to produce only mucosal vasoconstriction and insufficient to produce the concomitant reduction in the total bowel blood flow. This is probably the reason why there was a distinct rise in the temperatures of the lumen of the gut without an alteration in the temperature of the portal vein, liver and hepatic vein. The possibility of mucosal vasoconstriction which is not accompanied by a concomitant reduction in total flow was suggested by Grim (1963). The interpretation of this is a possible diversion of blood from the mucosa to the arteriovenous anastomoses. This could be effected either by the dilatation of the arterio-venous anastomoses (Peters & Womack 1938), or by an increase in the capillary resistance to flow (Walder 1952).

That mucosal vasoconstriction could take place early in haemorrhage even before a noticeable alteration in cutaneous blood flow was demonstrated by Landis and Scarborough. Scarborough (1952)

reported that on graded haemorrhage, a distinct colonic mucosal vasoconstriction was noted before any change in skin blood flow (monitored by thermocouples on the paws) occured. A more severe haemorrhage would perhaps be needed to bring about a significant rise in the liver and hepatic venous temperatures.

Although the above is nothing more than a qualitative picture, it still emphasises the susceptibility of the gastro-intestinal tract to blood flow changes. This confirms the findings of Lomax (1966), that the gastro-intestinal tract is more susceptible to blood flow changes than the other regions of the "core area".

Response of the core temperatures to sympathetic blockade in the warm environment.

Graf (1959) suggested the poor rectal mucosal blood flow and consequently the better thermal insulation, as the explanation for the rectum in human subject being hotter than the liver. If this be so, one may then wonder, what role is played by the resting vasoconstrictor tone in the maintenance of the temperatures of the 'core area.'

Bretylium tosylate, which is known to be a highly specific adrenergic blocker (Boura et al 1959; Smirk & Hodge 1959) was chosen for the present work. This drug has been used quite widely to reduce sympathetic tone in hypertensive human subjects (Green 1960). On injecting the drug, there was a fall, which never completely recovered, in the blood pressure. The new level of pressure obtained after the drug was lower than the pre-injection value.

There was also a fall in the values of the temperature differentials of the stomach, duodenum, ileum and large intestine. The values of the temperature differentials of the liver, portal and hepatic venous blood, were not significantly affected while the value for the rectum - aorta differential rose. All these reactions were transient, for the values rose towards the pre-injection levels after about an hour.

The observed fall in blood pressure must have been due to a reduction in the resting vasoconstrictor tone in the peripheral vessels. The reduction of tone must have culminated in an increase in blood flow to the gastro-intestinal tract and hence its fall in temperature. To reconcile the fall in gastro-intestinal tract temperature with the lack of effect on the portal venous temperature, I would like to suggest that the effect of the drug was more of mucosal dilatation; blood being shifted from the other tissues to the mucosal vessels without bringing about a marked increase in total bowel blood flow and hence portal flow. This sort of reaction has been known to occur with other blocking agents like ergotoxine. Schnitzlein (1957) observed mucosal engorgement in rats stomach with ergotoxine, although this same drug in Walder's experiments did not alter the perfusion rate of the stomach significantly (Walder 1952).

The recovery observed in temperatures throughout the gut may have been brought about by a complex reaction, involving a relative increase in the activities of the parasympathetic influences as well

as a partial recovery of the vasoconstrictor tone.

The wall of the gut, both vessels and muscular coat and perhaps the mucosal wall, are supplied with sympathetic nerves derived from the splanchnic nerves. The muscular wall as well as the mucosa of portions of the gut, e.g. the stomach and the duodenum (Wright et al 1940), are supplied with parasympathetic nerves derived from the vagal trunk, which itself originates from the dorsal motor nucleus of the vagus (Ranson and Clark 1959). Baylis and Starling (1899) suggested that the parasympathetic and sympathetic nerve supply to the gastro-intestinal tract effect a reciprocal control over the activities of the gut wall. It then means that the precipitation of an imbalance, by inhibiting or blocking the activities of one set of nerves, could per se lead to a preponderance in the activities of the other.

