Marshall Hall, the reflex arc and epilepsy

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ABSTRACT Marshall Hall (1790–1857), who graduated from the University of Edinburgh's Medical School in 1812, was considered one of the greatest physiologists of his day. He advanced knowledge in various areas of medicine, in particular elucidating the mechanism of reflex activity in 1833. Hall suggested that convulsive epileptic seizures arose from heightened activity in the afferent limb or the central component of the reflex arc. From 1838 onwards he developed the idea that reflex-mediated neck muscle spasm in seizures obstructed cerebral venous return, congested the brain and thus caused unconsciousness. Associated reflex-mediated laryngeal spasm then caused convulsing. This was the most comprehensive physiologically based explanation of the major features of the convulsive epileptic seizure then available. Hall subsequently advocated and employed tracheotomy to prevent epileptic convulsing. His idea was taken up, modified and made more acceptable by others, and for a generation was the widely acknowledged basis for interpreting epileptogenesis. However, from 1870 onwards it was superseded by John Hughlings Jackson's accumulating evidence that epileptic seizures often arose in the cerebral cortex.

KEYWORDS epilepsy, Marshall Hall, reflex arc, tracheotomy

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INTRODUCTION

The idea that reflex activity occurred in the nervous system can be found in various forms in the writings of Descartes, Thomas Willis, Whytt, Unzer and Prochaska.[1] However, the possible implications of the concept did not seem to be applied to explain pathological states until 1832, when Marshall Hall (Figure 1), on the basis of his animal experiments elucidating the mechanism of the reflex arc, used the idea to explain the mechanism of a number of disorders, including epilepsy. Before that, epileptic seizures had usually been explained in terms of excesses, or even explosions, of neural energy or nerve force, somewhere in the brain[2,3] or as consequences of postulated anaemia or venous congestion of the brain. This particular aspect of Hall's contribution to medical knowledge seems to have gone unnoticed in some more recent studies of his life and of his numerous scientific achievements,[4,5] although the idea, but only in its fully developed form, received attention in Temkin's monograph on the history of epilepsy.[6]

FIGURE 1 An illustration of Marshall Hall published in *The Lancet* in 1850.[7]

MARSHALL HALL – LIFE AND CAREER

Several accounts of Hall's life and career are available.[4,5,7–11] He was born in 1790 into a Nonconformist family that lived near Nottingham, where his father was a cotton manufacturer. Hall was educated there, and in 1809 began medical studies at Edinburgh University, from which he graduated MD in 1812. He then spent almost two years as a resident house physician at the Edinburgh Royal Infirmary. During this time he collected material for a subsequently published book on the diagnosis of disease. After leaving Edinburgh he visited medical centres on the continent and then commenced medical practice in Nottingham. There, in 1825, he became physician to the Nottingham General Hospital and was

elected to Fellowship of the Royal Society of Edinburgh. Over the previous decade he had built up a substantial practice in Nottingham and, besides his book on diagnosis, had published works on what he called mimoses (various general disorders) and on the practice of bleeding for therapeutic purposes, as well as authoring a number of case reports. He had also collected material for a subsequently published volume on aspects of gynaecology.

In 1826 Hall moved to London, where he again became a busy consultant although he never held any hospital or university appointment. He lectured in some of the London extramural medical schools, carried out a considerable amount of animal experimentation and medical student teaching in his own home, and seems to have become something of a favourite with the editor of *The Lancet*. In 1832 he was elected to Fellowship of the Royal Society of London for his work on the microcirculation of the Batrachia and fishes. He presented the investigation that made him famous, describing the mechanism of the reflex arc, first to the Zoological Society in December 1832 and then to the Royal Society itself, in 1833. He became FRCP in 1841, and gave the College's Gulstonian lectures in the following year, and the Croonian lectures in 1850, 1851 and 1852.

Over the years Hall published numerous papers in the medical press. There, as did some of his contemporaries, he at times repeated parts of the same material on more than one occasion, and republished it in separate monographs. Hall's prose style was usually sparse; he simply set down what he saw as facts in a rather *ex cathedra* fashion in relatively short, often serially numbered, paragraphs. The mental processes involved in arriving at his conclusions were often not made explicit, although their probable natures can usually be deduced from their context and from his other writings. As far as feasible, Hall seemed to try to derive generalisable conclusions from his experimental animal studies and clinical observations, and then developed these conclusions into wide-ranging hypotheses. He did not appear to accept criticism of his concepts or actions at all readily, and he became entangled in a number of controversies with colleagues and with the Royal Society itself.

