STUDIES IN DENERVATION

A.—METHODS

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Introduction

IT is proposed to report under the above general heading a number of investigations on patients with peripheral nerve lesions. The following titles indicate the nature of the papers.

- A. Methods.
- B. The Circulation in Denervated Digits.
- C. Inflammation and Trophic Ulcers in Denervated Areas.
- D. The Mechanism of Axonal Vasodilatation.
- E. Observations Concerning Adrenaline.
- F. The Circulation of the Skin of the Proximal Parts of the Limbs.
- G. Sebaceous Secretion.
- H. The Effect of Electrical Treatment on the Circulation and Recovery of Denervated Muscles.
- I. The Contractility and Excitability of Denervated Muscle.

The original intention of bringing these studies within the compass of one or two papers has been found impractical and for convenience of presentation and of reference the work has been divided into sections. These sections will be found to be of unequal merit as some merely report incidental observations which have not been elaborated. Another disadvantage of this method of presentation is that it leads to unnecessary repetition. This, however, has been obviated by the Editor who has kindly arranged to publish the papers seriatim. This grouping permits a single description of the patients and methods to suffice for the majority of these studies and allows of ready reference between papers. It is the purpose of the present paper to describe the methods and the subjects used in these investigations.

Methods

The skin temperature of the finger pads has been used as an index of the peripheral circulation and recorded by multiple gauge 34 copper-constantan couples leading to a galvanometer permitting readings to within 0.1° C. The simplicity of this technique recommended it even though rapid

changes are not observable. Moreover, the results are difficult to interpret in terms of actual blood flow due to a variety of factors such as sweating and the size of the digit affecting the cooling curve. However, for comparative purposes and especially for detecting the direction of a change of flow the method seems adequate.

The hands were supported on a sand bag reaching to the proximal interphalangeal joints and the couples held in place by a narrow strip of adhesive plaster on the dorsum of the middle phalanx. At times a shield of white paper was put between the fingers if it appeared likely that there was any transference of heat from a warm to a cold digit. In the case of the feet there was less difficulty in ensuring equal opportunities for air circulation around the two extremities. The room temperature was measured by a thermocouple suspended several feet above the parts under observation. Air movement was not measured but it was probably high and variable though direct draughts were avoided. Temperatures were recorded at intervals of one to three minutes from two or more digits of both lower or both upper extremities. In the charts reproduced only the results from representative digits are recorded and in most figures the time scale is too small to permit charting of individual measurements.

In some instances thermometry was supplemented by plethysmographic records of the digits taken according to the method of Bolton *et al.* (1936). In those records in which denervated and normal digits are compared the recording systems have the same sensitivity.

Blood flow measurements by the displacement method of Hewlett and Zwaluwenburg (1909–10) were obtained using a water plethysmograph.

Systolic blood pressure was measured in the digital arteries by slowly deflating a cuff 1.5 cm. wide on the proximal phalanx and determining the pressure at which pulsation first returned to the distal part of the digit. This pulsation was detected by the use of a plethysmograph and a sensitive tambour.

During the period of observation the subjects, clothed in shorts, half reclined in a comfortable

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chair and the limbs under investigation rested motionless slightly below heart level. Unless otherwise indicated the patients come direct from a comfortable ward and temperature recording started within 10–15 minutes so that the initial temperatures were a sample of their usual state. Before plethysmographic records were taken the parts were warmed by immersion in water at 38° C. for 15 minutes and the indifferent limbs were put in water at 44° C.

Various measures were used to modify the circulation. Thermoregulatory mechanisms were brought into play according to the method of Gibbon and Landis (1932) by immersing the indifferent limbs in baths which were filled with water at 18° C. or 44° C. hereafter referred to as cold or hot. At times this influence was augmented by covering or uncovering the trunk with a blanket. It was also possible to vary the room temperature by opening a window and by the use of electric heaters directed so that there was no direct radiation on the subject.

The local effect of moderate heat and moderate

FIG. 1.—Apparatus for intravenous injection of adrenaline, description in text.

cold was investigated by removing the thermocouples and immersing the feet or hands in agitated water at 18–20° C. or 37–38° C. for 5–15 minutes. The parts were then gently dried and the couples replaced. This procedure took 2–3 minutes.

The effects of more extreme heat and cold were studied by the method of Lewis (1929–31). The couples were held in place under a loosely fitting surgical glove by two layers of adhesive strapping. The distal one-and-a-half phalanges were then immersed in a moving stream of hot water or in a bath of crushed ice and water stirred by compressed air. The temperature of the ungloved opposite hand was recorded as a control.

Adrenaline was used in the strength of 1 in 500,000

freshly prepared from a 1–1,000 stock solution and normal saline. It was injected intravenously by the use of the apparatus shown in Fig. 1. This could be easily dismantled for sterilization. The adrenaline solution was connected by pressure tubing with the inner barrel of a double barrelled adaptor which extended to the shaft of the intravenous needle. This arrangement ensured that no large volume of saline was contaminated with adrenaline and so permitted the time relations of a period of injection to be accurately known. By the use of a three-way tap the adrenaline could be given either in brief periods by the use of a 1 c.c. syringe or for longer periods by the drip method. The rate of flow could be varied by adjusting the upper tap, and it was measured by counting the drops per minute. The saline solution was connected to the outer barrel of the adaptor and ran continuously to prevent blocking of the needle. The solutions were at room temperature and a cold sensation in the arm gave some patients a clue as to when injections were being given. The adrenaline solution tended to deteriorate rapidly after the first hour (see paper E, Fig. 2). After this time a fresh solution was prepared and the contents of the connecting tube washed out.

