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ELECTROMYOGRAPHY OF THE SPHINCTER ANI EXTERNUS IN MAN

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The conception that skeletal muscle consists of slow-acting and quick-acting elements, commonly described as red and white fibres, is long-standing (Ranvier, 1874). Recent pharmacological and histochemical studies have renewed interest in the subject (Paton & Zaimis, 1952) as has the technique of electromyography, used for example in investigations of postural activity. Following an investigation of the fibre content of the human gastrocnemius and soleus muscles (Walls, 1953), it occurred to us, if current descriptions of its action are correct, that of all the striped musculature of the body the external anal sphincter might be said to be the one most constantly in a state of tonic contraction. This muscle might therefore be expected to exhibit most convincingly the structure of so-called red muscle.

The first step therefore was to study the activity of the sphincter in normal subjects. Although workers in the field of electromyography have already seized upon most of the readily accessible surface muscles, only Beck (1930) appears to have studied the anal sphincter in this way. Using a string galvanometer and steel needle electrodes inserted at the muco-cutaneous junction to a depth of 4 cm, Beck studied the effects of distension of the anal canal in a number of dogs and in one man. Briefly his findings were these: during both contraction (shortening) and relaxation (lengthening) of the sphincter action currents were recorded; but once the muscle had become contracted or relaxed the action currents gradually lessened and sometimes disappeared. This observation seemed to Beck to provide evidence for a locking mechanism similar to that noted by Fröhlich & Meyer (1912) in the mollusc.

Beck published only records from dogs but stated that his one human subject gave similar results. His findings are clearly of great interest and well worth while re-investigating with the refined electromyographic apparatus

available to-day. Moreover, the subcutaneous portion of the external sphincter is of great importance clinically, for its fibres are frequently exposed at the base of chronic anal fissures, causing spasm and severe anal pain. In such cases there is invariably contraction and fibrosis of the subcutaneous sphincter, and for the operative cure of chronic fissure it is essential to divide this part of the muscle. These and other surgical considerations point clearly to the need for a proper understanding of the normal activity of the muscle.

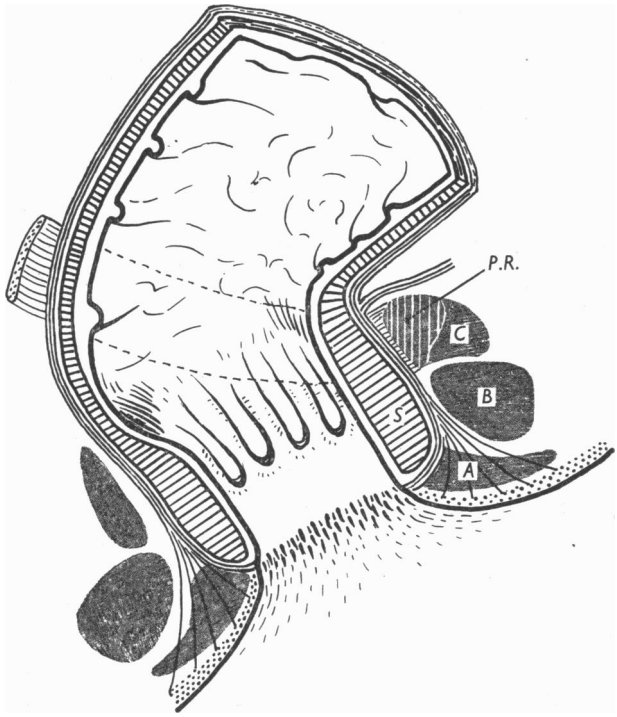

Fig. 1. The external anal sphincter (diagrammatic): *A*, subcutaneous; *B*, superficial; *C*, deep parts of the external sphincter; *S*, internal sphincter; *P.R.*, pubo-rectalis. Elastic fibro-muscular (involuntary) strands continuous with the longitudinal muscle of the gut can be seen running through the subcutaneous portion of the sphincter to the skin. (Redrawn after Grant.)

