ARTICULAR NEUROLOGY - A REVIEW

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ARTICULAR neurology is that branch of the neurological sciences that concerns itself with the study of the anatomical, physiological, and clinical features of the nerve supply of the joint systems in various parts of the body. As such, it is clearly of relevance not only to neurologists and neurosurgeons, but also to orthopaedic and physical medicine specialists and to physiotherapists; nevertheless, until recently it has never been the subject of specific and organised investigation.

For this reason this article summarizes some of the recent developments in this field, with particular regard to their more basic scientific features, in so far as these have emerged from the studies carried out over the past decade by workers in the Neurological Laboratory of the Royal College of Surgeons of England. These investigations have thus far embraced the temporomandibular, laryngeal, spinal, hip, knee, and ankle joints; and the detailed observations that have been made in regard to each of these joint systems can be found described in the references listed in the classified bibliography at the end of this article,

Extrinsic Innervation of Synovial Joints

Each synovial joint in the body has a dual pattern of nerve supply- first, by primary articular nerves that reach the joint capsule and ligaments as independent branches of adjacent peripheral nerves, often (but not exclusively) in company with articular blood vessels; and second, by accessory articular nerves, which are branches of related muscle (and sometimes cutaneous) nerves. Many of these latter articular nerves arise within some of the muscles that are attached to each joint capsule as intra-muscular branches of various muscle nerves, and reach the joint by running (embedded in the interfascicular connective tissue) through the substance of the muscle, Neurohistological studies have shown that each articular nerve contains a mixture of myelinated and unmyelinated nerve fibres whose diameters range from less than 1 micron to 13,u (and up to 17,u in a few instances), When these data are considered in combination with the results of oscillographic analyses of the impulse traffic in the articular nerves, of electrical nerve stimulation procedures, and of other neurophysiological investigations, it emerges that the fibres in articular nerves generally may be subdivided into the

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three major size categories indicated in Table 1, each of which has specific functional correlates conferred upon it by the particular nerve endings in the joint tissues that its constituent fibres supply.

A large proportion (at least 45%) of the total number of fibres in each articular nerve has diameters of less than 5 microns Most of these small myelinated and unmyelinated fibres are afferent in function and subserve articular pain sensation; but a small proportion of the unmyelinated fibres in this group consists of visceral efferent fibres of sympathetic origin that innervate the articular blood vessels-that is to say, these latter are articular vasomotor nerve fibres. There is no evidence of the existence in any articular nerve of secretomotor fibres, or indeed of any direct nervous influence on the production of synovial fluid other than that exerted indirectly by vasomotor nervous effects on the diameter of the articular blood vessels (and thus on joint blood-flow).

Another large proportion (some 45% to 55% of the total) of fibres in articular nerves consists of medium sized myelinated fibres between 6 and 12 microns in diameter, all of which are mechanoreceptor afferents. That is to say, these nerve fibres innervate small corpuscular endorgans of varying morphology (vid. inf.) located mainly in the fibrous capsules and fat pads of the joints, which respond to changing mechanical stresses in these tissues (see Table 11) and which subserve reflexogenic and kinaesthetic functions.

A third small proportion (some 10% or less) of fibres consists of very large myelinated fibres between 13 and 17/1 in diameter that are also mechanoreceptor afferents. However, these latter (as indicated in Table 11) innervate very large corpuscular endorgans (of relatively high threshold) that are confined to the joint ligaments; and thus this third group of afferent fibres is absent from those articular nerves that do not contribute branches to extrinsic or intrinsic joint ligaments. Their function appears to be entirely reflexogenic.

Articular Receptor Nerve Endings

The use of specially modified neurohistological staining techniques, correlated with neurophysiological observations of receptor endorgan behaviour, has shown that the nerve endings distributed through the tissues of all synovial joints may be classified into four distinct varieties in terms of morphological and behavioural criteria, as indicated in Fig. 1 and Table 11.

Type I Receptors

The Type I receptors, a group of which is shown in Fig. 1A, are globular or ovoid corpuscles with a very thin capsule that are similar to those described originally by Ruffini in subcutaneous and fascial connective tissues. They are numerous in the capsular tissues of all the limb joints, the apophyseal joints of the vertebral column and the temporomandibular joints-although their population density differs in the individual joints. For example, in the limbs the Type I receptors appear to be more densely distributed in the proximal (for example, in the hip) joints than in more distal (for example, the ankle) joints; whilst in the spine they appear to be more numerous in relation to the apophyseal joints of the cervical region than elsewhere. In each joint in which they are present, the Type I receptors are located mainly in the superficial (that is, in the external) layers of the fibrous capsule, within which they are distributed tridimensionally in clusters of up to 6 corpuscles per cluster; and each such cluster is supplied by the fine terminal branches of a single myelinated afferent axon that is some 6 microns to 9,u in diameter (see Table 11). Within the capsule of each individual joint, the clusters of Type I receptors show regional differences in their distribution density, in general being more numerous on those aspects of the joint capsule that undergo the greater changes in stress during natural joint movement: the details of the distribution of these receptors in relation to individual joints can be found in the references appended to this article.