Subjects.—The subjects were all young male members of His Majesty's Forces and these reports are a testament to their co-operation and endurance. For convenience they are listed in alphabetical order in Table I with the nature and site of their lesions along with the letter of the paper in which observations on them are discussed. If the letter is followed by a number it indicates the figure in which their records are shown. Unless otherwise stated the nerve lesions were complete as verified at operation and were in all respects typical and there was no evidence of trauma to the large vessels. The approximate time after the nerve injury at which the observations were made is given in the table.

A small group of patients with sympathectomies has also been available for study and details of these subjects are appended to Table I. The completeness of the operation was verified in each instance by a thermoregulatory sweat test using the chinizarin technique described by Guttmann (1940). The normal volunteers were members of the medical staff.

Comment

It is not profitable to attempt to summarize the results obtained in these investigations, but it may be helpful to indicate at the outset that they have little practical value in the treatment of peripheral nerve injuries. In general their chief significance appears to be that they demonstrate the ease with which physiological methods may be applied to the study of phenomena in the human. The fact that in some instances the particular juxtaposition of the results has led to conclusions at variance with those drawn by previous workers shows that in addition to ease of investigation even such a

TABLE I—PERIPHERAL NERVE LESIONS

Subject	Nerve	Level	Nature of Injury	Time to operation	Time to investigation	Paper and figures
R.A.	L. Sciatic	Thigh	G.S.W.	5 months	4 months	H 3, I 10
C.B.*	R. Sciatic	Buttock	G.S.W.	3 months	2 months	B 7, I 3
J.B.	L. Ulnar	Wrist	Cut	16 months	15 months	B 2
R.B.	L. Ulnar	Elbow	G.S.W.	6 months	8 months	B 2
S.B.	L. Brachial plexus	Trunks and cords	? traction	2 months	3 months	B 4, 11, 12, E H 3, 4
T.B.	R. Median	Forearm	Fracture	11 months	11 months	B 2
H.D.	R. Brachial plexus	Upper trunk	Traction	None	5 months	F 1
A.E.	R. Ulnar	Wrist	Cut	2 months	See Fig. 1, Paper B	B 1
A.H.	L. Sciatic	Buttock	G.S.W.	15 months	18 months	B, C 3, 4, E 9
L.H.	L. Median Ulnar Radial	Forearm	G.S.W.	4 months	4 months	B 3
A.I.	Digital nerves to R.F.3	Palm	Cut	1 month	2 months	B 2
F.J.	R. Ulnar	Elbow	Cut	5 hours 4 months	3 months	D 1-4, I 13
H.J.†	L. Ulnar	Elbow	Neuritis	—	—	B 13
A.K.	L. Ulnar	Upper arm	G.S.W.	8 months	8 months	B 2, 14, I 1, 7
B.K.	L. Median	Forearm	G.S.W.	9 months	9 months	E 6
A.L.	R. Ulnar	Forearm	Cut	2 months	30 months	B 13
A.M.	R. Post. tibial	Lower leg	Crushed at operation	—	2 months	E 4
J.M.*	R. Ulnar	Axilla	G.S.W.	6 months	4 months	B 2, C 1, 2, E
T.M.	R. Ext. popliteal	Thigh	G.S.W.	12 months	8 months	I 4
J.P.	R. Post. tibial	Ankle	G.S.W.	16 months	15 months	E 4, 5, 7
A.R.	R. Brachial plexus	Trunks and cords	Traction	None	4 months	H 3, 4
B.R.	L. Ext. popliteal	Knee	Traction	3 months	5 months	I 5
L.R.	L. Median Ulnar	Upper arm	G.S.W.	7 months	7 months	B 2, 12, E 8 I 6, 11, 12
N.R.	R. Median	Wrist	Cut	7 months	9 months	B 2
S.R.	R. Ulnar	Forearm	G.S.W.	12 months	14 months	B 2, 9, C
L.S.	L. Sciatic	Thigh	G.S.W.	6 months	5 months	B 2, E 2
N.T.	L. Femoral	Groin	G.S.W.	—	3 months	F 1
R.W.	R. Sciatic	Thigh	G.S.W.	7 months	6 months	B 8, I 2, 7, 9
S.W.	R. Median	Wrist	Cut	See below	20 years	B 5, 14, E 1, 3

* Lesions clinically complete but at operation some evidence of commencing regeneration.
† Nerve involved in scar tissue due to cubitus valgus.

Subject J.R.—R. Stellate Ganglionectomy performed by Mr. C. H. Cullen for hyperhydrosis marked on the right side of the face and less marked on the arm. Vascular responses normal before operation. Result—complete anhydrosis above T 3. See paper B 8, 10, 12.

Subject C.S.—Bilateral Lumbar Sympathectomy performed by Mr. C. H. Cullen for thrombo-angiitis obliterans. Nearly normal vasodilatation in left foot and slightly deficient in right foot before operation. Result—complete anhydrosis below L 4 and patchy in L 4. See paper B 8.

Subject S.S.—R. Stellate Ganglionectomy performed by Mr. C. H. Cullen for mild Raynaud's disease of two years' duration in a man of 35 who had worked out of doors with compressed air tools for two years before the onset. Result—complete anhydrosis above T 3. See papers B 6, 9, E and F 1.

Subject S.W.—R. Thoracic Sympathectomy performed by Prof. Geoffrey Jefferson for a cold sensitive state of the right hand. Result—complete anhydrosis above T 4. See papers B 5, 14 and E 1, 3.

restricted field as the limb presents fruitful opportunities for research. It should also be mentioned that these investigations have only been possible because as a result of the organization of the Emergency Medical Service a large group of subjects was available for study.

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