ANATOMY

Fig. 1 shows diagrammatically the structure of the human external anal sphincter in sagittal section. It should be noted that in man the pubo-rectalis constitutes the strongest part by far of the levator ani muscle. It is disposed as a sling round the ano-rectal junction, and many of its fibres pass to the deep part of the external sphincter with which it is stated to act.

METHODS

Electromyographic investigation

Seven normal male subjects, aged 20–43, were used for these experiments. Surface electrodes consisting of 1 cm diameter silver–silver chloride disks were applied to the skin on each side of the anal aperture overlying the subcutaneous portion of the sphincter. The skin was prepared by the application of electrolyte jelly (Cambridge Instrument Co.) which was rubbed gently in. The electrodes were applied with a cushion of the electrolyte jelly and strapped in position with elastic adhesive strapping. Surplus electrolyte jelly was removed very carefully to minimize short circuiting of the electrodes, which in these experiments, were closer together than usual. In spite of the extreme sensitivity of the anal skin the presence of the electrodes was unnoticed by all subjects after only a minute or two, and it seems unlikely that their presence significantly affected sphincteric tone. The use of needle electrodes was considered, but on the advice of our clinical colleagues was not attempted.

The action potentials were amplified by an Ediswan 6-channel electroencephalograph with ink-writer recorders. There was no significant loss of fidelity by the use of the ink-writers and the advantage of an immediately visible record outweighed any other considerations (Floyd & Silver, 1952).

In most experiments recordings were also made from gluteal muscles and occasionally from anterior abdominal wall muscles. During most of the recordings the subjects were lying on the left side on a couch. In certain experiments the subjects stood upright and carried out various manoeuvres such as weight-lifting. Some experiments were also conducted in the sitting position, during defaecation, enema retention, and during sleep.

Histological investigation

Ten human external anal sphincter muscles, removed on average 24 hr after death, were examined histologically. Staining techniques employed were: haematoxylin and eosin, the Sudan method, Heidenhain's iron-haematoxylin, Mallory's connective tissue stain, and Weigert's elastic stain with tetrazine counterstain.

RESULTS

Resting tone

In all subjects the anal sphincter was found to be in a state of tonic contraction, the degree of tone varying with posture and different forms of activity (Fig. 2*a*). It was found that if a subject remained alert and interested in the proceedings the tone was somewhat greater than when he composed himself for rest. There was considerable variation between subjects and some fluctuations in tone in the same subject from time to time at rest. The resting tone though frequently slight was never absent. The question of the behaviour of the muscle during sleep will be discussed below.

Voluntary contraction

The subject was instructed to make a maximal effort to indraw the anal orifice. This movement was accompanied by a vigorous outburst of action potentials from the external anal sphincter in all seven subjects. The gradation of contraction which could be elicited demonstrated that there is a considerable degree of voluntary control of the sphincter (Fig. 2*b*).

During voluntary contraction simultaneous electrical recordings with surface electrodes were also made from the gluteal muscles. Contraction of the sphincter without, or with very little, associated gluteal muscle activity was commonly observed (Fig. 2*b*). Voluntary contraction of gluteal muscles was usually associated with sphincteric contraction (Fig. 3), but occasionally gluteal activity was observed without any change in sphincter tone, as shown in Fig. 4. In two subjects the retention of an enema was accompanied by continued powerful contraction.

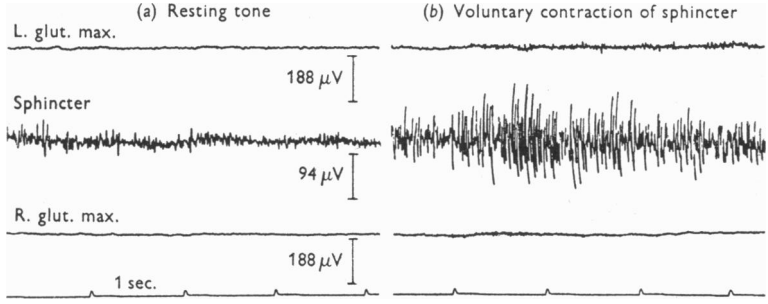

Fig. 2. Simultaneous electromyograms of external anal sphincter together with both gluteus maximus muscles, subject lying on couch on his left side, showing (*a*) resting tone, (*b*) voluntary contraction of sphincter. Note the associated slight gluteal activity. Time: 1 sec.

