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CENTRAL PATHWAYS OF SOME AUTONOMIC REFLEX DISCHARGES

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SUMMARY

1. Electrical stimulation of spinal sensory nerves evoked discharges in inferior cardiac and renal nerves. In the anaesthetized cat both an early and a late response could be recorded in each nerve.

2. For any one afferent input the central delay of the late cardiac nerve response was significantly less than that of the late renal nerve response. The central delay of the early responses was similar for both nerves. In the spinal cat only the early response was present.

3. Cooling the floor of the 4th ventricle abolished the late responses in renal nerves, but left reflex volleys in white rami and intercostal nerves unchanged.

4. Stimulation in the brain stem evoked responses in both cardiac and renal nerves which had a shorter latency than the reflexes evoked in these nerves by stimulating dorsal roots.

5. The late responses could be abolished by lesions in the cervical spinal cord.

6. Such evidence led to the conclusion that there are two pathways for reflex discharge into inferior cardiac and renal nerves, one involving a supraspinal relay and the other confined to the spinal cord.

INTRODUCTION

Several authors have brought forward evidence that some reflexes which involve an input and output at the spinal level may be mediated through supraspinal centres when medulla-cord connexions are intact. Both Ranson (1916) and Johansson (1962) concluded that pressor and depressor reflexes of somatic afferent origin were relayed mainly through the medulla. Alexander (1946) and Sell, Erdelyi & Schaefer (1958) recorded reflex volleys in post-ganglionic fibres of the sympathetic outflow to heart and kidney in anaesthetized cats. They concluded that these reflex volleys also depended on a pathway through the medulla. However, there is

evidence that the cardiovascular system retains some capacity for reflex adjustment in the absence of supraspinal centres (Sherrington, 1906; Langley, 1924; Sahs & Fulton, 1940; Kuntz, 1945; Downman & McSwiney, 1946; Richin & Brizzee, 1949; Mukherjee, 1957). The present experiments were carried out to examine features of the central organization of certain sympathetic reflex volleys carried in nerves which might be concerned in cardiovascular function. The results suggested that the reflex discharge evoked in renal and inferior cardiac nerves, by stimulation of spinal sensory nerves, may involve either a supraspinal or a spinal path under different experimental conditions.

METHODS

Thirty-two cats were used. For most experiments anaesthesia was induced with a solution of chloralose (35 mg/kg) and urethane (700 mg/kg) in 0·9 % NaCl given intraperitoneally. For the spinal preparation the following procedure was adopted. After initial ether induction a glass cannula was placed in the trachea and both common carotid arteries ligated. The spinal cord was then exposed by laminectomy at T_1 and completely transected. Finally, the animal was decerebrated at the intercollicular level, ether was discontinued, and all wounds were closed. An antibiotic (2 ml. of Seclomycin, Glaxo) was given intramuscularly to prevent infection. These animals were placed in a cage on a heated table and rectal temperature was kept within the range 36–38° C; this sometimes fell overnight to 32° C, and the cats were then slowly warmed until rectal temperature was again about 36–38° C. A total of 60–100 ml. of fluid (milk 2 parts, water 1 part) was given in 20 ml. amounts by stomach tube at regular intervals throughout the day. The bladder was emptied by withdrawing urine by needle puncture in the anterior mid line of the abdominal wall. These decerebrate-spinal cats were kept for up to 36 hr before recording.

Renal nerves were exposed retroperitoneally and dissected free in the region of the kidney peduncle close to the renal artery, using a binocular dissecting microscope. The inferior cardiac nerves were exposed in the retropleural space after removing the head and neck of ribs 2 and 3, and the nerves were then dissected along their course with the carotid artery. They were cut peripherally so as to give 1–2 cm of nerve for recording. In some experiments recordings were made from certain thoracic white rami communicantes. These were exposed in the retropleural space between the intercostal nerve and the sympathetic chain. They were then cut close to their entry into the sympathetic chain and freed centrally up to the spinal nerve. Limb nerves and intercostal nerves were exposed by removing overlying skin or muscle and cut peripherally. Dorsal and ventral roots were exposed by laminectomy and longitudinal incision of the dura mater. The dorsal roots were cut close to the spinal ganglion whereas the ventral roots when required were cut close to their origin from the cord. Limb nerves, intercostal nerves, dorsal and ventral roots were stimulated through bipolar stainless-steel wire electrodes. Square wave pulses of 0·3 and 1·7 msec duration were available from a stimulator synchronized with the oscilloscope time base and were delivered through isolation units. A maximal stimulus was one which elicited the largest example of the reflex response under investigation. Fine silver wire electrodes were used for recording, and the volleys were amplified and displayed on one of the beams of a dual-beam Tektronix oscilloscope (Type 555). All nerves and exposed tissues were protected from drying or cooling by a deep pool of liquid paraffin at 37° C contained within the skin edges. Blood pressure was recorded through a cannula filled with heparinized 0·9 % NaCl in the left carotid artery and connected to a Statham P23A transducer. After d.c. amplification (Tektronix Type Q unit) the B.P. trace was displayed on one of the beams of the oscilloscope. Only part of the trace