In 1852 Hall virtually handed his practice to his protégé John Russell Reynolds. Over the last years of his life, Hall became increasingly concerned with various social issues – such as the disposal of sewage and slavery – and published on these. Late in his career, he introduced more satisfactory techniques of artificial respiration[12,13] and for the detection of strychnine poisoning.[14,15] He died in August 1857, after a long period of increasing physical limitation imposed by dysphonia and dysphagia. Considerable detail concerning his final illness and the autopsy findings (probably upper oesophageal carcinoma) appeared in *The Lancet*.[9]

HALL'S IDEAS ON EPILEPSY

In his famous paper on the reflex arc read to the Royal Society on 26 June 1833 and published in the Society's *Philosophical Transactions*,[16] Hall proposed that disturbances of reflex mechanisms might explain various disorders, including asthma, croup, epilepsy, tetanus, hydrophobia, chorea, tenesmus and strangury. He considered that the anatomical basis of the reflex mechanism allowed a possibile new classification of neurological diseases into (i) centric and (ii) eccentric types. On this basis he wrote:

> Epilepsy is plainly of two kinds: the first has a centric origin in the *medulla* itself: the second is an affection of the reflex function, the exciting cause being eccentric, and acting chiefly on the nerves of the stomach or intestines, which consequently form the first part of the reflex arc.

Hall's *medulla* included not only the present-day *medulla oblongata*, but also the white matter of the spinal cord. In effect, Hall proposed that the convulsive element of the epileptic seizure could arise from increased activity in the afferent limb of the reflex arc that began in the gastro-intestinal tract or other viscus, or arise from increased activity originating within the central nervous system itself. Hall attributed the instigation of increased activity in the afferent limb of the reflex arc in epileptic seizures to 'irritation', without clarifying the precise nature of the irritative process. Central nervous system disorders of various types could cause his 'centric' epilepsy.

At this stage, Hall's hypothesis accounted for the convulsive component of the tonic-clonic epileptic seizure but not for the associated loss of consciousness. His 'eccentric' variety of epilepsy coincided with the earlier classificational category of sympathetic (gastro-intestinal, uterine, laryngeal, etc.) epilepsy.[17–9]

For several years after this, Hall's intellectual position regarding epilepsy remained unchanged. On 16 and 22 February and 2 March 1837 he read to the Royal Society another paper which, to his immense and continuing annoyance, was subsequently refused publication in the *Philosophical Transactions*. Instead it appeared in print in his *Memoirs on the Nervous System*,[20] bound together with his 1833 *Philosophical Transactions* paper.[16] In the second part of these *Memoirs* (i.e. in what had been his second paper to the Royal Society) he reiterated his view that:

> The remarks which I have made, in reference to convulsions in infants, are applicable to epilepsy. This disease arises from causes acting through the medium of the excitor nerves, or upon the central part of the system, or the spinal marrow. In the former case the cause is seated in the stomach, the intestine, the uterus and acts through excitor nerves. In the latter,

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> it is seated within the cranium or spinal canal. In all, it acts directly or indirectly on the spinal marrow, the mediate or immediate source of all convulsive diseases.

In his *Lectures on Diseases of the Nervous System*,[21] published in 1836, Hall indicated that centric epilepsy was incurable, while eccentric epilepsy was potentially curable (without providing evidence for this assertion). In 1838, in his *Lectures on the Theory and Practice of Medicine*, he renamed his eccentric epilepsy 'centripetal' epilepsy.[22] These latter lectures mentioned an insight regarding unconsciousness during epileptic seizures, which Hall later worked into a more comprehensive interpretation of epileptic seizure mechanisms. When discussing treatment for his centripetal epilepsy, he mentioned that the attack sometimes 'consists in a momentary loss of consciousness' and that 'sometimes this oblivium precedes the attack of convulsions'. He then posed the question, 'what is the cause and nature of this momentary loss of consciousness?' and provided the following answer:

> A spasmodic affection of the larynx has obviously much to do in this disease, as well as in causing the crying inspiration of croup-like convulsions of infants; so much, indeed, that I doubt whether convulsions could occur without closure of this organ. Convulsion is frequently prevented for hours together by continuously watching the threatenings of it, and dashing cold water on the face. Now the action of cold water upon the trifacial nerve, affects by a reflex influence the opening of the larynx and an act of inspiration, and thus prevents a series of muscular actions which constitute convulsions, viz., closure of the larynx, forcible efforts at respiration, and general spasmodic contraction in the muscles. It is a singular idea, that tracheotomy would effectively prevent epileptic seizures.[22]

He continued his answer by asking another question in the paragraph that followed:

> Does such a spasmodic action take place in the muscles of the neck unnoticed, compress the veins which convey the blood from the brain, and induce the oblivium to which I have just alluded?