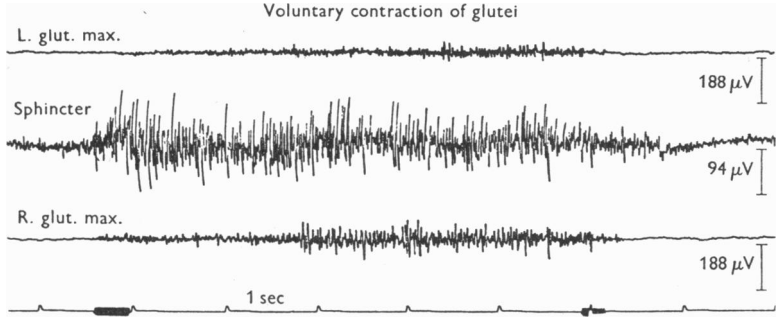

Fig. 3. Electromyograms of external anal sphincter and glutei maximi during voluntary contraction of both gluteal muscles. Subject lying on couch on his left side. The associated activity of the sphincter is clearly seen. This was the most frequent finding; compare Fig. 4.

Increased intra-abdominal pressure

Increase of intra-abdominal pressure produced by such various activities as speaking, coughing, laughing or weight lifting was always associated with an increase of sphincter tone. This is illustrated in Figs. 5 and 6. Fig. 5 is an electromyogram of the external anal sphincter showing gradation of activity with increase of volume of speech—the louder the speech the greater the activity of the sphincter. The increase of activity with coughing is shown in Fig. 6.

It was found, however, that according to how the intra-abdominal pressure was increased the sphincter might contract more vigorously or might relax. One way of raising the intra-abdominal pressure is by making an expiratory effort. When a maximal expiratory effort was made there was a continuous

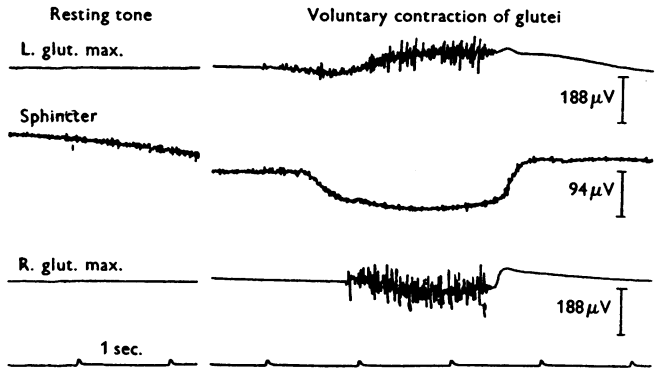

Fig. 4. Electromyogram of external anal sphincter and glutei maximi during voluntary contraction of both glutei, subject lying on couch on his left side. There is no change in sphincter tone. This is seldom found; compare Fig. 3.

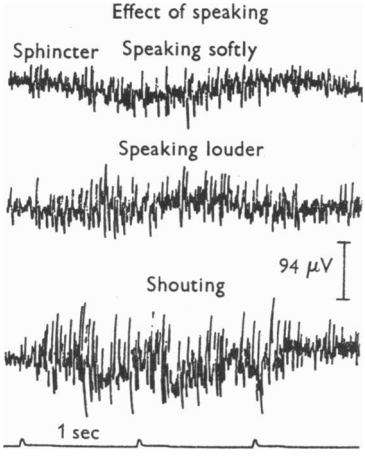

Fig. 5.

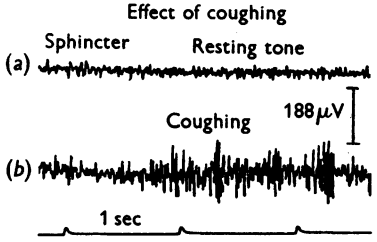

Fig. 6.

Fig. 5. Electromyogram of external anal sphincter showing gradation of activity with increase of volume of speaking, subject lying on couch on his left side.