It is known that Bretylium tosylate blocks the sympathetic nerves - by accumulating in the nerve endings (Boura & Green 1959). It may also block by interfering with the glucose or energy metabolism of the nerves, as has been suggested for guanethidine (Zaimis 1965), in addition to the accumulation. By whichever way this is achieved, the blockade of sympathetic activities might precipitate a relative increase in the activity of the cholinergic mechanisms of the gut. This may include motor activities as well as secretion; an increase in the activities of which have been shown to increase gastro-intestinal temperature, even in the face of vasodilatation. Masek (1946)

showed that, in spite of hyperaemia, the injection of histamine caused a rise in gastric temperature because it increased the motility and secretions, since nicotinic acid which caused hyperaemia but no increase in motility and secretion caused no rise in temperature. This then is perhaps one of the factors responsible for the observed recovery of temperatures. Another possible factor is a partial recovery of vasoconstrictor tone in response to circulating adrenaline, produced from the adrenal medulla. Bretylium is known to have no blocking effect on the release of adrenaline from the adrenal medulla nor on the response of vessels to circulating exogenous adrenaline. If anything at all, it enhances the response these vessels to circulating adrenaline (Nickerson 1965).

Either or both of these mechanisms may account for the recovery.

Whilst some fall in the temperature differentials of the gut was obtained with adrenergic blockade, it appears that the role of resting vasoconstrictor tone in the determination of the 'core' temperatures is very slight. In the case of the liver, portal and hepatic venous temperatures for instance, the role is negligible. This may mean that there is not much vasoconstrictor tone in these vessels at rest in the warm environment.

The role of cholinergic influences in the maintenance of canine 'core' temperatures in the warm environment

The work of Masek (1946) has already been cited to show the possibility of increased motor and secretory activities of the gastro

-intestinal wall increasing the intraluminal temperatures. Burn and Dutta (1948) found that the injection of atropine, benadryl, penthidine and quinidine caused a fall in the body temperature of mice. They then concluded that the maintenance of body temperature depends on a mechanism in which acetylcholine plays a part. What role these cholinergic mechanisms play in the determination of the levels of "core temperatures" is not known. The vagus nerve is known to supply efferent parasympathetic fibres, amongst others, to the stomach, duodenum, ileum, the ascending and transverse portions of the large intestine (Schmidt 1932) as well as the liver.

It is well known that there are spontaneous and often rhythmic contractions of smooth muscles in the gastro-intestinal tract at rest. This spontaneous contraction, which may be primarily myogenic in origin, is known to be influenced both by nervous and humoral factors. (Texter 1963). Acetylcholine is known to be continuously produced and released in the wall of the gastro intestinal tract (Feldberg and Lin 1950). The acetylcholine thus released has been claimed to be mainly for motor activities (Le Heux 1918-1919) and Magnus (1920) of either the smooth muscles or of the villi (Beznak 1936). It is also known to provide enough stimulus for the continuous secretion of succous enterious (Wright et al 1940).

The role of these cholinergic mechanisms in the determination of "core temperatures" was studied in two ways. The first was by pharmacological parasympathectomy using atropine sulphate 1mg/kg body weight, while the second was by cervical vagotomy.

Response to intravenous injection of atropine sulphate

It is a well known fact that atropine inhibits gastro intestinal motility (Veach (1937); Adler et al (1940); Youmans et al 1943). This inhibition, brought about by a mechanism of surmountable competitive inhibition of cholinergic receptor sites (Innes and Nickerson 1965), involves both a reduction of tonus as well as propulsive motility of the muscular wall (Gruber et al 1930 and Ingelfinger 1943). Gastric secretions may also be reduced by atropine (Innes and Nickerson 1965).

The first noticeable reaction of atropine sulphate was a fall in blood pressure. The fall lasted about five minutes and a rise to a new level followed. The value of the new pressure was always lower than the pre-injection value.

There was also a marked fall in the temperatures of the stomach, duodenum and ileum but a slight fall in the temperature of the large intestine, relative to the aorta. The rectum-aorta temperature differential was not affected. The fall in the temperature differentials observed in the upper portions of the guts recovered after about an hour. It should be pointed out however, that the duodenum-aorta temperature differential displayed the most prominent fall. While others almost completely recovered, its new value was still significantly lower than the pre-injection value.

The liver-aorta temperature differential fell during the first 80 mins but it recovered almost completely after two hours. While the

portal vein temperature was not affected throughout, the hepatic vein temperature showed wild oscillations.

The fall in the temperature differentials of the gastro intestinal tract, without a marked alteration in the portal venous temperature, could mean a greater removal of heat from the gut wall by a slight increase in blood flow, a greater percentage of which is diverted to the mucosa. The slight increase in the blood flow could be brought about passively by the relaxation of the gut wall(Sidky and Bean 1958), as a result of the removal of the parasympathetic effect, or actively by an increase in the activities of the sympathetic nerves, which are now "released". This greater extraction of heat, accompanying the increased blood flow, might tend to cool the mucosa without necessarily altering the temperature of the portal vein.