was shown in each photographed record but in a series the level of systolic and diastolic pressures could be read. Breathing was recorded by an intraoesophageal balloon and a Grass PT6A transducer. In some experiments a Grass model 5 polygraph was used in parallel with the oscilloscope to record B.P., heart rate and breathing; heart rate was recorded using a Grass Tachograph 5P4 preamplifier. Reflex jerks from muscle when they were troublesome were prevented by repeated intravenous doses of decamethonium iodide (C_{10}) (100 μg/kg), with positive pressure artificial ventilation. Anaesthetized animals were allowed to recover from their paralysis between the repeated doses of C_{10}, and depth of anaesthesia was checked, using a sluggish blink reflex and the absence of flexor responses as indicators of adequate anaesthesia. Measurements of latency were made from projected enlargements of original photographs of records and represent the average of 20–40 responses. Where several shocks were used the latency was measured from the first stimulus artifact to commencement of the potential wave. The later shocks affected only the size of the response.

For brain-stem stimulation the head was held in a stereotaxic head holder and tilted nose down at 45° to the Horsley–Clarke horizontal plane to allow the vertical stimulating electrode to avoid the tentorium cerebelli. The brainstem was stimulated through a unipolar electrode inserted, with a micrometer control, through holes drilled in the occipital bone. Square wave negative-going pulses were delivered through a Pt wire (25 μ diameter) sealed into a fine glass tube with varnish, total outside diameter being 150–300 μ. The other electrode was a Pt plate attached to the reflected cranial muscle. In experiments in which the brainstem was cooled the floor of the 6th ventricle was exposed by occipital craniotomy followed by removing the overlying portion of cerebellum by suction. A freon cooling probe similar to that described by Clark (1963) (1·1 mm o.d.) was used for cooling, the tip of the probe touching the floor of the ventricle in the mid line 2–3 mm rostral to the obex. At the end of each experiment the cat was killed by excess nembutal. The brainstem and spinal cord were then removed and fixed in 10% formol saline, and serial frozen sections (50 μ) were cut in the appropriate planes. The brain stem sections were stained by the method of Weil (1928) to show the site and depth of the electrode tracks. The spinal cord sections were examined unstained.

RESULTS

Anaesthetized preparations

Reflex latency. The findings of Sell *et al.* (1958) were confirmed. Total latency of reflex responses in cardiac nerves was shorter than those in renal nerves, whether radial or saphenous nerves were stimulated (Fig. 1). It was also found that similar time relations were obtained when stimulating intercostal nerves or dorsal roots. For example, in one experiment the 1st and 13th intercostal nerves were stimulated maximally. The reflex responses in a cardiac nerve had mean total latencies of 49 and 54 msec respectively, while the renal nerve reflex discharges had total latencies of 85 and 90 msec respectively. Latency of the cardiac nerve response was always shorter by 36 msec. In ten cats in similar experiments the difference of latency was 25–50 msec, cardiac nerve responses preceding renal nerve responses whatever level of afferent pathway was stimulated.

The possibility that some portions of the reflex discharge were in a select fraction of motor outflow with longer latency characteristics was ruled unlikely. In some experiments recordings were made from several of the

separate bundles constituting the cardiac and renal nerves. Reflex motor volleys were not found in all of the bundles but in those where they were present (usually two or three out of a total of four or five) similar latencies were found for the volley set up in each bundle when stimulating any one afferent pathway.

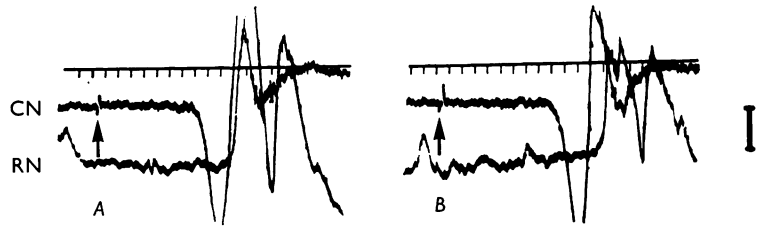

Fig. 1. Reflex responses recorded simultaneously in the inferior cardiac nerve (CN, initial response downwards) and in a renal nerve (RN, initial response upwards) which were evoked by maximal single shock stimulation at arrow to *A*, the central cut end of the contralateral superficial radial nerve, and *B*, the central cut end of the contralateral saphenous nerve. In both cases the response in the CN is earlier. Cat anaesthetized chloralose–urethane. Time marker 10 msec. Voltage calibration 100 μV.