Fig. 6. Electromyogram of external anal sphincter, showing (*a*) resting tone, and (*b*) activity during coughing. Subject lying on couch on his left side.

build-up of sphincter activity which outlasted the expiratory effort by 1–2 sec, as shown in Fig. 7. This record also shows the fluctuations in resting tone referred to earlier.

When the subject was simply asked to strain, sphincteric tone was always

increased. This is illustrated in Fig. 8 which also shows the activity of the anterior abdominal wall muscles during this procedure.

When, however, the subject made an attempt at defaecation an associated relaxation of the sphincter was found, but not in every subject. The record in

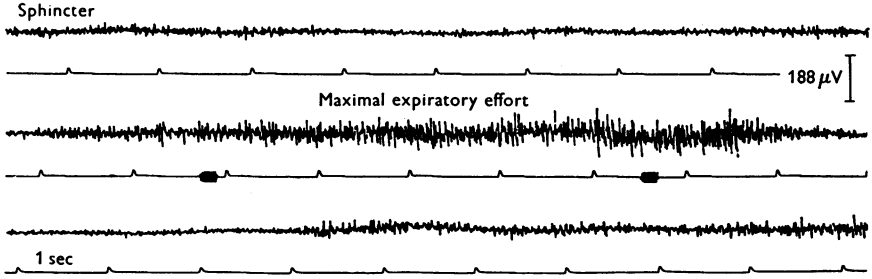

Fig. 7. Electromyogram of external anal sphincter, showing the resting tone and (between the signal marks) the increase in tone during a maximal expiratory effort. The record reads continuously from above downwards. Subject standing.

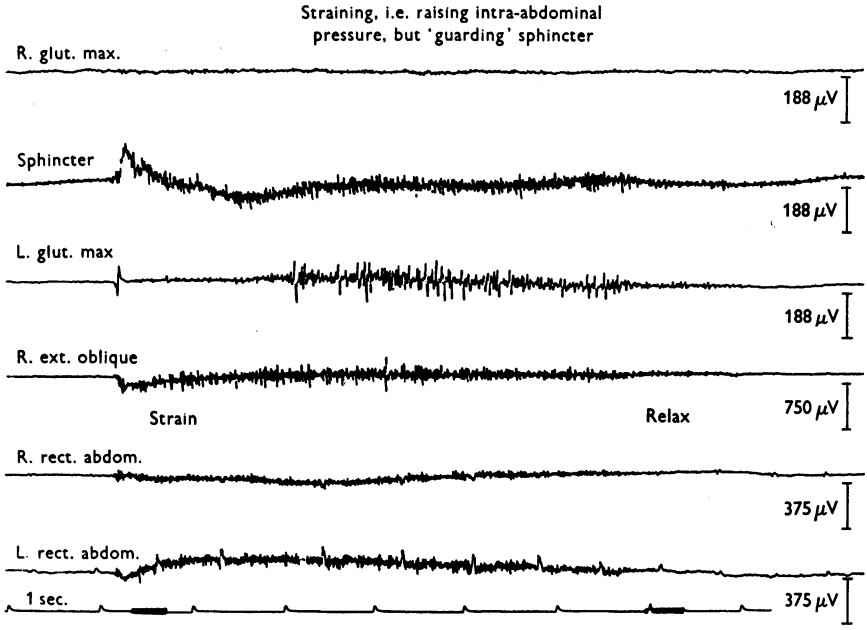

Fig. 8. Simultaneous electromyograms of external anal sphincter, glutei maximi and anterior abdominal wall muscles, showing increased sphincter tone during straining without attempted defaecation. Subject lying on couch on his left side.

Fig. 9 shows a marked decrease in sphincter activity with a build up of anterior abdominal wall muscle tone during a defaecatory effort. The record also shows a period of enhanced sphincter activity at the end of the effort—a rebound or after-discharge. The failure on the part of certain subjects to produce relaxation of the sphincter during attempted defaecation is probably due to the

difficulty in securing full co-operation in what must be regarded as a psychologically difficult situation.

Digital examination of the rectum

Such an examination always elicited a brisk and vigorous increase of sphincter tone which was maintained throughout the examination and consistently showed a further burst of activity at the moment of withdrawal.