It appears however, that atropine sulphate did not alter the total heat production in the gut, since if this had been changed there would have been a concomitant change in the temperature of the portal venous blood.

The recovery observed could be brought about by either one or both of two factors. First, there could be an increase in vasoconstrictor tone to the vessels of the gut wall, most probably the mucosa, due to the release of sympathetic activities, as a result of the removal of cholinergic influences. Secondly, there is the possibility of some atropine resistant motor activity, which might tend to raise the heat production in the gut wall. Such atropine

resistant motor activities have been described and are said to be due to some unidentified humoral factors (Fulgraff and Schmidt 1964).

The slight fall noted in the liver-aorta temperature differential might have been due to an increase in liver blood flow on the injection of atropine sulphate. Grab, Jansen and Rein (1928) observed a similar increase in canine hepatic blood flow after atropine administration. This may mean an increase in hepatic arterial contribution to the flow. Besides this, however, the atropine could cause an inhition of a cholinergic heat generating mechanism which could also account for observed fall.

Response to cervical truncal vagotomy

Cervical vagotomy led to a distinct rise in the temperature differentials between the stomach, duodenum, ileum and the aorta, while that of the large intestine did not rise so distinctly. The rectum-aorta temperature differential on the other hand fell slightly. The liver and portal venous temperatures rose a little, relative to the aorta while the hepatic venous blood temperature rose quite distinctly.

The rise in body temperature after vagotomy was explained by Tschechkow (1902) and Freund (1913) as being brought about by a reduction in evaporative heat loss due to slow breathing. This does not seem to explain the situation in the animals used for the present work since the respiration was controlled by a positive pressure pump delivering at a constant rate of 12 cycles/min.

This rise in temperature could have been the result of a reduction in blood flow to the gastro intestinal tract. Peter et al (1963); Ballinger, Padula and Camishion (1965), observed a similar diminution in the blood flow of the gastric and superior mesenteric arteries, following sectioning of the vagus nerves.

Reduction in flow of this kind affects the mucosal flow and may reduce the heat conducted away, so culminating in the observed rise. The rise in the liver and hepatic venous blood temperature differentials can be explained on the same basis too. This may be due to the reduction of flow in the portal vein. Reduction of blood flow in the rectum has already been shown to reduce its temperature. The effect of vagotomy on the large intestine is not as prominent as the other portions because the large intestine is still supplied by parasympathetic supply derived from the nervi erigentes. There is thus some opposition to the activities of the sympathetics, the net effect of which is thereby reduced.

The above experiment shows that, while the cholinergic influences do play a role in the determination of the levels of the temperatures, as evidenced by the falls in temperatures when their influences were removed, their role in the warm environment is slight. This may be due to low motor activities of the guts in the warm environment; a fact which may not be suprising, since it is known that on exposure of the body to a warm environment, an inhibition of gastro intestinal motility is obtained. (Bisgard and Nye 1940; Cordier and Piery 1950).

The constipation which accompanies fever has been attributed to a reduction in tone and peristaltic movement of the intestine by the rising body temperature (Hamre 1928).

The role of both adrenergic and cholinergic mechanisms in the maintenance of canine core temperatures in the warm environment.

Simultaneous injection of both bretylium tosylate and atropine sulphate, caused a tremendous reduction in the temperatures of the stomach, duodenum, and ileum with respect to the aorta. The large intestine did not show very much change while the rectum displayed a rise in its temperature differentials. The temperature of the portal vein was not altered at all, while those of the liver and hepatic vein showed a slight rise. These latter responses were however not significant.

The fall in the gastro intestinal tract temperatures relative to the aorta, without alteration in the portal venous aortic temperature differential must have been due to greater thermal extraction from the mucosa accompanied by a slight reduction of portal flow, owing to reduced systemic blood pressure. This greater thermal extraction could have been brought about by an increase in mucosal blood flow. This might result from a passive vasodilatation of the mucosal blood vessels following the inhibition of sympathetic vascular tone, as well as muscle tone in the gut wall. The observed increase in the rectal temperature perhaps means a greater arterial blood supply to it, following the above described passive vasodilatation.

Although the foregoing experiments indicate that neither the adrenergic nor the cholinergic mechanisms by themselves play any important role in the determination of the temperature levels found in the gastro intestinal tract in the warm environment, yet the combined role of both of them is more significant. Much more important factors involved however, are the unidentified heat producing mechanisms - going on perhaps in the mucosa, which are not blocked either by bretylium tosylate or by atropine sulphate or even a combination of both drugs.