Central delay. A more direct comparison was obtained by determining the central delay of the reflexes, thus eliminating the differences in the long peripheral motor pathways and the delay in the peripheral ganglion. In the anaesthetized cat the over-all latency of the reflex obtained by stimulation of the central cut end of a dorsal root was determined. The appropriate ventral root (VR) was then severed at its origin and the latency of the direct motor response was recorded when stimulating the peripheral cut end of the root. This time was then subtracted from the total latency of the reflex to give an estimate of central delay (Fig. 2). The time taken for the afferent volleys to travel from the stimulus cathode on the dorsal rootlets to the cord entry was ignored, but to minimize this error the distance of the stimulating cathode from the spinal cord was kept to 2 mm. For these estimates of central delay T_3 and T_{10} segments were used because maximal stimulation of their ventral roots gave the shortest latency responses in cardiac nerve and renal nerve respectively. Also these latter segments make an important contribution to cardiac and renal nerve outflow respectively (Bradford, 1889; Bronk, Ferguson, Margaria & Solandt, 1936; Ranson & Billingsley, 1918; Sell *et al.* 1958).

In one experiment the motor outflow to the cardiac nerve was restricted to T_3 segment by sectioning the white rami (WR) of T_1 and T_2 and also the sympathetic chain between T_3 and T_4 on the same side; the motor outflow to the renal nerves was similarly restricted by sectioning the sympathetic chain between T_9 and T_{10} and cutting ventral roots T_{11} to L_1 inclusive. Maximal single shock stimulation of T_3DR and T_1DR was used

to evoke reflex responses in cardiac and renal nerves; these were recorded before and after limiting the recorded outflow to one WR–VR contribution. In both cases the average latency of the response was increased by 4 msec.

Since this increase was so small subsequent experiments were performed with all motor paths between cord and sympathetic chain intact. From forty estimates in four cats the central times had a range of 39–45 msec for T_3DR input to cardiac nerve and 45–53 msec for T_{10}DR input to renal

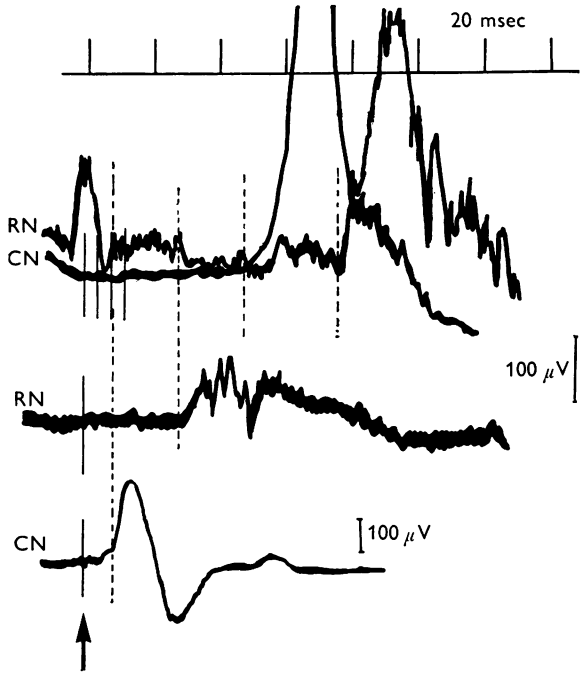

Fig. 2. The figure illustrates the method used for determining central delay of the reflexes. Top, time trace. Middle two traces; the maximal reflex responses recorded simultaneously in the inferior cardiac nerve (CN) and a renal nerve (RN) evoked by stimulation of T_{10}DR with four shocks at arrow. Bottom two traces; the direct motor responses in RN and CN elicited by single shock stimulation to T_{10}VR and T_3VR respectively. The time interval between the interrupted lines drawn through the take-off of reflex and motor volley for each nerve was used as an estimate of central delay. Traces were drawn and aligned from enlargements of original records. Cat anaesthetized chloralose–urethane.

nerve. In any one experiment the cardiac central delay was the shorter by 6–10 msec. It is possible that segmental afferent density may differ at T_3 and T_{10} levels and lead to different degrees of summation in the two pathways. Therefore in one cat central delays were determined when stimulating T_{10}DR and recording the outflow into renal and cardiac nerves.

After determining the latency in the motor pathways, central delays of the T_{10}DR to renal nerve and T_{10}DR to cardiac nerve were calculated (Fig. 2). The reflex in the cardiac nerve had a central delay of 44 (S.E. of mean ± 0·41) msec compared with that in the renal nerve which was 50 (S.E. of mean 0·27) msec. Even though the afferent volley enters the spinal cord at the segmental levels which are the origin of the renal nerve supply, the central delay of the cardiac nerve response was still some 6 msec shorter.