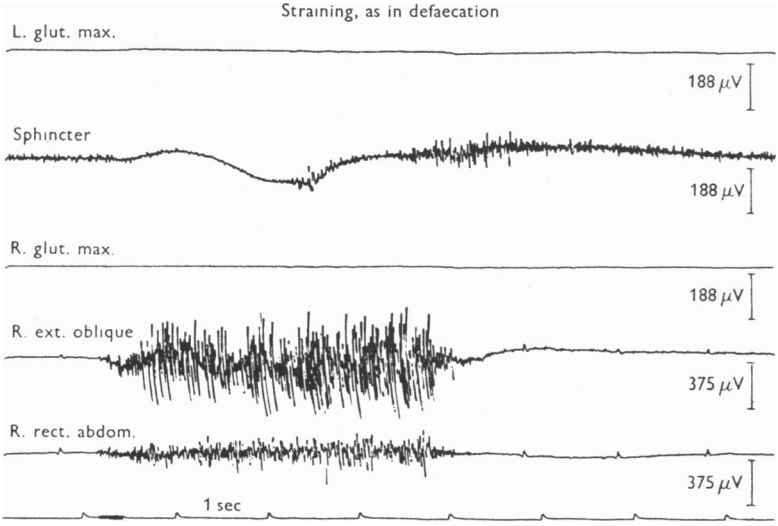

Fig. 9. Simultaneous electromyograms of external anal sphincter, glutei maximi and anterior abdominal wall muscles, showing relaxation of sphincter during an attempt at defaecation. Subject lying on couch on his left side.

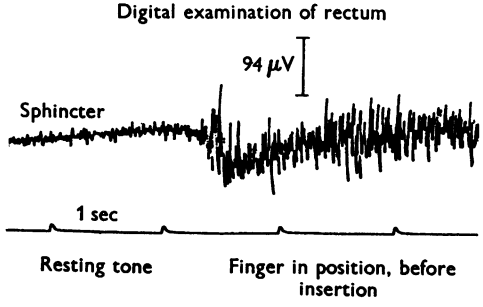

Fig. 10. Electromyogram of external anal sphincter showing the sensitivity to very light pressure with the finger on the anal margin. Subject lying on couch on his left side.

After withdrawal of the finger the increase in tone subsided somewhat slowly. Even the slightest contact of the finger with the anal margin sufficed to produce an immediate burst of activity. This striking sensitivity is illustrated in Fig. 10, which shows a large increase of sphincter tone resulting from very light pressure with the finger on the anal margin.

In Fig. 11 the build-up in sphincter activity during insertion of the finger is seen in the latter part of the record. Fig. 12 is part of the same record as Fig. 11, with a few seconds gap between, during which the finger was stationary in the rectum. On withdrawal of the finger, which commenced at the signal

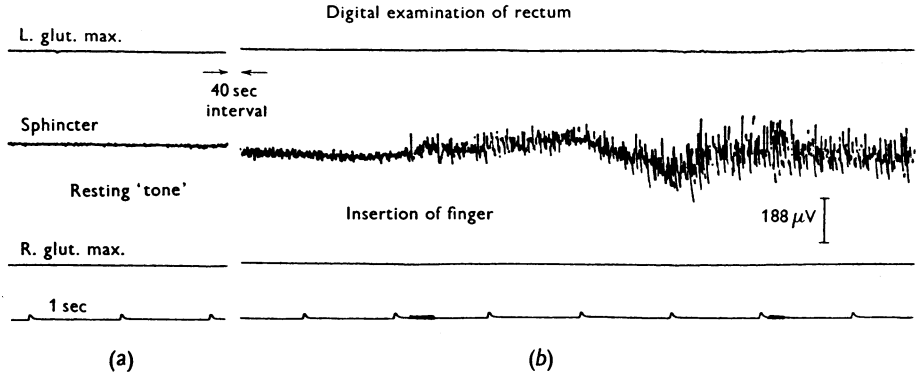

Fig. 11. Electromyogram of external anal sphincter (*a*) resting tone 40 sec before digital examination, and (*b*) showing vigorous activity associated with insertion of finger into anal canal. First signal mark: entry begins. Second signal mark: entry complete, finger stationary. Subject lying on couch on his left side.