The identification of these mucosal activities requires further ivestigation.

THE RESPONSE OF "CORE" TEMPERATURES TO ENVIRONMENTAL COOLING

Although there is no general agreement on the effect of moderate body surface cooling on the temperatures of the internal structures in anaesthetized animals or human subjects, it appears that the more common response reported is a slight rise (Federov and Shur (1948); Grayson (1950); Masuda et al 1953). On the other hand, it is more common to find that environmental cooling leads to a fall in the temperatures of the internal organs of anaesthetized animals (Grayson and Mendel 1956; Grayson et al 1966). Other authors have found the reverse reaction though (Marshak 1939; Donhoffer et al 1962). It is believed, however, that what follows exposure to environmental cooling in anaesthetised animals depends on the depth of anaesthesia.

Temperatures in deeply anaesthetised animals tend to fall continously in the cool environment,while temperatures in lightly anaesthetised animals may arise.

The net result is that interpretations based on absolute temperature changes have been very conflicting. It is therefore difficult to give a generalised statement on this from them.

Whilst the absolute temperatures fall, it is quite possible for temperatures differentials between these internal organs and the aortic blood to rise. (Grayson et al 1966).

Interpretations based on temperature differentials have been found more reasonable and more consistent with expectations than those based on absolute temperature changes.

In the present work,environmental cooling from about 29.2°C to about 21.8°C, did not always lead to a fall in the absolute temperatures of the animals,but most of the time to a rise. Fall or rise, however, it was observed that there was always a significant rise in the temperature differentials between all the regions of the gastro-intestinal tract, including the rectum, and the aorta. There were also increases in the temperatures of the portal vein, liver and hepatic vein,relative to the aorta. The increase in the portal venous temperature differential probably indicates an increase in gastro-intestinal heat production. This agrees with the findings of Fedorov and Shur (1942).

There was no material alteration in the pattern of distribution of the temperature along the length of the gastro-intestinal tract

during environmental cooling. The only noticeable change was that the differences between the duodenal temperature and those of the other regions were reduced. In other words thermal gradients between them, unlike the findings of Spealman (1945) and Stupfel and Severinghaus (1956), became less prominent. There was also no alteration in the difference between the temperatures of the duodenum and the liver. The difference between the stomach and the liver temperatures was however reduced. That is, although in the control experiment, the stomach was originally cooler than the liver.it now showed a clear cut warming up. The ileum which was originally 0.01°C cooler than the liver finished up 0.05°C hotter than it, while the difference between the liver and large intestinal temperatures closed up on body chilling. The rectum too showed some distinct warming on environmental cooling. These findings accords well with those of Grayson et al (1966) who noted an increase in the jejunum-liver relationship on cooling. Findings in this experiment do not however agree with the findings of Libelli & Poggi (1946) and Haterius & Maison (1948) who observed an increased gradient between the liver and rectum in dogs cooled by immersion.

The rise in the gastric temperature differential on cooling was one of the most prominent. This type of gastric reactivity was reported by Spealman (1945) who showed that gastric temperature, which was initially cooler than rectal temperature, rose 0.8°C above it on cold immersion.

THE MECHANISMS INVOLVED IN THE RESPONSE OF CORE TEMPERATURE TO ENVIRONMENTAL COOLING

The observed rise in temperature differentials could be due to a number of factors, such as, an increase in heat production (Kosaka 1930; Marshak 1939; Federov and Shur 1942; Donhoffer et al 1962; Grayson et al 1966) or to a reduction in blood flow into the tissues (Grayson et al 1966). An increase in heat production could be brought about either by enhanced motor activities of the muscular coat, or increased metabolic or secretory activities of the mucosa, or even by all three processes acting in unison. When there is a reduction in the blood flow to the mucosa of the gut for instance, there is a concomitant rise in the temperature, due to the fact that less heat is conducted away from it. This has already been shown in the haemorrhage series.

The role of cholinergic and adrenergic mechanisms in the production of the observed rise in the temperature differentials was studied.

The role of cholinergic mechanisms in the response of the core temperatures to environmental cooling

Cooling the animals two hours after the intravenous injection of atropine sulphate produced an increase in the temperature differentials between various regions of the gastro-intestinal tract and aortic blood. The most prominent rise in temperature differentials was displayed by the stomach; the rise being higher than that obtained in the control situation. In all the other regions however, after

atropine, the response to environmental cooling was reduced (as compared with the control series). This may probably be due either to the inhibition of some cholinergic mechanisms which normally increase their activities on cooling, or to an increase in the inhibitory activities of adrenergic influences, or to both.