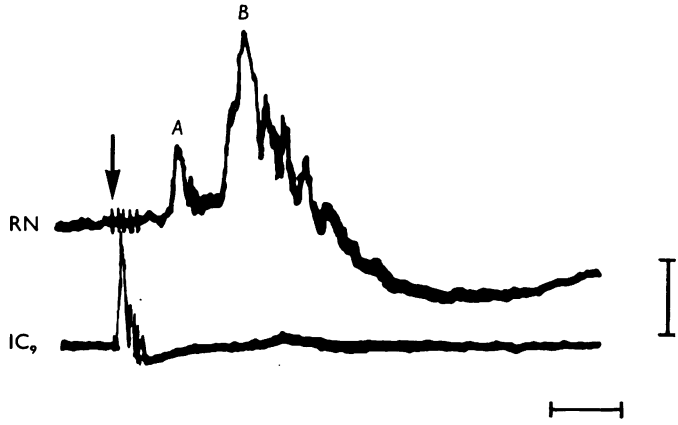

Fig. 3. Maximal responses recorded in a renal nerve (RN) and the 9th intercostal nerve (IC_9) elicited by stimulation at arrow with five shocks to the central cut end of the 10th intercostal nerve. There is an early response *A* (latency 38 msec) and a later response *B* (latency 66 msec) in the renal nerve. Time marker 50 msec. Voltage calibration RN 200 μV, IC_9 500 μV. Cat anaesthetized chloralose–urethane.

In some anaesthetized cats the large long-latency volleys described above were preceded by a smaller shorter-latency discharge (Fig. 3). The central delay of these early responses was usually shorter for renal nerve than for cardiac nerve when comparing one cat with another, although no direct comparison can be made since they have not been analysed in the same cat. Thus in one anaesthetized cat the early response in the cardiac nerve had an average central delay of 14 msec calculated for T_3DR input to cardiac nerve. In two other cats similarly anaesthetized the central delay of the early responses in the renal nerve averaged 10 and 12 msec, calculated for T_{10}DR input to renal nerve. Both these early and later responses appear to be carried in post-ganglionic fibres, at least in the renal nerve, since they were abolished after hexamethonium iodide 2 mg/kg given intravenously. At the same time pre-ganglionic transmission was unimpaired as evidenced by the presence of reflex discharge in T_{10}WR. This would confirm that the large difference in timing between the early and late response in a nerve is a consequence of differences in the central

pathways involved and is not due to a difference in the composition of the peripheral motor pathway.

Spinal preparation

These cats were anaesthetized with ether for decerebration and spinal cord section at T_1, and were allowed up to 36 hr to recover from spinal shock. In all cases mean arterial B.P. ranged from 70 to 90 mm Hg and breathing was spontaneous. The pinna reflex, blink reflex, flexor and crossed extensor reflexes were present within the first 2 hr after cord section and

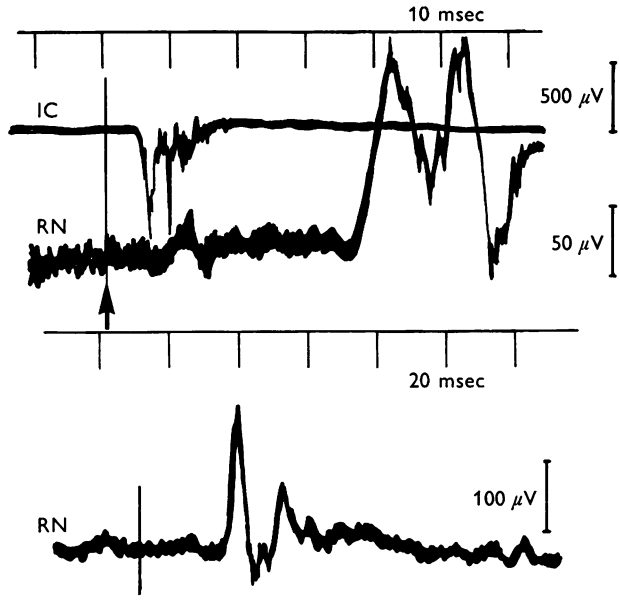

Fig. 4. Reflex discharges recorded in the unanaesthetized decerebrate spinal cat 36 hr after the cord was transected at T_1. IC is the maximal reflex response in the 9th intercostal nerve and RN (upper trace) is the maximal reflex response in a renal nerve, both elicited by stimulating at arrow the central cut end of T_{10}DR. Time marker for these records 10 msec. In the lowermost record on a slower time base (20 msec time marker) is shown the direct motor response in the renal nerve elicited by stimulating the peripheral cut end of T_{10}VR. The central delay of the reflex in the renal nerve in this cat was 11·0 msec (S.D. $\pm$ 1·1). Paralysed with decamethonium and artificially ventilated.