Physiologically, the Type I receptors behave as low threshold, slowly - adapting mechanoreceptors responding to the changing mechanical stresses obtaining in the part of the fibrous capsule in which they lie. For this reason, a proportion of the lowest threshold Type I receptors in each joint capsule is always active in every position of the joint, even when it is immobile. This ' resting discharge ' usually has a frequency of 10-20 impulses per second, and is generated partly by the stresses created regionally within the joint capsule by the varying degrees of tone in the muscles attached to it, and partly by the overall capsular stress created by the fact that the intracapsular (that is the intraarticular) pressure is normally some 5-10 mm Hg less than the external atmospheric pressure. Alterations - either increases or decreases-in the rate of this resting discharge occur whenever the joint is moved actively or passively by manipulation, whenever the tension in the related muscles changes isotonically or isometrically, or whenever the pressure gradient between the interior of the joint and the atmosphere is altered sufficiently. In addition, as the mechanical stress in particular parts of the joint capsule increases with active or passive movement or with isometric changes in muscle tone, additional Type I receptor clusters of increasing threshold are recruited seriatim thereby augmenting the total quantum of afferent activity being discharged along the articular nerves into the central nervous system.

The Type I receptors may thus be categorised as static and dynamic mechanoreceptors, whose discharge pattern signals static joint position, intraarticular or atmospheric pressure changes, and the direction, amplitude, and velocity of joint movements produced actively or passively.

Type 11 Receptors

The Type 11 receptors, one of which is illustrated in Fig. 1B, are elongated, conical corpuscles with a thick multi-laminated connective tissue capsule enclosing a single (or sometimes multi-stranded) unmyelinated nerve terminal that ends in a bulb or a Y-shaped bifurcation near the apex of the corpuscle. Some previous workers have regarded these nerve endings as a modified form of the Vater-Pacinian corpuscle, but for reasons discussed in detail elsewhere we do not agree with this homology. In fact, true Pacinian corpuscles are not found in the tissues of any joint anywhere, although they are numerous in peri-articular tissues (and in periosteum) in many parts of the body.

The Type 11 corpuscles are present in the fibrous capsules of all joints in numbers that vary with the particular joint; but in the limbs they are relatively more numerous in distal (for example, the ankle) joints than in more proximal joints such as the hip. They are also particularly numerous in the temporomandibular joints, and in the intercartilaginous joints of the larynx. They are located mainly in the deeper layers of the fibrous capsules of the joints, particularly at the border between the fibrous capsule and the sub-synovial fibro-adipose tissue where they often lie alongside or coil around the articular blood vessels. They are distributed in each joint capsule in clusters of 2-4 corpuscles per cluster, each such cluster being innervated by a branch of a parent myelinated afferent articular nerve fibre some 9 microns to 12 microns in diameter, as indicated in Table II It should also be noted that similar clusters of Type 11 endings are present on the surfaces of all the fat pads related to synovial joints, whether these be intra-articular or extra-articular.

These Type 11 corpuscles behave as low threshold, rapidly - adapting mechanoreceptors. For this reason they are entirely inactive in immobile joints, and become active for brief periods (of one second, or less) only at the onset of joint movement-that is to say, at the moment at which sudden changes of stress occur in the regions of the joint capsule or fat pad in which they lie. When they are so stimulated, each cluster of Type, 11 receptors emits a brief, high-frequency burst of impulses into the related afferent axon that lasts less than one second-and very often less than half-a second.

Furthermore, as the diameter of the afferent nerve fibres innervating the clusters of Type 11 corpuscles is somewhat greater than that of the fibres innervating the Type I clusters, the centripetal conduction velocity of the Type 11 volley is faster by some 20-40 m/sec than that of the impulses emanating from the Type I corpuscle. In summary, then, the Type 11 corpuscles can be regarded solely as dynamic mechanoreceptors, whose brief, high-velocity discharges signal joint acceleration and deceleration whether these situations are created by active or by passive joint movement.