The possible cholinergic mechanisms which may be increased include motor and secretory activities. There have been reports of increases in gastro-intestinal motility on moderate body chilling (Wertz and Sterkel (1920); Sato (1935) and Bisgard and Nye 1940). Although findings which conflict with this have been reported (Freude 1927 and Atkinson 1928) but this has been explained on the basis of the severity of cooling. Sato (1935) explained that the response to cooling depends upon the depth of tissues cooled in the process. Demonstrating this in the rabbit, he showed that when the body surface cooling was severe enough to cool the wall of the stomach directly, instead of the usual enhanced motility, there was an inhibition. The effect of directly cooling the wall of the stomach has been shown by a number of workers to be an inhibition (Carlson 1916, Atkinson (1928), Schule (1896); Mueller 1905) The above named workers did this by introducing cold fluid directly into the stomach. Mueller and Holscher (1929) demonstrated increased secretions of both gastric and duodenal juices on body surface cooling. Bisgard and Nye (1940) also, in explaining the increased gastric motor activities observed on body cooling, attributed this to an increased

gastric acid secretion, which they regarded as the primary response. Evidence has already been presented to show that both reactions could be blocked by atropine.

That increased motor and secretory activities could lead to a rise in gastric temperature, was well demonstrated by the work of Masek (1946) Blockade of these two activities in a regular response to cooling will definitely reduce the heat producing activities and thereby the temperature rise of the gastro-intestinal tract.

Atropine blockade however did not reduce this response very much.

Cooling the animal after an hour of steady value recording post-abdominal vagotomy, led to a steady rise in the gastric, rectal and large intestinal temperatures with respect to aortic temperature. The values of the duodenal and ileal temperature differentials, only rose after an initial fall. The fall in the case of the duodenum was quite steep. The final post cooling value was 0.05°C less than the precooling mean. In short vagotomy, if anything, caused an enhancement of the gastric and rectal responses, but it caused a massive reduction in the response of the large intestine. The response of the ileum was abolished while that of the duodenum was not only abolished but reversed.

That the gastric response was not reduced by vagotomy may mean either that vagotomy does not remove all the parasympathetic nervous

supply of the stomach - or that its response is not influenced by the vagus nerve in any way. It is known that the stomach receives another parasympathetic nerve supply from the splanchnic nerves (Semba, Noda and Fujii 1963). How much influence these fibres exert is difficult to assess, but it may not be considerable. The reaction of the stomach after atropine was similar to that after vagotomy, thus suggesting that the mechanisms of the gastric response may be different from the other; not being blocked by parasympathectomy. This may have to do with acid production which Bisgard and Nye (1940) suggested was secondary to the release of histamine or histamine-like substance on body chilling (Horton and Brown 1932).

The persistence of the response of the rectum is of course, due to the fact that it is not supplied by the vagus nerve at all and so vagotomy cannot possibly affect it.

The reduction in the large intestinal response is probably due to the fact that in addition to its parasympathetic supply from the nerve erigentes, the site of measurement, which is the ascending limb, receives some vagal supply. The removal of the vagal supply precipitates an imbalance between parasympathetic and sympathetic activities. The increase in the inhibitory activities of the sympathetic nerves might likely be responsible for the reduction.

The abolition of the ileal response is perhaps due to both an inhibition of the usual cholinergic contributions to the response by vagotomy and a possible further active inhibition of the motor activities by the "released" sympathetic nerves. Kewenter (1965)

showed that the sympathetic nerve supply of the ileum-exerts an inhibitory influence on its motor activities. This was not observed in the jejunum. It then means perhaps that the ileum is either more richly supplied with sympathetic nerves than the proximal portions of the intestine or that its supply, unlike the ones of the proximal portions, influence also muscular activities.

The complete reversal of the duodenal response emphasises the tremendous importance of its vagal supply in its reaction to environmental cooling. Besides the possible increase in motor activities which might have been inhibited, the duodenal response probably invôlves an increase in the secretory activities of the mucosa. Wright et al (1940) showed that vagal stimulation augments secretions in the duodenum but not in the jejunum and ileum. From this, it is possible to speculate on the possibility of the duodenal secretory cells receiving more vagal supply than those of the other portions of the intestine. In an attempt to explain why total duodenectomy led to, amongst others, hypothermia which was relieved by duodenal extracts, Ugolev (1960) suggested that the duodenum, in addition to its role in digestion, must be secreting an unidentified substance which influences the whole organism. It would seem therefore, that the functional integrity of the duodenum, with respect to heat producing mechanisms depends on the intact supply of vagus nerves to it.