at the time of recording were brisk and sensitive. In these animals repetitive stimulation of thoracic spinal nerves with 3 V for 10 sec at 270/sec produced a rise in B.P. of 40–60 mm Hg. Before recording, the cats were paralysed with decamethonium iodide 100 μg/kg i.v. to eliminate reflex movements, and positive-pressure artificial ventilation was given. In all cases spinal cord section was anatomically complete when checked at post

mortem. In these preparations reflex discharges into branches of the renal nerve could always be evoked by intercostal or thoracic DR stimulation (Fig. 4). The renal nerve reflexes were of short latency and no later response was evident. Central delays were determined when stimulating T_{10}DR and the range in six cats was 8–15 msec. (mean 11·4, S.D. ± 2·15 msec). The possibility that such discharges could be due to direct current spread from stimulus cathode to VR or spinal interneurones was eliminated by crushing the dorsal rootlets proximal to the stimulating electrodes. This abolished the reflex.

Effect of the anaesthetic on the latency of the reflexes in the spinal cat. Since comparisons were made between the unanaesthetized spinal preparation and the anaesthetized cat with medulla-cord connexions intact it was necessary to determine whether the anaesthetic altered the reflex latency or if it would block the early response and bring up a later response. It was found that the anaesthetic had little effect on the latency of the spinal reflex volleys in the renal nerves. In two decerebrate-spinal cats intercostal and T_{10}DR-evoked reflexes were recorded in a renal nerve 30 hr after cord section. A full anaesthetic dose of chloralose and urethane, appropriate for the weight of the cat, was slowly given intravenously and the renal nerve reflexes were monitored during the administration and up to 5 hr afterwards. It was found that the over-all latency of the T_{10}DR-evoked reflexes was increased only by some 3 msec; to quote specific examples, from 42 (S.D. ± 1·1) msec to 45 (S.D. ± 1·3) msec in one cat and from 36 (S.D. ± 0·9) msec to 39 (S.D. ± 1·1) msec in the other cat. In both cases the size of the responses was little altered.

Cooling the medulla

Reference has been made to suggestions that the central pathways of cardiac and renal nerve reflexes may pass through the medulla. To test whether medullary activity was essential for the long-latency responses, in four cats anaesthetized with chloralose and urethane the floor of the 4th ventricle was cooled while eliciting the reflexes. Reflex volleys were evoked in a renal nerve by stimulating the ipsilateral 9th intercostal nerve. At the same time reflex volleys were recorded in T_{10}WR, which gives an index of other sympathetic reflexes of short latency, and also in the 10th intercostal nerve, which gives an index of somatic reflex activity mediated by spinal arcs (Downman, 1955). Both of these latter reflexes were elicited by the stimulation of the 9th intercostal nerve. Blood pressure, heart rate and breathing were monitored throughout the procedures. All reflexes were recorded before, during and after cooling, the medulla being cooled for a period of 8–15 min. During such cooling, the B.P. fell by 60–80 mm Hg to a mean pressure of 50–60 mm Hg, with

acceleration of the heart. Spontaneous breathing was abolished within 1–3 min after cooling commenced, depending on the position of the probe; the cats were then given artificial ventilation. It was found that cooling the floor of the 4th ventricle in the mid line 2–3 mm rostral to the obex abolished the late reflex response in a renal nerve. At this time the spontaneous base-line activity of the nerve was much reduced in size, becoming more continuous and no longer being in bursts synchronized with the