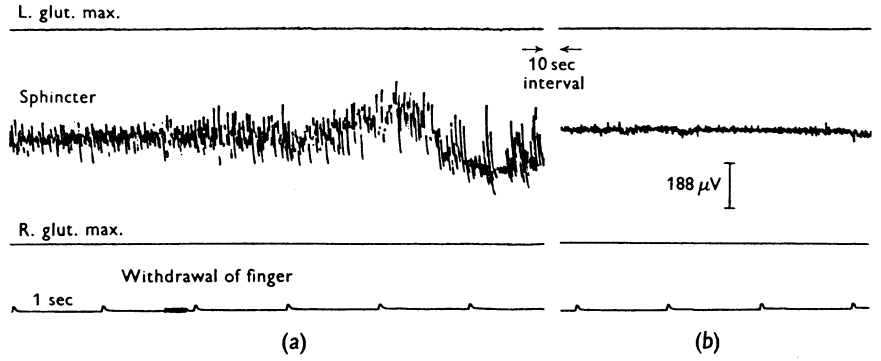

Fig. 12. Continuation of record in Fig. 11 after interval of 2 sec showing (*a*) further outburst of activity on withdrawal of finger, and (*b*) tone 10 sec later.

mark in Fig. 12*a*, there was a vigorous burst of sphincter activity coinciding with the moment of removal of the finger. Tone diminished rapidly and resting tone 10 sec later is shown in Fig. 12*b*. Tone is still greater than before digital examination was commenced; see record (*a*) of Fig. 11.

Activity during sleep

In two subjects records were taken from the external anal sphincter during sleep, simultaneously with a 3-channel electroencephalogram. The latter record was taken in order to obtain evidence of when the subject was in fact

asleep, and the appearance of slow wave activity and K-wave complexes was taken as the criterion. The resting tone of the sphincter diminished from the commencement of the experiment as the subject became composed for rest, and reached a minimum at which there was barely discernible activity during the periods of sleep. During temporary disturbance of sleep and within a few seconds of awakening there was an increase in sphincter activity.

DISCUSSION

It is generally stated in the standard anatomical text-books that the anus and anal canal are normally kept closed by the tonic contraction of the external anal sphincter aided by the pubo-rectalis and internal sphincter, and that, in forcible voluntary occlusion of the canal, the first two muscles increase their activity. Although the internal sphincter is an unstriped muscle, Thompson (1899) believed that it is to a slight degree under voluntary control.

The present findings support the view that the external anal sphincter maintains closure of the anal canal by tonic contraction, but the degree of tone on occasions can be very slight as compared with the activity found in the same subject at other times. In subjects composed for rest we have observed considerable reduction of the action potential discharge, i.e. of the tonic contraction, but in no such instances were action potentials completely absent from the record.

During the levels of sleep at which the e.e.g. showed slow wave activity and K-wave complexes, action potentials in the sphincter became minimal. Thus it must be concluded that external anal sphincter tone is greatly reduced during sleep. On awakening and also during temporary disturbance of the sleep rhythm there was a return of sphincter activity and hence of sphincter tone. Presumably the closure of the anal canal during sleep is achieved by the internal anal sphincter, but it would be very difficult to verify this.

Our results also confirm that the external anal sphincter is under voluntary control. This control can be exerted with considerable precision over a wide range of muscle activity. The action potential discharge during maximum voluntary contraction was comparable with that found during enema retention.

An action of the external sphincter and pubo-rectalis not as a rule sufficiently emphasized is that of closing the anal aperture firmly during the contraction of the levatores ani and the other constrictor muscles of the abdomino-pelvic cavity during powerful muscular efforts not connected with defaecation, e.g. vomiting, expiration, parturition.

Intra-abdominal pressure is raised by contraction of the anterior abdominal wall muscles or by contraction of the diaphragm, as in straining, or in expiratory efforts (Floyd & Silver, 1950; Campbell & Green, 1953). In the present study contraction of the external anal sphincter was found in all

procedures in which the intra-abdominal pressure was raised, with the single exception of defaecation. Thompson (1899) stated that the external anal sphincter is at first relaxed during the passage of the rectal contents through the anal canal, but later may become forcibly contracted thereby assisting and completing the action of the circular fibres of the bowel. The present experiments substantially confirm these views.

