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REVIEW

The place of neuroanatomy in the curriculum

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SUMMARY

Increasingly, with major changes taking place worldwide in health care studies courses (including medicine and dentistry), there is a need to critically evaluate the place, timing, and content of components that used to be grouped collectively under the banner of 'anatomy'. This is certainly true for neuroanatomy where there are so many new research developments that it is difficult to keep pace with changes in the subject and where clinical relevance, for the present time and for the future, is a major consideration. In this chapter we emphasise the need to provide a universally accepted terminology, to outline core syllabuses for medicine and dentistry and to review how syllabuses might develop for other health care courses, for science and psychology courses, and to make a case for neuroanatomy courses to follow the practice of university education in hinting at the frontiers of knowledge as well as providing professional training.

Key words: Anatomy – Neuroscience – Education – Syllabus – Medical – Dental

INTRODUCTION

Within the anatomical sciences, neuroanatomical research is nowadays probably one of the most productive area for investigation, although it has often been reported that the brain remains one of the least understood organs in the body[1]. Given the huge volume of neuroscience research being undertaken, it is not surprising that many universities have, within their anatomy faculty, a significant number of neuroscientists and it is therefore not surprising that such academics fervently wish their students to understand the finer points of their research findings. Indeed, it is almost axiomatic that a university education requires that students are taken to the frontiers of knowledge and that they gain some appreciation of research endeavour from their teachers[2]. However, the quantity of research in neuroscience being undertaken is so great that it cannot be expected that undergraduate students from whatever discipline that requires tuition in neuroanatomy can extend their experience beyond core material. Nevertheless, in contrast to a voluminous literature concerning the teaching of gross anatomy to students in the health care professions[3], to date there has been little discussion concerning the role of neuroanatomy in these professions.

In this paper, we intend to tackle issues that require further debate as a contribution to ensuring that undergraduate students appropriately have both education and training in neuroanatomy. Here we concentrate on issues that are pertinent to medical students, dental students, other health care studies, science students, and psychology students. Regardless of the discipline, it seems to us that debate should centre around four matters:

- Establishing an acceptable terminology for neuroanatomy.
- Defining relevance and core neuroanatomical

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knowledge.
- Understanding the importance of university education as well as professional training.
- Putting the teaching of neuroanatomy in the correct context within a course.

Before dealing with specific health care courses, we will deal with matters relating to terminology since this is common to all.

NEUROANATOMICAL TERMINOLOGY

Presently, the International Federation of Associations of Anatomists (IFAA) has responsibility on a worldwide basis for the reviewing of terminologies in the anatomical sciences (under the auspices of the IFAA's Federative International Programme for Anatomical Terminology (FIPAT))[4]. One of the sub-groups of FIPAT is concerned specifically with neuroanatomical terminology. This is a new group within FIPAT that aims to provide the scientific community with a terminology within the next few years. This group is following the principles set out for the development of other terminologies for gross anatomy, for embryology and for histology. In particular, eponyms are not recommended, although it is appreciated that this in itself might be at variance with neurological terms used in the clinic. Consequently, it is recognised that there needs to be a coming together of the anatomical terminologies with clinical usage. This is a long-term aim but clearly, without the congruence of scientific and clinical terminologies, there will remain problems for educators within the field of neuroanatomy. This potential "Tower of Babel" is being unfortunately built yet higher as a result of the various biomedical scientific disciplines using different terminologies. To indicate the present 'disorder' within neuroanatomical terminology, there is a lack of agreement as to whether terms should reflect the embryological origin of a structure/region or whether the historical names given to the mature nervous system should be retained.

Presently, the FIPAT group dealing with neuroanatomical terminology is headed by Hans ten Donkelaar (The Netherlands) with 4 advisors: Jonas Broman (Sweden), Paul E. Neumann (Canada), Luis Puelles, (Spain), Alessandro Riva (Italy), and Shane Tubbs (USA). In the mission of FIPAT it is stated that: "The central objective of FIPAT in the coming years must be to aim for a standardised anatomical terminology across the health sciences, thereby facilitating efficient information exchange, and indeed more effective patient management". Latin is central. To FIPAT's activities – "The Latin term is the formal, official version. It enables translation into any vernacular and provides an exact point of intersection for communication across disciplines, languages, countries, regions and associations". Since the development of the terminology is on going, the reader is referred to the FIPAT website for further information and guidance [4].