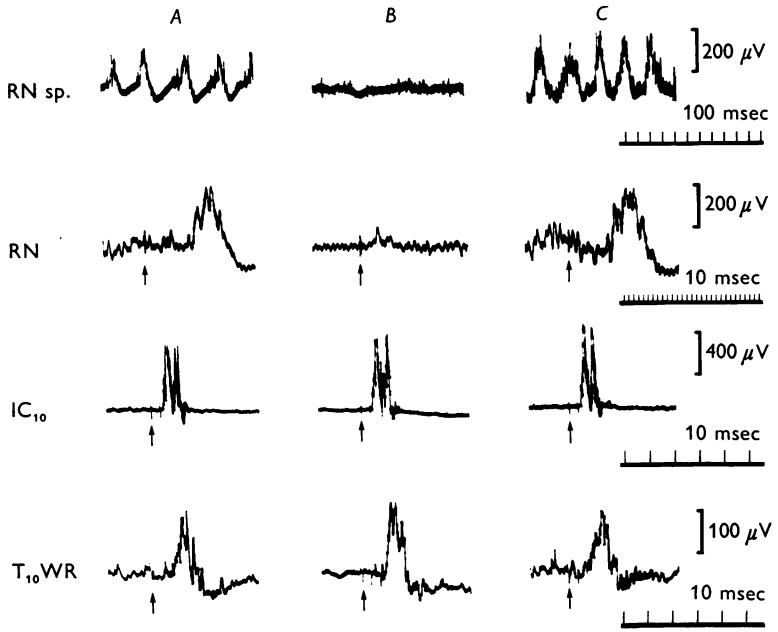

Fig. 5. This figure shows the effects of cooling the floor of the 4th ventricle on reflex responses in a renal nerve (RN), an intercostal nerve (IC_{10}) and a thoracic white ramus ($T_{10}WR$). RN sp = spontaneous base-line activity in a renal nerve. Below are shown the maximal reflex responses recorded in RN, IC_{10} and $T_{10}WR$, all elicited by stimulation at arrow with three shocks to the central cut end of the 9th intercostal nerve. *A*, control records before cooling. *B*, responses 8 min after cooling the floor of the 4th ventricle 2–3 mm rostral to obex. *C*, responses 8 min after rewarming the medulla. Cat anaesthetized chloralose-urethane.

pulses. The renal nerve reflex responses could again be elicited on rewarming the medulla by removing the cooling probe and flooding the region with 0·9% NaCl at 37° C. These renal nerve reflexes were back to control values some 3–10 min after rewarming, the recovery time depending on the duration of the cooling (Fig. 5). Within this period the spontaneous activity had returned to its appearance before cooling; also spontaneous breathing returned and B.P. and heart rate recovered their initial levels. In contrast to the effect on the renal nerve responses, the

intercosto-intercostal reflexes which were recorded at the same time were not changed during the cooling. It was also found that the reflex volley of T_{10}WR was unchanged in amplitude during the cooling, but the rising phase of the volley was steeper (Fig. 5).

Brain stem to cord timings

In order to gain some idea of the time which might be involved in a descending pathway from brain stem to cardiac nerve or renal nerve, responses were elicited by stimulating in the brain stem above the obex. The brain stem was explored stereotaxically with unipolar Pt-in-glass electrodes delivering square wave negative-going pulses of 1–4 V and 1·7 msec duration and at a frequency of 400/sec through an isolation unit. Exploration in a coronal plane was commenced in the mid line and continued laterally in vertical tracks 1 mm apart, the electrode being inserted into the brain stem dorsoventrally, and stimulation was carried out at 0·5 mm intervals of depth. Several coronal planes were explored in this manner in each cat and the shortest latency of the evoked responses in the nerves was determined. Central delays for reflexly and directly evoked discharge were calculated as described above using T_3VR and T_{10}VR for direct peripheral motor timings to the cardiac and renal nerves respectively. For example, in an anaesthetized cat volleys were set up in the renal and cardiac nerves by brain stem stimulation. A minimum latency was obtained when stimulating with four shocks at a frequency of 400/sec at a point in the ventromedial reticular formation 3 mm rostral to the obex and 1 mm left lateral of the mid line. Here the direct central time for brain stem to cardiac nerve was 34 msec and to renal nerve was 44 msec. The reflex central delay for T_1DR to cardiac nerve was 39 msec and that for T_1DR to renal nerve was 50 msec (Fig. 6). This would allow 5–6 msec for the ascending conduction over a distance measured approximately as 160 mm between the T_1DR entry and the brain stem stimulating electrode. The calculated ascending intraspinal conduction speed would then lie in the range of 20–30 m/sec. In other experiments the shortest direct central time of the brain stem-evoked responses in cardiac nerve had a range of 25–34 msec (four cats) and in renal nerve a range of 41–44 msec (four cats). These findings indicate that the short latency (10–14 msec) responses seen in some intact cats were not mediated through a supraspinal relay, but were wholly spinal. On the other hand the longer latency (39–53 msec) responses could involve a supraspinal relay if one postulates an ascending path conducting at 20–30 m/sec or more.

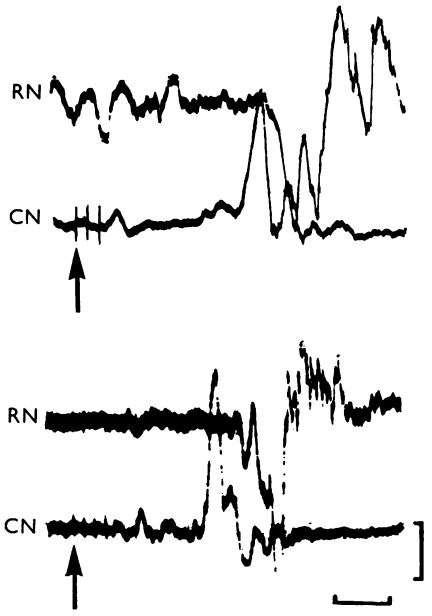

Fig. 6. In the top two records are shown the maximal responses recorded in a renal nerve (RN) and the inferior cardiac nerve (CN) elicited by stimulation at arrow with three shocks to the central cut end of T_1DR. In the bottom two records are shown the maximal responses in RN and CN elicited by ipsilateral unipolar stimulation (four shocks) at a point in the ventromedial reticular formation 3 mm rostral to obex and 1 mm left lateral of mid line. The latency of the direct brain stem evoked responses is shorter than that of the reflexly evoked responses. Time mark 20 msec. Voltage calibration 100 μV. Cat anaesthetized chloralose–urethane, paralysed C_{10}, artificially ventilated.