There is also the possibility that there might have been, in

addition to the passive inhibition of motor activities by the removal of the vagus, a further active reduction in the motility by an activation of the sympathetic nerves.

The gradual recovery of the temperatures of both the ileum and the duodenum might be due to an increase in the adrenergic influences. This might either increase the heat producing activities of the wall of cause an increase in vasoconstrictor tone, which might tend to conserve the heat more efficiently and thus raise the temperature of the gut.

There was a substantial reduction in the response of the liver and portal vein to environmental cooling. The reduction in the portal venous response may be due to the reduction of the heat producing capacity of the gut after vagotomy. The effect on the liver may be due to an inhibition of some unidentified cholinergic heat producing mechanisms which normally occurs in the liver.

The role of adrenergic influences in the response of the core temperature to environmental cooling

While acknowledging the possibility of increased metabolic activities taking part in the response to cooling, Grayson et al (1966) suggested that the rise in the temperature of the jejunum with respect to the aorta was mainly brought about by blood flow changes - possibly due to an increase in vasoconstrictor tone to the gastro intestinal blood vessels.

It is a well known fact that on exposure to cold stress, there

is an increase in the amount of adrenaline in circulation. This is probably due to an increase in the amount released from the adrenal medulla (Cannon, Querido, Britton and Bright 1927). Besides the vaso-constrictor activities of adrenaline, the metabolic or calorigenic actions too are well known. Innes and Nickerson (1965b) mentioned that after the conventional dose of adrenaline there was always a 20-30% rise in oxygen consumption which may be due to increased fat metabolism. It therefore means that since there is the possibility of increased adrenaline secretion on cold exposure, there is consequently the possibility of its increased metabolic activities as well as increased contribution to the vasoconstrictor tone taking place on body chilling.

Bretylium tosylate did not greatly affect the response of the gut to environmental cooling. The effect on the ileum was more prominent than elsewhere. There was a slight enhancement in the response of the rectum, but a slight reduction in those of the liver and the portal vein . The reduction in the gastro-intestinal and portal venous blood temperature rises with respect to the aorta; may be due to a reduction in the increase in vasoconstrictor tone as well as perhaps a reduction in the increased adrenergic calorigenic activities (particularly the glucose metabolism of the smooth muscles of the gut wall), which normally take place during body cooling. The direct effect of bretylium on the metabolism of the smooth muscles of the gut wall may not be ruled out, since it has

been suggested that it is possible for nerve blockers to have direct effects on the effect or cells themselves (Zaimis 1963).

It is very difficult to assess the role of adrenergic influences in the response of the gastro-intestinal tract to environmental cooling in the present work, because of the possibility of an incomplete blockade of adrenergic activities by bretylium tosylate. It is known that while bretylium blocks responses to adrenergic nervous stimulations, it does not block responses to exogenous adrenaline - nor does it block responses to adrenaline released from the adrenal medulla. There is therefore the possibility of failure to block the effect of adrenaline released from the adrenal medulla in the present work, thus failing to inhibit completely the likely increase in vasoconstrictor tone, the possible increase in the metabolic activities due to adrenaline. The reduction of the response of the liver to cooling by bretylium, though significant was not very much, and this could be due to an inhibition of the normal increase in vasoconstriction, which thus enables the hepatic artery to supply more of cooler blood to the liver. It is very possible that some of the adrenergic calorigenic metabolic activities may also be blocked.

On the whole however, except in the case of the ileum it does not appear as though adrenergic influences play more than a slight role in the mechanisms of the temperature differential rises, in response to body surface cooling.

The role of both adrenergic and cholinergic influences

Environmental cooling after a combined administration of both bretylium tosylate and atropine sulphate led to a slight reduction in the response of the stomach, but a large reduction in the response of the duodenum, ileum and large intestine. There was distinct enhancement of the response of the rectum. There was a slight reduction in the response of the portal vein, which is paradoxical. The reduction in the response of the liver was significant.

The reduction of the gastro-intestinal response might be due to a combination of increased mucosal blood flow and an inhibition of the heat producing mechanisms which are brought about by increased release of acetycholine and adrenaline in the wall of the gut.

The combination of drugs however failed to block completely the response of the gut to environmental cooling. This then means that quite apart from these two mechanisms other mechanisms do exist to account for the response. It is significant that, with all these blockade procedures, the most that happened to the gastric response was a slight reduction.