Type III Receptors

Type I and Type 11 corpuscles are joint capsule receptors primarily, whereas the Type III corpuscles an example of which is shown in Fig. 1C - are confined to the joint ligaments, both extrinsic and intrinsic. They are the largest of the articular corpuscles and are identical structurally with the tendon organs of Golgi of which they appear to be the articular homologue As can be seen in Fig. 1C, each Type I corpuscle is a fusiform endorgan applied longitudinally to the superficial surfaces of the joint ligaments, usually near their bony attachments, and consists of a filmy connective tissue capsule enclosing a mass of densely arborising nerve filaments derived from a large myelinated parent afferent axon that may be up to 17 microns in diameter, as indicated in Table 11.

A few of these corpuscles are found on all the extrinsic (that is, the collateral) ligaments of the limb and spinal apophyseal joints and on all intrinsic joint ligaments, such as the cruciate ligaments in the knee joint and the ligamenturn capitis femoris in the hip joint. A few are also present in relation to the lateral ligament of the temporomandibular joint; but they are absent from the longitudinal and interspinous ligaments of the vertebral column.

The data available thus far suggest that the Type III corpuscles behave as high-threshold, slowly - adapting mechanoreceptors in a manner similar to that of the majority of Golgi endorgans related to tendons. For this reason they are completely inactive in immobile joints, and only become active towards the extremes of active or passive joint movement-that is to say, when considerable stress is generated in joint ligaments. It will also be apparent that the generation of comparable ligamentous stresses by the application of longitudinal traction to the limbs will likewise (should the traction be of sufficient force) activate them. In all these circumstances the Type III corpuscles then emit a stream of impulses that travels centripetally at high velocity in the large diameter afferent fibres in the articular nerves into the related parts of the central nervous system; and this discharge adapts only very slowly if the extreme joint displacement or joint traction be maintained.

Type IV Receptors

The Type IV category of articular receptor nerve-endings embraces the non-corpuscular nerve-endings in the joint tissues, and is represented either by lattice-like plexuses of small unmyelinated nerve fibres (as in Figure ID) or free nerve-endings (as in Figure 1E). These terminations are derived from the smallest of the afferent fibres in the articular nerves, as indicated in Table 11, some of which (those between 2 and 5 microns in diameter) are thinly myelinated, whilst the remainder (those less than 2 ,u in diameter) are unmyelinated. The plexus or network system of terminals is prominent in the limb, spinal apophyseal and temporomandibular joints, in each of which it is distributed throughout the fibrous capsule and the adjacent periosteum, the articular fat pads (both external and internal) and the adventitial sheaths of the articular blood vessels. In the capsular tissue of these Joints free nerve-endings are relatively sparse, being confined largely to the extrinsic and intrinsic joint ligaments, as depicted 'in Figure 1E In brief 'it seems that plexus system is the main variety of the Type IV receptor ending in fibrous capsules and joint fat pads, whereas the free nerve-ending variety is more characteristic of joint ligaments.

Either variety of this Type IV category constitutes the pain receptor system of the articular tissues; and as such, the plexuses and free nerve-endings are entirely inactive in normal circumstances-but they become active when the articular tissues containing this type of ending are subjected to marked mechanical deformation or tension, or to direct mechanical or chemical irritation-such as may be provided by the exposure of the nerve endings to agents such as histamine, bradykinin, or 5-hydroxytryptamine (which substances are constituents of inflammatory exudates, and are produced by damaged or necrosing tissues). In this connection, it should be emphasised that the Type IV category of receptors is entirely absent from the synovial lining of every joint that has been examined, and is also lacking from the menisci present in the knee and temporomandibular joints, and from the intervertebral discs. There is no mechanism, then, whereby articular pain can arise directly from the synovial tissue or menisci in any joint, and surgical removal of synovial tissue or joint menisci likewise does not involve removal of pain-sensitive articular tissues per se.

Functions of Articular Receptor Systems

The nerve-endings and their afferent fibres that have been described thus far are responsible for two main functional consequences-the provision of articular sensation and the generation of reflex influences on the activity of the related striated musculature.

Articular Sensation

The joint tissues, by virtue of their nerve supply, are provided with two types of sensory innervation, mechanoreceptor sensation and pain sensation, the former providing the basis for kinaesthetic and postural perceptual experience.

Postural and kinaesthetic perception-that is to say, conscious awareness of static joint position and of the direction, amplitude, and velocity of joint movements -is provided primarily by the input from the Type I mechanoreceptor nerve endings that have been described above, supplemented by visual observation of joint position and movement and by the concomitant sensory input from cutaneous mechanoreceptors located in the skin over the joints. For many years it was erroneously believed that these types of sensation were contributed by afferent discharges reaching the brain from receptors in the striated musculature including the muscle spindles; but it is now clear (from a considerable body of evidence that cannot be reviewed here) that this is not the case, and that both postural and kinaesthetic sensation is based to a very considerable extent on perceptual awareness of the afferent discharges delivered to the paracentral and parietal regions of the cerebral cortex from the Type I receptors that are distributed throughout the fibrous capsules of all synovial joints, by way of collateral branches of the articular afferent fibres in the dorsal nerve-roots that ascend in the posterior columns of the spinal cord to the gracile and cuneate nuclei, and their relays therefrom to the thalamus by way of the medial lemniscus. For this reason injuries to or diseases affecting the fibrous capsules of joints that lead to degeneration of the corpuscular nerve-endings located therein produce profound impairment of postural and -as can be shown by careful clinical examination of patients with a variety of joint injuries and diseases.