NEUROANATOMY FOR MEDICAL STUDENTS

We begin with discussion of the teaching of neuroanatomy for medical students not just because of the importance of this profession to the human condition in general and the individual's health in particular but because many of the topics covered under this heading will be similar for other courses dealing with health care or at least will have a resonance. In the past, it was a firmly held principle that, before being placed in front of patients, there needed to be a substantial period of time (2 to 3 years usually) when the students were acquainted with the scientific basis of medicine. Thus, the model was established that the healthy body was the first object of study subsequently followed by interpretation of this knowledge to appreciate how disease produced abnormalities. This model is exemplified by the findings in the Flexner Report in the USA (1910)[5].

However, medical schools are increasingly shifting their emphasis away from this principle and towards "basic medical training" that is utilitarian and, in this respect, towards what is deemed to be of "clinical relevance"[6]. The drivers for emphasising medical training and clinical relevance seem to us to arise partly from social and political needs, partly from appreciation that increasingly students wish to engage with clinical matters at the outset of their studies, and partly from trends in medical education. In terms of neuroanatomy, since much of the research presently being undertaken seems to be complex and occasionally speculative it can appear to medical course organisers as being not yet of core clinical relevance. As a consequence, and given the wealth of new knowledge available in other disciplines, a downgrading of the amount of neuroanatomy taught to medical students might be expected. In this regard, it is well documented that there has been a decline in anatomical education within medical courses worldwide[7]. Indeed, within the USA contact hours for gross anatomy has fallen from an average of 170 hours in 2002 to approximately 150 hours in 2012. By contrast, the situation for the teaching of neuroanatomy in the USA has not been so dramatic, contact hours decreasing from 95 hours to 83 hours from 2002 to 2012. Comparing 2009 with 2012, contact hours increased with lecture hours remaining essentially the same with an increase in laboratory hours[8].

Defining clinical relevance and core neuroanatomical knowledge

There is no doubt that much neuroanatomical research is scientifically challenging and generates much excitement in both the scientific and general communities. It is thus potentially of great benefit both to neuroscience and to clinical medicine. Nevertheless, the amount of neuroanatomical information presently being generated is beyond the requirements of the medical undergraduate and consequently those who are responsible for medical courses are keen to ensure that the students do not suffer from factual overload[9]. It can also be argued that it is hard to identify what new findings might become clinically relevant when we are so close in time to the work produced. Whether a solution lies in providing research-linked teaching in selected areas or leaving higher-level content to postgraduate studies is a matter of some debate.

The drive to ensure clinical relevance and to satisfy the aspirations of medical students to be clinically engaged at an early stage in their studies has, however, had some unfortunate, though not entirely unseen, consequences. Firstly, clinical relevance is often narrowly defined as being disease-orientated and this impoverishes medicine by

Table 1. List of core clinical topics that require neuroanatomical knowledge at the early stages of medical education.