The role of the gastro intestinal bacterial flora in the determination of its temperatures

The existence of bacterial flora in the gastro-intestinal tract has been well established. Their activities have been suggested to explain the high rectal temperatures measured in human subjects (Bazett 1951). Rubin Horvath and Mellette (1951) showed that gut sterilisation did not produce any difference between the rectal

temperatures of treated and "normal" patients.

Gut sterilisation carried out with neomycin sulphate in the present work did not produce a material difference between the temperatures measured in all the regions of the gastro-intestinal tract from those of normal dogs. The temperature of the rectum was also not significantly different from those of normal dogs.

On cooling these animals, there was no evidence of reduction in the response of the upper portions of the gut, to body surface cooling. The reduction in the response of the rectum was slight. This could be due to a genuine reduction in the bacterial colony in the rectum. While this gives the impression of some contribution from bacterial metabolic activites, it might be pertient to point out that there is a possibility of the direct effect of neomycin sulphate on the rectal mucosa, thus reducing its ability to respond to environmental cooling.

The experiment emphasises however, the fact that the role of the bacterial flora in the maintenance of normal rectal temperature in the warm environment, is negligible. There is a possibility of increased metabolic activities from them contributing rather slightly to the rise observed in the rectal temperature on body cooling.

CONCLUSION

Findings in the present work emphasise the variations in temperatures recorded from different sites in the 'core area'. This confirms therefore the views already expressed by Bazzett (1949) Burton and Edholm (1955) and Bregelman & Brown (1965), that the concept of the body being visualised as comprising a central core with a constant temperature say 37°C, is inadequate.

Definite thermal gradients along the gastro-intestinal tract with peaks in the duodenum were found. The high temperatures found in the gastro-intestinal tract and the high temperature differentials between the portal venous blood and the aorta, potray the gastro-intestinal tract as a potent heat producer. It therefore confirms earlier speculations of Fedorev and Shur (1942) and Grayson et al 1966. Calculations based on the values of portal flow taken from the work of other authors (Burton - Opitz (1911); Grab (1929); Blalock and Mason (1936); Grindlay et al (1941) and Green et al (1959), as well as on the temperature differential between the portal vein and aorta in the present work, a heat production of 8.6 cals/min was obtained. Basing this on the 1.60 Cals/kg/hr. obtained by Galvao (1947) as the total heat production of tropical dogs, it was found that the heat production of the gastro-intestinal tract may be as much as 32.4% of the total heat production at rest. This figure, though close to the 40% obtained by Grayson et al (1966) for

the heat production of the gut in human subject, cannot be taken as more than semi quantitative. A more reliable calculation will have to await further research, in which simultaneous measurement of portal blood flow and temperature differential as well as (A - V.) oxygen differences will be done. The flow will have to be measured with methods other than thermal dilution, which might tend to alter the temperature differentials of the portal vein.

Bretylium tosylate alone did not greatly reduce temperature levels in the "core area" in the warm environment. Atropine sulphate also did not greatly affect the temperature levels nor did vagotomy affect the temperature levels adversely. Simultaneous injection of both atropine and bretylium however produced additive influences which reduced the temperatures quite steeply, though they did not abolish the temperature differentials. What this means is perhaps that the role of these two mechanisms in the maintenance of the levels of the temperature in the gut and even in the liver is not important. In the warm environment there is perhaps not much vasoconstrictor tone and perhaps little of muscular activity either. This therefore raises the question of what exactly is producing the heat and where is it located?

The use of atropine was based on the assumption that it would block cholinergic mechanisms such as the contractile activities of the muscular coat, sheath of muscularis mucosae, and the villi, since all these are supposed to be stimulated by the acetylcholine continu-

ously released in the wall of the gut (Feldberg and Lin 1950). The use of bretylium was also based on the possibility of vasoconstrictor tone in the blood vessels as well on some metabolic activities which are driven by adrenaline.

Blockade of both influences removes therefore the role of motor activities and blood flow changes in the determination and maintenance of the temperature levels. What is left is perhaps some secretory and metabolic activities of the mucosa, which might be under the control of humoral factors, other than adrenaline.

Thyroxin has been suggested as one of the possible humoral factors involved in thermoregulation (Barde (1946); Cate (1946) and Masquood (1951). The above mentioned authors showed that hypothermia which often results from thyroidectomy is stopped by throid extracts. There is the possibility that this influences the glucose as well as the lipid metabolisms of the mucosa thereby increasing its heat production. There may yet be some unidentified humoral factors which may be involved.