Lesion of ascending pathway

Since the evidence presented above suggests that an ascending pathway could be involved in the mediation of the late reflexes in cardiac and renal nerves, attempts were made to cut such a pathway. In five anaesthetized cats, cuts were made in the dorsal part of the cervical spinal cord at C_4. The late reflex in a renal nerve elicited by stimulation of an afferent input low in the cord, i.e. the 10th intercostal nerve, was abolished by a lesion which included both dorsal horns and the dorsal part of the lateral funiculi shown by the hatched area in the section of spinal cord (Fig. 7). The renal nerve responses to stimulation of an afferent input high in the cord above the lesion, i.e. the 2nd cervical nerve, was still present although a little smaller and of longer latency. This would suggest that an ascending pathway from the 10th thoracic segment had been cut. A lesion at C_4 level which was confined to the dorsal columns had no effect on the renal nerve

reflexes elicited by either C_2 spinal nerve or the 10th intercostal input. From the five experiments it became evident that in order to abolish the reflexes from an input below the lession, at least both dorsal horns and

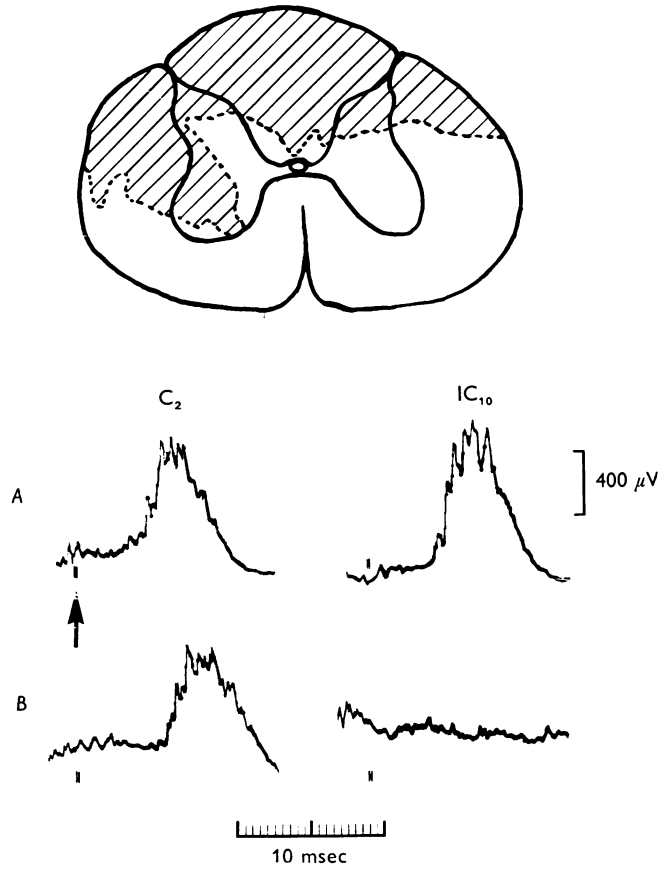

Fig. 7. Effect on the late reflex in a renal nerve of making cuts across the spinal cord at C_4 level as shown by the hatched area in the section of cord drawn above. In the records below are shown the maximal late reflex responses in a renal nerve elicited by stimulation with two shocks (indicated by the double artifact shown above arrow in the first record) to, in the first column, the central cut end of C_2 nerve, and, in the second column, the central cut end of the 10th intercostal nerve IC_{10}. *A*, control records before making the lesions; *B*, records after making the lesions. The response to an afferent input (IC_{10}) below C_4 was abolished by the lesions. Mean arterial B.P. fell from 110 mm Hg before the lesions to 60 mm Hg after the lesions were made. Cat anaesthetized chloralose–urethane.

the dorsal part of the lateral funiculi had to be included in the cut. In only one experiment was this accomplished without causing a fall in mean arterial B.P. or a reduction in the spontaneous base-line activity in the

renal nerve. Since the cuts extended into regions which may contain descending vasomotor pathways (Wang & Ranson, 1939; Kerr & Alexander, 1964) a reduction in the number of active descending fibres may account for the fall in B.P. and for the lessening of the spontaneous activity in the renal nerve seen in four of the above cats. A similar explanation may account for the increase in latency and smaller size of the C_2-evoked renal nerve reflexes after making the lesions. It was noticeable that in the one experiment where there was little effect on B.P. or spontaneous activity in the renal nerve the C_2-evoked reflexes were only slightly reduced and their latency was little altered.