DEVELOPMENT OF THE CENTRAL NERVOUS SYSTEM
Interpretation and application of knowledge of embryology for the basic understanding of clinical situations associated with central nervous system malformations (spina bifida, meningocele, meningomyelocele, myelocele, syringomyelocele, encephalocele , hydrocephalus, anencephaly)
Recognition of the importance of folic acid (and derivatives) in the prevention of central nervous system defects
SPINAL CORD
Interpretation and application of knowledge of the relationship of the spinal cord in performing basic medical procedures (e.g. lumbar puncture)
Interpretation and application of knowledge of the distribution of pathways and nuclei that are affected by transverse sectional injury of the spinal cord (space occupying lesions, traumatic injury, vascular injury)
Interpretation and application of knowledge of the distribution of pathways and nuclei in a situation related to lower motor neuron injury (poliomyelitis, degenerative disease)
BRAINSTEM
Interpretation and application of knowledge of the distribution of pathways and nuclei of the brainstem to enable the understanding of such clinical procedures as CT and MRI scans and neuropathologic evaluation of the nervous system central postmortem).
Interpretation and application of knowledge of the distribution of the pathways and nuclei in the brainstem that produce space-occupying brainstem lesions (tumours of the pons, tumours around the midbrain and aqueduct) or vascular lesions (Wallenberg syndrome [lateral medullary syndrome], Weber syndrome [superior alternating hemiplegia]).
CEREBELLUM
Interpretation and application of knowledge of the functions associated with cerebellar pathways in understanding some of the symptoms associated with cerebellar disease (hypotonia, postural changes, ataxia, impaired ability reflex, abnormal eye movements, speech disorders, dyskinesia).
Interpretation and application of knowledge of the functional impairment of the cerebellum in a situation of excessive alcohol intake.
FOREBRAIN
Interpretation and application of knowledge of the distribution of nuclei at different levels of the forebrain for understanding of some clinical procedures (CT and MRI scans, neuropathologic evaluation of the central nervous system postmortem).
Interpretation and application of knowledge of the basal ganglia" in understanding clinical symptoms of Chorea and Parkinsonism.
Interpretation and application of knowledge of the forebrain in relation to space occupying lesions of the cerebral cortex (brain tumour , intracranial hemorrhage) or vascular injury.
BRAIN VENTRICLES AND CSF FORMATION
Interpretation and application of knowledge of structures involved in the production, circulation, and reabsorption of cerebrospinal fluid for understanding some clinical situations such as hydrocephalus and increased intracranial pressure.
Interpretation and application of knowledge of the relationships of brain ventricles and the central canal of the spinal cord, together with choroid plexuses, in understanding tumours of the ventricles.
BLOOD VESSELS OF THE CENTRAL NERVOUS SYSTEM
Interpretation and application of knowledge of the distribution of the arterial supply of the brain for understanding stroke, cerebral aneurysms, intracranial hemorrhages and some diagnostic procedures (e.g. cerebral angiography).
Interpretation and application of knowledge of the venous drainage system of the brain in understanding some clinical situations (e.g. disease of the cavernous sinus) .
FUNCTIONAL CORRELATION OF THE CENTRAL NERVOUS SYSTEM
Interpretation and application of knowledge in the evaluation of lesions at different levels of Central Nervous System pathway (injury at the level of the receptors, peripheral nerve injury, injury to the posterior root, spinal sensory syndromes, sensory syndromes of the brainstem and thalamus, sensory syndrome of the internal capsule, altered sensitivity following central semiovale injury and at the level of the cerebral cortex, Duchenne cell lesions of the anterior horns of the spinal cord or of motor nuclei of the cranial nerves, muscular dystrophy following injury to the peripheral nerves and diseases consequent to changes to the motor plate, primitive muscular dystrophy disease, injury to the cerebral cortex/centrum semiovale and internal capsule, brainstem injury, injury of the pons, lesions of the medulla oblongata, damage to the optic tracts, damage to respiratory, acoustic and vestibular systems).

a failure to accept the functionality model of medicine that recognises the importance of normality and health[10]. Secondly, medicine is further impoverished by becoming disengaged from the standard university educational experience of taking students to the frontiers of knowledge[2]. There are conceptual problems relating to defining core elements within a medical course[11]. Presently, it seems that each medical school has its own version of what is a core syllabus and this certainly applies to neuroanatomy. To take two examples known to the authors: At one university it is considered that all the medical student should study relates to meningitis, headaches, trauma, cranial nerves and their testing, and damage to peripheral nerves. At another university, clinical neurology is left to the clinicians, while at another university (one employing one of the authors), there is a much more extensive and detailed list of core clinical topics that require neuroanatomical knowledge at the early stages of medical education (Table 1).