A decade later, from 1847 onwards, Hall[23–6] developed this idea into an interpretation of epileptogenesis that embraced both the convulsive element and the loss of consciousness in generalised tonic-clonic epileptic seizures. His 1847 account[23] envisaged epileptogenesis as comprising three phases. In the first phase, 'irritation' of the spinal cord and/or *medulla oblongata* occurred either as a local phenomenon or via the agency of peripheral irritation of afferent ('excitor') nerves. In the second phase, this irritation of the neuraxis produced convulsive contraction of the neck muscles, particularly the platysma (a process Hall termed *trachelismus*), and also spasm of the larynx (*laryngismus*). In the third phase, the neck muscle contraction compressed the jugular veins, resulting in cerebral congestion. This congestion caused unconsciousness and so produced what Hall called 'cerebral epilepsy' (petit mal). If the *laryngismus* was severe enough, convulsing developed, transforming the event from simple unconsciousness into a *haut mal* (grand mal) seizure. Hall did not explain exactly how laryngeal spasm was responsible for widespread convulsing, though he did write that 'epilepsy is strangulation, and strangulation is epilepsy'.[24] Possibly he thought that this was in itself a sufficient explanation, and that going into the intermediate stages of his proposed mechanism was unnecessary.

Hall later added the vertebral veins to the jugular venous system as the vascular structures that were compressed by neck muscle contraction during epileptic seizures. He called this more widespread cervical venous compression *phlebismus* and indulged his penchant for creating new terminology by replacing the terms petit mal and grand mal with *epilepsia minitor* and *epilepsia gravior*, respectively. In a series of papers entitled 'The neck as a medical region' which appeared in *The Lancet* in 1849,[25] Hall extended his neck muscle spasm idea (*trachelismus*) to explain the pathogenesis of additional disorders as diverse as apoplexy, hidden seizures, infantile convulsions, paralysis, mania and delirium.

He also began to advocate tracheotomy in managing epilepsy. He had already touched on this possibility in 1838,[22] as quoted above, but had then proposed it for the stupor or coma that could follow seizures. Between 1848 and 1857 he emphasised that, used for epilepsy, tracheotomy could prevent only the consequences of *laryngismus*, namely the convulsive component of the epileptic seizure. It would not prevent loss of consciousness. Hall published several papers on details of the operation and the instruments and devices he had developed to facilitate the procedure.[26–9] To the end of his career, he seems to have retained his belief in the efficacy of the operation when carried out for the indication that he recognised.

THE OUTCOME OF HALL'S EPILEPTOLOGY

Deficiencies in the fully developed version of Hall's hypothesis concerning epileptogenesis were soon recognised. In 1849 Todd[30] doubted whether venous congestion of the brain could explain unconsciousness during epileptic seizures, and suggested that cerebral anaemia was a more adequate mechanism. Kussmaul and Tenner's animal exsanguination experiments[31] supported Todd's suggestion. Todd also described how he had been able to induce convulsions in tracheotomised experimental animals, and therefore argued that

laryngismus did not explain convulsing during seizures. In 1852 Radcliffe[32] also rejected Hall's hypothesis. Radcliffe pointed out that Hall's interpretation required neck muscle contraction to be present before *phlebismus* could develop and cause loss of consciousness in seizures. However, in human epilepsy convulsing (and unconsciousness) began before any venous congestion of the head could be recognised.

In contrast, Brown-Séquard[33] at first was in overall agreement with Hall's concept and criticised Todd's refutation of Hall's ideas, arguing that the state of the spinal cord in Todd's animals would have differed from that in human epilepsy. Brown-Séquard also reported that, in his own spinal epilepsy model in guinea pigs, repeatedly cauterising the laryngeal surface with silver nitrate minimised or prevented convulsing. This observation suggested to him that laryngeal hypersensitivity rather than airways obstruction was the epileptogenic factor. Perhaps in response to this interpretation, and to various published criticisms of Hall's idea, Brown-Séquard in 1857[34] and in 1860[35] modified Hall's hypothesis and proposed a greater role for eccentric mechanisms in epileptogenesis. He also postulated the existence of 'unfelt' as well as 'felt' epileptic auras.