DISCUSSION

Recordings from post-ganglionic fibres of the cardiac and renal nerve outflow have shown that sensory nerve stimulation may evoke two types of reflex discharge, an early small amplitude response and a later large amplitude response, the latter being more frequent under the conditions of these experiments. The results show that for the late response the cardiac nerve reflexes were always earlier by 25–40 msec irrespective of the level of the sensory input. Sell *et al.* (1958), and Weidinger, Fedina, Kehrel & Schaefer (1961) have recorded similar differences in the timing of these late reflexes. When central delays are determined this difference is much reduced but again the delay of the inferior cardiac nerve response is shorter by some 6–10 msec. It appears that the latency of the late reflex is dependent, not so much on the proximity of the input to the motor outflow at the spinal segmental level, but more on the distance of these levels from some centre rostral to both cardiac and renal nerve outflow. Alexander (1946), Sell *et al.* (1958) and Weidinger *et al.* (1961) suggested that the reflex centre is in the bulbar reticular formation. The results of bulbar stimulation show that there is time for conduction in an afferent limb to the medulla. This would involve an ascending pathway having an intraspinal conduction speed of at least 20–30 m/sec. This ascending pathway could be cut by lesions in the cervical spinal cord which were similar in extent to those which were found by Johansson (1962) to abolish the somato-pressor reflex. Ranson (1916) considered that the ascending fibres of the somato-pressor reflex were much more localized, being confined to the tracts of Lissauer. In the present experiments, in order to abolish the late reflexes in the renal nerves the lesions had to be bilateral and more extensive than those in Ranson's experiments, including most of the posterior horns and the dorsal part of the lateral funiculi. Weidinger *et al.* (1961) localized by section a region 2–3 mm rostral to the obex which they considered was the site of relay for the reflex volleys which correspond to the late responses

of the present investigation. We found that the most effective site for abolition of late renal nerve reflexes by cooling the floor of the 6th ventricle also lay some 2–3 mm rostral to the obex. From such evidence it appears therefore that the afferent limb of the late reflex passes at least as high as the medulla. The short latency of the early low amplitude reflex in renal and cardiac nerves sometimes seen in anaesthetized cats would suggest that they are purely spinal, especially since the central delays were similar to those of the reflex volleys evoked in spinal cats. It is concluded that either of two pathways may be involved in the reflex discharge into inferior cardiac and renal nerves when stimulating somato-sensory nerves. One is purely spinal with a central delay, e.g. for renal nerve of 8–15 msec, and the other is spino-bulbo-spinal with a central delay, e.g. for renal nerve of 45–53 msec. This latter would correspond to that demonstrated by Sell *et al.* (1958). In the anaesthetized cat the spinal pathway is often not conducting and the reflex responses are mediated through the medullary pathway. Whether these spinal arcs are similarly depressed in the unanaesthetized cat cannot be stated.

The sympathetic reflex arcs are greatly depressed after cord section, in the present experiments the arcs under investigation taking at least 9 hr for full recovery. During this period somatic reflexes such as flexor reflexes and muscle jerks soon returned, and remained brisk and sensitive throughout. This accords with other experimental findings that vasomotor and other autonomic reflexes take longer to recover from spinal shock than do somatic reflexes (Brooks, 1933; Sahs & Fulton, 1940; Wang, 1964). This time factor probably accounts for the failure of Alexander (1946), Sell *et al.* (1958) and Weidinger *et al.* (1961) to evoke reflex discharge in the cardiac and renal nerves in acute spinal cats. In their experiments only 2–3 hr was allowed for recovery after cord section before the reflexes were tested.

Fulton (1926) first postulated long-circuiting of some somatic reflexes through supraspinal paths, but without direct evidence. Gernandt & Shimamura (1961) and Shimamura & Livingston (1962) showed that intersegmental somatic reflexes are subserved by both local segmental spinal arcs and also by a supraspinal relay. Wang (1964) showed that both a spinal and a medullary pathway may be active in sudomotor reflexes. The evidence presented here gives further support to the theory of long-circuiting of some apparently spinal reflexes. When the long path is conducting the short path may be non-conducting. There is much evidence that a descending tonic inhibition can suppress somatic and sympathetic spinal reflexes (Sherrington & Sowton, 1915; Alexander, 1946; Downman, 1955; Holmqvist & Lundberg, 1959; Alderson & Downman, 1965). The fact that occasionally both the short-latency and the long-latency reflexes were

recorded together in the anaesthetized cat suggests that the inhibitory bias from the supraspinal centres can vary.

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