Such diversity of clinical training clearly cannot be accepted educationally. To do so ultimately disadvantages both the student/prospective medical practitioner and the patients by not having more universally agreed standards and syllabuses. Indeed, if the medical schools, with the support of the anatomical and neuroscience communities, do not tackle these matters then eventually other outside authorities will (e.g. government agencies). In the European context, it is conceivable that the European Union could, through the Bologna process[12], define core syllabuses that are reinforced by common examinations to be passed before being licensed to practise medicine (as in some parts of the world, e.g. USA[13]). This would inevitably lead to league tables for medical schools, teaching that would be examination-focused, learning that was strategic according to what was assessed, and therefore further away from the established university education model.

Various attempts have been made to provide core syllabuses by international organisations. For example, the Anatomical Society within Great Britain and Ireland has provided a core syllabus for gross anatomy (that includes some elements of neuroanatomy)[14] and other gross anatomy core syllabuses have been developed by anatomical societies in America and in the Netherlands[15]. As yet, however, there are no internationally-agreed syllabuses and there is no syllabus that specifically deals with neuroanatomy. To deal with this problem, the IFAA, together with the Trans-European Pedagogic Anatomical Research Group (TEPARG), supported by the European Federation for Experimental Morphology (EFEM), is in the process of formulating a core syllabus for neuroanatomy in the medical curriculum using a Delphi Panel to initiate the process[16]. It is intended that this core syllabus will be published on the web when it will become available for comment and amendment by interested parties (anatomical, neuroscientific and clinical). This core syllabus will not dictate what can, or cannot, be taught but will be a guideline for what should appear at some stage within the medical curriculum. Furthermore, it will not dictate how the subject will be taught or specifically when it will be taught. Just as for a neuroanatomical terminology, it is recognised that the input of clinicians into the development of the IFAA/EFEM core syllabus is essential. Analysis of the opinions of the Delphi Panel for neuroanatomy provides a “core syllabus” that is outlined in Table 2. It is important to realise at this stage that these suggestions will be modified further by input from anatomists worldwide. Furthermore, in the future, the neuroanatomy syllabus will be published in a scientific/anatomical journal to include not just core material but also recommendations and information concerning material that is not deemed appropriate for teaching during initial medical training.

The importance of a university education

We have already made mention of the paradox between the needs of a university education versus the needs of medical training. In our view, this paradox should not exist, unless it is considered that medical schools should be separate from university institutions. We consider that one way of avoiding this paradox is for medical students to receive some form of university education in the biomedical sciences prior to clinical training. The standard model of medical education was once that the student would have a 2 or 3 years receiving education in the biomedical sciences (preclinical part of the course)[5]. This model is becoming less and less recognised by medical educationalists and the issues previously mentioned about early exposure to the clinic and clinical relevance have become more important than scientific training. Within some universities, for example Oxford and Cambridge in the United Kingdom, medical students are required to complete three years of scientific training leading to a scientific degree from the university before being fully enrolled within those universities’ medical schools. Throughout the USA, medicine is a postgraduate course and the students are usually required to have undertaken a Bachelors degree prior to admission into the medical course. There are of course financial as well as political complications for the rest of the World in moving to the US model of postgraduate education. Nevertheless, we are concerned that, in the absence of debate, our medical students will be less well versed in the scientific basis of medicine and that the trend that we see in cutting scientific courses will continue to the detriment of the medical profession. This matter in our opinion does not only apply to neuroanatomy but to all other aspects of the biomedical sciences. It is relevant here to report that the opinions of laypersons (putative patients) should be sought on this matter. This has been done for gross anatomy where laypersons strongly express the view that their confidence in the medical profession would be greatly diminished should anatomy be downgraded or dissection by students not performed[17]. Similar studies have yet to be undertaken for other anatomical sciences (including neuroscience).