Garry (1934) fully reviewed problems relating to the innervation of the external sphincter and of its reaction to curarization. In the light of present-day knowledge of the varying pharmacological responses of different skeletal muscles, one of his comments seems to reveal great prescience, namely, that it may be unwise to assume that all striped muscle is qualitatively the same. He further remarked that the external sphincter seems to be an extreme example of a red muscle with small fibres rich in sarcoplasm. However, in a preliminary histological study, some of the sphincter material examined by us showed the presence of muscle fibres of apparently two types, some possessing certain of the characters commonly ascribed to red (dark) fibres, and others those of white (light or pale) fibres. In a personal communication Dr Bacsich of Glasgow University confirmed that he also had noted the presence of two fibre types in the external sphincter, and further communicated that he had noticed the same thing in the upper part of the oesophagus, an observation which has also been made by one of the present authors (E. W. W.). Further work is proceeding on the histological features of the human external anal sphincter muscle fibres. It is tempting to suggest that the external sphincter muscle in man may contain a proportion of quick-acting fibres with a brisk response for the immediate prevention of anal penetration by reinforcement of the tonic action of the rest of the muscle. For it must be borne in mind that in most mammals two muscles, the pubo-coccygeus and ilio-coccygeus, act as depressors of the tail, the basal part of which functions as a perineal shutter. In orthograde primates, however, the tail no longer helps to close the perineum, its muscles serving to support the pelvic viscera (Keith, 1948).

SUMMARY

1. The activity of the external anal sphincter has been studied electromyographically in seven normal male subjects.

2. It has been shown that the sphincter is always in a tonic state during waking hours. During sleep the tone becomes minimal. A wide range of variation is found in different subjects.

3. Raised intra-abdominal pressure is always accompanied by increase in sphincter tone, except that in straining for defaecation sphincter tone decreases.

4. Two types of muscle fibres corresponding perhaps to so-called red and white fibres were seen in a number of the external sphincter muscles examined.

We are grateful to our students for their co-operation in these experiments, and to Miss E. D. Hewland for drawing Fig. 1.

REFERENCES

BECK, A. (1930). Elecktromyographische Untersuchungen am Sphincter ani. *Pflüg. Arch. ges. Physiol.* **224**, 278–292.

CAMPBELL, E. J. M. & GREEN, J. H. (1953). The expiratory function of the abdominal muscles in man. An electro-myographic study. *J. Physiol.* **120**, 409–418.

FLOYD, W. F. & SILVER, P. H. S. (1950). Electromyographic study of patterns of activity of the anterior abdominal wall muscles in man. *J. Anat., Lond.*, **84**, 132–145.

FLOYD, W. F. & SILVER, P. H. S. (1952). Comparative merits of ink-writer and cathode-ray oscillographs for electro-myography. *J. Physiol.* **117**, 36–37*P*.

FRÖHLICH, A. & MEYER, H. H. (1912). Untersuchung über die Aktionsströme anhaltend verkurzter Muskeln. *Zbl. Physiol.* **26**, 269–277. Cited by BECK, A. in *Pflüg. Arch. ges. Physiol.* 1930, **224**, 278–292.

GARRY, R. C. (1934). The movements of the large intestine. *Physiol. Rev.* **14**, 103–132.

KEITH, A. (1948). *Human Embryology and Morphology.* London: Edward Arnold and Co.

PATON, W. D. M. & ZAIMIS, E. J. (1952). The methonium compounds. *Pharmacol. Rev.* **4**, 219–253.

RANVIER, L. (1874). De quelques faits relatifs à l'histologie et à la physiologie des muscles striés. *Arch. Physiol. norm. path.* Série 2, 1, 5–15.

THOMPSON, P. (1899). *The Myology of the Pelvic Floor. A contribution to Human and Comparative Anatomy.* London: McCorquodale.

WALLS, E. W. (1953). The fibre constitution of the human gastrocnemius and soleus muscles. *J. Anat., Lond.*, **87**, 437.