Articular pain sensation, on the other hand, is generated when the plexiform or free nerve-ending system located in the joint tissues is irritated mechanically or chemically-as by marked mechanical deformation or direct mechanical irritation of the fibrous capsule and ligaments of a joint (as with joint dislocation, for instance), or by the intra-articular accumulation of an inflammatory exudate - the afferent impulses being delivered to the cerebral cortex by way of the spinothalamic and spinoreticular tracts.

Arthrokinetic Reflexes

Afferent discharges from the receptors in joint tissues also exert potent reflex influences on the activity of the limb, paravertebral, and respiratory musculature at spinal and brain-stem levels that are of profound significance for physiotherapists, in so far as these reflex effects play a major part in evoking and controlling the changes in the activity of these muscle groups that are associated with active and passive movements of joints in various parts of the body, and with the application of limb and spinal traction. The remainder of this article deals with mechanoreceptor articular reflexes, as these are less familiar to clinicians than are the reflex effects of mechanical or chemical stimulation of the pain receptor system in joint tissues.

Mechanoreceptor reflex effects on muscle tone are exerted by afferent discharges from both Type I and Type 11 receptors, the former being of greater clinical importance in influencing posture and gait than the latter. The differing influence of the two types of reflex input on the same group of muscles may be demonstrated by multichannel electromyography of the muscles operating over a joint (such as the ankle) that contains significant populations of both receptor types

Fig. 2A shows, passive plantar flexion of the fool evokes a brief, high-amplitude discharge of motor units in the related tenotomised tibialis anterior muscle (due to the initial transient discharge of the Type 11 mechanoreceptors located in the stressed anterior capsule of the ankle joint) that rapidly melts into a more prolonged discharge of motor units that persists (with a gradual diminution in amplitude and frequency) as long as the foot is held in the plantar-flexed position- this latter activity being evoked from the slowly-adapting Type I mechanoreceptors that are also present in the anterior joint capsule. Fig. 2B illustrates the comparable diphasic pattern of reflex effects exerted on the gastrocnemius muscle by passive dorsiflexion of the foot.

On the other hand, as the hip-joint capsule contains few Type 11 receptors but many Type I receptors, passive movements of this joint evoke only slight phasic effects on the activity of the related musculature, the dominant reflex effects being mainly of the slowly-adapting variety (see Fig. 3). The recordings in Fig. 3 also illustrate the fact that arthrokinetic reflexes are mutually coordinated (in terms of reciprocal facilitation and inhibition) between the different functional muscle-groups operating over a joint, and that their influence is bilateral in that afferent discharges from mechanoreceptors in one joint influence the tone of the muscles operating over the homologous joint of the opposite limb as well as that of the ipsilateral musculature.

Other experiments (see bibliography) have shown that afferent discharges from the Type III mechanoreceptors related to the collateral and intrinsic ligaments of joints are probably not evoked in circumstances of active and passive joint movement within physiological ranges because of the high threshold of these receptors; but at the extremes of joint displacement, or in the presence of powerful distracting or traction forces applied across joints, they may be activated to produce profound reflex inhibition of activity in some of the muscles operating over the joint (accompanied by moderate facilitation of activity in other muscles operating over the same joint).

Additional experimental and clinical observations (see bibliography) have shown that loss of the normal arthrokinetic reflexes provided from the mechanoreceptors in a joint as a result of trauma or disease results in profound abnormalities of limb and spinal posture and movement. It is now clear, therefore, that such articular mechanoreceptors (hitherto largely neglected by physiologists and clinicians) are of considerable importance in the circumstances of everyday life-not only in respect of their potent contribution to perceptual awareness of joint position and movement, but also in respect of their powerful reciprocal reflex regulation of muscle tone in posture and movement. Serious attention must therefore be given by clinicians -and not least, by physiotherapists-to the role of articular reflexes in the regulation of normal and abnormal posture and movement, in addition to their perceptual functions; and articular reflexes must now assume major significance in all clinical considerations of locomotor physiology and pathology, including the effects of surgical operations on and the effects of immobilization of joints.