A different model has existed within the United Kingdom and Ireland, the existence of an intercalating science degree that involves students opting out of their medical studies for one (sometimes two) years to specialise usually in a biomedical science discipline. Traditionally, only the academically top students in the year would be offered the opportunity to intercalate. In recent times, the numbers of intercalating students have increased markedly as a result of studies suggesting that it was a good pathway for the development of research skills and for promotion to academic medicine[18]. With the recent development of integrated courses and the emphasis on medicine being more of an applied social science, it could be envisaged that difficulties might arise with opting out from medical studies to study the biomedical sciences (although this needs to be investigated in the future to ensure the continuance of this valuable opportunity for scientific training).

The context of teaching neuroanatomy

The traditional approach for the teaching of neuroanatomy is for there to be a separate course for the topic that is taught by neuroscientists and that appears not too early in the course because of the complexity of the topic. Although such courses may be timetabled in close proximity to other cognate subjects (for example, head and neck anatomy) there would be no further attempt at integration within this model. The disadvantages of this arrangement are obvious in terms of the lack of integration, although the advantage of the student being exposed to a well-defined body of knowledge is also clear. Other medical schools have integrated neuroanatomy within anatomical courses. Thus, the teachers would understand, and probably teach, other areas within anatomy and would be able to provide a strong integrated morphological basis for the topic. An example of such integration would be the teaching of neuroanatomy with, or alongside the teaching of gross anatomy of the head and neck. Without such integration, there is the obvious danger of students learning about neuroanatomical aspects of the cranial nerves at a totally different time to the learning of the cranial nerves from the aspect of the anatomy of the head and neck.

A commonly found model nowadays is for integrated teaching of neurosciences covering all biomedical aspects. Thus neuroanatomy would be taught alongside neurophysiology, neurochemistry, neurohistology, neuropharmacology and neuroradiology. Given the range of disciplines required for these neuroscience courses there is the danger that neuroanatomy is not given the depth of coverage that would be considered suitable for either scientific or clinical purposes. Advantages accrue from the integration and also from possible diminution of overlap should there be separate courses. The integration of neuroanatomy and/or neuroscience with clinical disciplines has further advantages in relating the topics to clinical relevance but could suffer from further dilution of the scientific basis of the subject. Furthermore, there could be difficulties relating to positioning such a course within the overall medical curriculum. While there are advantages in having such a course taught at a discreet time in the overall medical curriculum, increasingly medical educationalists are thinking about such courses being a theme that "snakes" its way throughout the entire medical course. The belief is that the biomedical sciences should appear throughout the medical course so that material is delivered, not for integration within the scientific discipline, but for providing foundation material for the clinical course as and when a clinical topic is taught or delivered. Despite these considerations, a recent survey has shown that, at least in the USA in 2012, 66% of courses in neuroanatomy were stand-alone courses with only 20% being incorporated within integrated curricula (the remainder having mixed curricula)[19]. A further model (proposed initially by Jerome Bruner) might be for 'spiralling' of material throughout the curriculum[20]. The authors admit to seeing advantages and disadvantages in all these 'systems' and much research in needed to assess them in the context of teaching neuroanatomy.

Concerning methods of teaching neuroanatomy, although there have been reports concerning the methods of teaching gross anatomy preferred by professional anatomists and by medical students[21], similar studies have yet to be undertaken for neuroanatomy. For gross anatomy, practical methods of teaching the subject were preferred (i.e. dissection by the students, prosection and demonstration, radiographic and living anatomy) but theoretical methods (including e-learning) were not well regarded. The authors would be surprised if similar findings from medical students and professional anatomists did not also apply to the teaching of neuroanatomy. Indeed, given the importance of imaging in clinical neurology, practical training seems to us to be essential, although success will depend as much upon students' spatial abilities (another area for future research) as upon any methodological concerns.