The rise in the temperature differential in response to environmental cooling was not much reduced by bretylium tosylate. It is difficult to conclude what the role of adrenergic influences in the response to environmental cooling may be, in as much as most of the cholinergic influences which may increase as a result of the imbalance between the activities of the parasympathetic and the sympathetic nerves are heat producing. Howbeit it appears that the role

is not a primary one. This may include mucosal vasoconstriction, which might tend to increase thermal insulation. Vasoconstriction in the gastro-intestinal tract has been suggested (Grayson et al 1966) especially mucosal vasoconstriction (Wolf and Wolff 1943) as one of the mechanisms involved in the response of the gastro-intestinal tract to environmental cooling. Adrenergic influences seem important in the response of the ileum, it may also be in the case of gastric response.

Atropine did not reduce the response much. This may be due to failure to block all the cholinergic activities, due to the development of atropine resistant contractions.

Vagotomy on the other hand completely blocked and even reversed the response of the duodenum, while it just blocked the response of the ileum. It also reduced the response of the liver. This indicates that there might be a reflex increase in the discharges of parasympathetic nerves, during body surface cooling. This appears to be of paramount importance in the response of the duodenum and ileum to environmental cooling. Sato (1935) had earlier shown the importance of the vagus nerve in the response of the gastro-intestinal tract to environmental cooling. He obtained an inhibition, instead of the usual enhancement, of gastric motility after vagotomy. Vagotomy has also been shown to cause a greater fall in cloacal temperature (Cacioppo and Bevilotti 1946) as well as colonic temperatures (Stupfel and Severinghaus 1956) on environmental cooling.

The experiment shows that cholinergic mechanisms have some importance in the response of the duodenum, ileum and the large intestine to environmental cooling. It is however difficult to give a quantitative assessment of the role of these mechanisms in the response of the "core area" to environmental cooling, since their blockade leaves the activities of the sympathetic nerves uninhibited. The reversal of the response of the duodenum and the complete blockade of the ileal response after vagotomy may be contributed to by a further inhibition of muscular activities by the increased sympathetic activities. Even then, it is not very difficult to see that the duodenum and ileum depend very much on cholinergic mechanisms for their response. This may also be true, to some extent, of the large intestine whose parasympathetic activities, though not completely blocked, showed evidences of active participation.

It is difficult to say which of the cholinergic mechanisms is being blocked by atropine or vagotomy. There is the possibility that what is most active in one region may not be so important in another region. Wright et al (1940), for instance, showed evidence that vagal stimulation augments the secretions of the duodenum but not of the ileum and jejunum. Since active vagal participation has been demonstrated, it may just be pertinent to suspect that one of the mechanisms of the duodenal response is increased secretion. What exactly is being secreted is still unknown. It may include

the yet unidentified substance Ugolev (1960) suggested, which may have a profound role to play on the body as a whole, including temperature regulation.

In the case of the ileum then, may be the greater percentage of cholinergic influences is effected through other mechanisms besides secretion.

The response of the stomach has been shown to be immune to cholinergic blockade either by atropine or vagotomy. It was only influenced slightly by bretylium and a combination of bretylium with atropine. This perhaps means that the mechanism of the gastric response to environmental cooling is not much susceptible to cholinergic and adrenergic blockade. The response may well be a secondary response to increased acid production, which is itself influenced by the histamine released from the surface of the body, on cooling as was postulated by Bisgard and Nye 1940.

In spite of bretylium, atropine, vagotomy and atropine with bretylium, it has not been possible to abolish the temperature differentials between these various regions of the gastro intestinal tract and the aorta. This means that besides muscular, secretory and transport mechanisms (which was reduced to nil in the present work), there are other mechanisms which are of primary importance in the maintenance of this high gastro-intestinal temperatures. These

may include mucosal metabolic activities, the study of which requires more sophisticated experiments, such as the study of labelled A.T.P in the mucosa and what becomes of them during body chilling.

The present work lends a clear support to the conclusion of Donhoffer et al (1962) that "striated muscle is neither the only, nor the primary source of thermoregulatory heat production, and that under conditions of moderately increased heat loss, the internal organs are the most important site of thermoregulatory heat production".

Considering the very high blood supply to the duodenum and the fact that, inspite of this, it still has the highest temperature in the abdominal cavity, it might be just right to conclude that the duodenum, perhaps produces the greatest amount of heat per gram weight in the "core area".

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