Furthermore, Brown-Séquard suggested that his postulated increased afferent input into the reflex arc in seizures always spread to higher levels within the central nervous system. There it activated (i) the origin of the cervical sympathetic outflow to produce cerebral vasospasm, resulting in brain anaemia and loss of consciousness, and (ii) the descending motor pathways to produce convulsing.

Hall's protégé, John Russell Reynolds,[36] and also Brown-Séquard,[34] had noted that observable neck muscle spasm was not always present during epileptic seizures. In 1861 Reynolds[37] modified Brown-Séquard's[35] rather one-sided interpretation of the events that instigated epileptogenesis and envisaged a greater role for central processes in activating the *medulla oblongata*, including its vasomotor control mechanism. Reynolds[37] also proposed that, during epileptic seizures with convulsing, Hall's *trachelismus-phlebismus* mechanism contributed to maintaining the unconsciousness already initiated by cerebral vasospasm.

For a time, there was contemporary interest in Hall's advocacy for tracheotomy in preventing human epileptic convulsing.[38–41] Various published reports usually showed that, after tracheotomy, there was less cyanosis during seizures and perhaps less severe convulsing, but the convulsive component of the seizure was not fully abolished. This latter rather crucial point was not emphasised in the reports, although Bucknill[38] and Lockhart Clarke[42] criticised other aspects of Hall's rationale for the procedure. Radcliffe[43] denied that tracheotomy was of value and mentioned three patients who had died during seizures after having undergone the operation. Reynolds[37] found it necessary to write of his benefactor's idea that 'the evidence in favour of tracheotomy is extremely doubtful'. Mounting experience failed to bear out Hall's claims for tracheotomy in managing epilepsy, and the procedure disappeared from use for that particular indication.

By the 1860s the older hypothetical mechanisms of epileptogenesis – cerebral anaemia and cerebral congestion, and sudden release of brain energy – had largely been superseded by refinements of Hall's hypothesis. It was against this background that, after 1870, John Hughlings Jackson[44] began to persuade his contemporaries that epileptogenesis was usually a cerebral cortical and not a brain stem phenomenon. As increasing human and experimental animal evidence for the validity of Jackson's ideas accumulated, Hall's reflex hypothesis of epileptogenesis lost its attractiveness and began to fade from medical awareness, not much more than a decade after its originator's death.

DISCUSSION

Hall's reflex hypothesis of the mechanism underlying epileptic seizures was but one component of an overall contribution to fundamental and applied physiological knowledge that persuaded the editor of *The Lancet,* on the occasion of Hall's death, to term him 'the greatest physiologist of the age'. Hall's chief single achievement was probably his elucidation of the mechanism of the reflex arc. He built on his reflex concept to explain various disease processes, including epileptogenesis. Hall's interpretation was physiologically based and accounted for most of the then-recognised seizure phenomena more adequately than previous concepts, although it did not explain the phenomenon of the seizure aura, which Hall on one occasion[24] mentioned was a cerebral phenomenon, without attempting to interpret it further.

Hall's hypothetical mechanism was fairly quickly recognised to be not entirely satisfactory in certain respects, for example in relation to the production of unconsciousness during seizures and the role of laryngeal spasm in causing convulsing. However, the existence of the hypothesis invited its refinement by some of Hall's successors, notably Brown-Séquard and Reynolds, who produced increasingly plausible explanations of epileptogenesis. In its original version and subsequent modifications, Hall's interpretation of epileptogenesis held sway for a third of a century or longer, before it gradually yielded place to Jackson's evidence that epileptic seizures arise in the cerebral cortex.

Hall's use of tracheotomy for treating epileptic seizures was an unfortunate example of a course of action that

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appeared appropriate in relation to contemporary theory but proved wrong in practice. Yet this outcome did not seem to persuade its originator that the underlying theory itself was wanting.

Although now only of historical interest, in its time Hall's epileptology was an ingenious, though in retrospect largely erroneous, attempt made by a very distinguished and innovative clinician and scientist to provide a rational and physiologically based mechanism and treatment for a common but little-understood disorder.

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