NEUROANATOMY FOR DENTAL STUDENTS

It cannot be denied that dental students require much less understanding or knowledge of neuroanatomy than their medical colleagues. That said, there are clearly areas of specialisation that require greater understanding and knowledge because of clinical necessity and/or research interest from the perspective of head and neck functioning. In particular, the dental student should have a good education relating to the trigeminal nerve and its central connections, head and neck pain (including, of course, dental and periodontal sensation), taste, and the neurological control of mastication, deglutition and speech. Presently, there is concern in some quarters that dental students do not get a broad grounding in neuroanatomy in order to properly understand the specialist topics. Furthermore, unlike the curriculum for medical students, a core syllabus has yet to be devised. However, we conjecture below what such a core syllabus might comprise and would urge the anatomical authorities that are developing core curricula (e.g. the IFAA) to progress swiftly to the realisation of such curricula along the lines presently been adopted to devise the medical neuroanatomy syllabus (see above). Table 3 is a conjectured core neuroanatomy syllabus for dental students devised by the authors.

NEUROANATOMY FOR STUDENTS OF HEALTHCARE STUDIES

Healthcare studies take a variety of forms and involve various clinical professions, including nursing, physiotherapy, osteopathy, chiropractic, occupational therapy, radiography and radiotherapy, podiatry, pharmacy, optometry, and speech therapy. Clearly, these professions require neuroanatomical knowledge and understanding to varying degrees. For example, physiotherapists should have a detailed knowledge of motor functioning, speech therapists a detailed understanding of the organs involved in phonation and articulation and the neurological control of speech, chiropractors have to understand the detailed anatomy of the spinal cord and the autonomic nervous system. As yet, however, core syllabuses for the healthcare disciplines relating to neuroanatomy have not been devised.

NEUROANATOMY FOR SCIENCE STUDENTS

Neuroanatomy features strongly in many biomedical science degree schemes. Indeed, many universities nowadays have distinct neuroscience bachelor degree schemes. Such schemes have been criticised on occasions as being unnecessarily reductive but their appearance in universities signals the major research endeavours being undertaken in all branches of the neurosciences. Clearly, students studying neuroanatomy as part of a science degree require core knowledge in excess of that needed for students on health care schemes, including medicine. For example, while it may be recommended that sectional anatomy of the CNS is taught on some health care courses, this would be necessary core material for science students. More importantly, since many science students would be expected to consider careers in research (either as researchers or technicians), practical training in neuroanatomical techniques is core and goes beyond just knowledge and understanding of neuroanatomical facts. A further important consideration is the necessity of going beyond core material and to take the students to the frontiers of knowledge. This is best accomplished by allowing their teachers to expand upon the core syllabus by a more detailed, discursive and critical appraisal of their own areas of neuroanatomical interest and expertise. Finally, it is important for a science student to appreciate the “culture”, history and philosophical approaches relating to the discipline of neuroanatomy.

NEUROANATOMY FOR PSYCHOLOGY STUDENTS

The development of neuropsychology requires a high level teaching of the anatomy of the central nervous system. In the main, the teaching of neuroanatomy is organized during the first years of psychology undergraduate courses in order to give the student a basis for understanding the main functions of importance to psychologists (e.g. memory) or to enable comprehension of functional imaging. Neuroscientists and biologists teach this field in psychology departments. However, important differences in the curriculum and syllabus exist. Some universities do not integrate the teaching of neuroanatomy in their curriculum; some have integrated neuroscience courses involving all the basic sciences. Others, where the psychology taught is conceptual or theoretical, provide less instruction than those where there is an emphasis on laboratory-based neuroscience research. An example of curriculum for psychology student can be found in the book of Baciu[22]. It is clear that no core syllabus presently exists for neuroanatomy in undergraduate psychology courses. Some indeed may argue against the need for such a core syllabus on the grounds that a research-led curriculum perforce is dictated by the specialisms of the department or school managing the course. This argument is to misunderstand the nature of a core syllabus – it is NOT meant to specify what ONLY should be taught but what is the FOUNDATION for further specialisations.

CONCLUSIONS

We wish to make the following points that reinforce our belief that the scientific basis of neuroanatomy should exist as well as its clinical context:

1. Following developments throughout the

world (e.g. The Flexner Report in the USA[23]), there is a strong view that medicine should be a university-based course. This was proposed to ensure the delivery of professional, scientifically based courses that resulted in medical practitioners being well-rounded and learned persons respected as such in society. In our view, it is axiomatic that biomedical courses such as neuroanatomy help to deliver this view;
2. Medicine is not just a disease-based discipline but is also concerned with functionality and health and this applies to study of neuroanatomy as much as to any other system in the body;
3. It is important that clinicians and neuroanatomists talk similar languages (terminologies) and should follow developing international norms;
4. The need to develop flexible, core neuroanatomical syllabuses that have international acceptance is educationally important to ensure consistency, reliability and transparency in medical training worldwide and also politically important to provide an 'evidence-based approach' to curricula development;
5. All medical students should be exposed to scientifically- and clinically-relevant courses in neuroanatomy/neuroscience that take them to the frontiers of knowledge. This may be delivered in several ways… e.g. by medicine being a postgraduate course, having 3 years of scientific training before clinical training, by a programme of students opting out to pursue intercalating science degrees.

It should not be interpreted that we are arguing for a complete return to traditional means of teaching courses for healthcare professionals. We are neither traditionalists nor modernists but take from all pedagogic procedures that which, through evidence, appear to provide the most appropriate learning and teaching methodologies. We also accept that courses for healthcare professionals are concerned with training but where we draw the line is where this goes too far and diminishes appreciably the education of practitioners in the ways of science. It is after all not a question of science versus the clinic but of both. As a wise man said: "Give unto Caesar that which is Caesar's and unto God that which is God's".

END NOTES

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Table 2. Delphi Panel "core syllabus" for neuroanatomy

Development of the Nervous System

A medical student should have core anatomical knowledge of:

1. The early stages of neurulation
2. the development of the brain from neural tube clo-

Effector Endings

A medical student should have core anatomical knowledge of:

1. a "motor unit"
2. the basis for clinical examination of sensory modal-

The Neuron

A medical student should have core anatomical knowledge of:

1. the structural classification of neuronal types
2. the main neurotransmitters at synapses
3. the actions of neurotransmitters

The Peripheral Nervous System

A medical student should have core anatomical knowledge of:

1. the structure of both myelinated and un-myelinated nerve fibres
2. the arrangement of a typical spinal nerve and nerve roots

Receptor Endings

A medical student should have core anatomical knowledge of:

1. the stretch (myotactic) reflex
2. the structure and function of Golgi tendon organs –

Dermatomes and Muscular Activity

A medical student should have core anatomical knowledge of:

1. the concept of the segmental innervation of skin (dermatomes)
2. the concept of segmental innervation of muscles

Spinal Cord

A medical student should have a good knowledge of the anatomy of the spinal cord, including:

1. the arrangement of the meninges of the spinal cord – dura, arachnoid and pia mater
2. the functional localisation of neurons in the ventral horn
3. the functional localisation of neurons in the dorsal horn
4. the intermediolateral horn, the grey commissure and the central canal
5. the basic structure of white matter in the spinal cord
6. functional knowledge of the ascending tracts in the posterior white column – fasciculi gracilis & cuneatus
7. functional knowledge of the ascending tracts in the lateral white column – posterior spinocerebellar tract
8. functional knowledge of the ascending tracts in the lateral white column – anterior spinocerebellar tract
9. functional knowledge of the ascending tracts in the lateral white column – lateral spinocerebellar tract
10. functional knowledge of the ascending tracts in the lateral white column – posterolateral (Lissauer's) tract
11. functional knowledge of the ascending tracts in the anterior white column – anterior spinothalamic tract
12. functional knowledge of the lateral spinothalamic tract (anterolateral system) – pain and temperature pathways (including injury to the later spinothalamic tract)
13. functional knowledge of pain control in the CNS - the analgesia system
14. functional knowledge of the anterior spinothalamic tract (anterolateral system) – light touch and pressure pathways (including injury to the anterior spinothalamic tract)
15. functional knowledge of the posterior white column: fasciculi gracilis & cuneatus – discriminative touch, vibratory sense and conscious muscle joint sense (including injury to the fasciculus gracilis and fasciculus cuneat
16. functional knowledge of the posterior spinocerebellar tract – muscle joint sense pathways to cerebellum

Medulla Oblongata

A medical student should have core anatomical knowledge of:

1. the location of the medulla and its relationship to other components of the brainstem, both anatomically and functionally
2. the major anatomical features of the medulla
3. while the internal structure of the medulla as seen in transverse section is not core, it may be recommended to enable students to know the main tracts and nuclei within the medulla.
4. the arterial blood supply of the medulla, particularly to appreciate the effects of vascular disorders.
5. the clinical effects of raised pressure in the posterior

Pons

A medical student should have core anatomical knowledge of:

1. the gross anatomical appearance of the pons and relate the pons to the other components of the brainstem
2. While the internal structure of the pons as seen in transverse section is not core, it may be recommended to enable students to know the main tracts and nuclei within the pons and to aappreciate differences of internal structure between caudal and cranial parts of the pons

Cerebellum and the 4th ventricle

A medical student should have core anatomical knowledge of:

1. the gross appearance of the cerebellum and its relationship to other regions of the brainstem
2. the functional architecture of the cerebellar cortex (molecular, Purkinje and granule cell layers)
3. the deep cerebellar (intracerebellar) nuclei – dentate, emboliform, globose and fastigial nuclei)
4. the white matter of the cerebellum – intrinsic, afferent and efferent fibres of cerebellar hemispheres
5. the corticopontocerebellar pathway
6. the gross anatomy of the 4th ventricle (roof and floor,

Cranial nerve nuclei and their central connections

A medical student should have core anatomical knowledge of:

1. the motor nuclei of the cranial nerves (somatic motor, branchomotor and general visceral nuclei)
2. the general sensory nuclei of the cranial nerves
3. the central connections of the olfactory nerve
4. the optic nerve - central connections - optic chiasma, optic tract and lateral geniculate body, geniculocalcarine tract
5. neurons of the visual pathway and binocular vision
6. direct and consensual light reflexes
7. the accommodation reflex
8. the corneal reflex
9. lesions of the visual pathway
10. trigeminal cranial nerve nuclei – central connections
11. trigeminal neuralgia
12. the abducent cranial nerve nucleus
13. lesions of the oculomotor, trochlear and abducens nerves
14. facial cranial nerve nuclei central connections
15. facial nerve lesions and Bell's palsy
16. the vestibular nuclear complex
17. the cochlear nerve
18. glossopharyngeal cranial nerve nuclei central connections
19. the carotid sinus reflex
20. vagus cranial nerve nuclei central connections
21. accessory cranial nerve central connections
22. salivation and swallowing reflexes
23. hypoglossal cranial nerve nucleus central connections
24. clinical tests for examining cranial nerves
    brainstem death

Midbrain

A medical student should have core anatomical knowledge of:

1. the location and external features of the midbrain
2. the aqueduct
3. the crus cerebri
4. the substantia nigra
5. the red nucleus
6. the superior and inferior colliculi
7. cranial nerve nuclei III and IV

Diencephalon and pituitary gland

A medical student should have core anatomical knowledge of:

1. the general arrangement of the diencephalon
2. the 3rd ventricle
3. the location and relationships of the thalamus
4. the general functions of the thalamus
5. the location and relationships of the hypothalamus
6. the general functions of the hypothalamus
7. afferent and efferent connections of the hypothalamus
8. the mammillary bodies
9. the optic chiasma
10. the location and relationships of the pituitary gland
11. division of the pituitary into adenohypophysis and neurohypophysis
12. the control of the pituitary and the general principles of neuroendocrinology

Cerebral hemispheres

A medical student should have core anatomical knowledge of:

1. the structural components of the cerebral hemispheres
2. the main sulci and gyri of the cerebral cortex
3. the lobes of the cerebral hemisphere
4. internal structures – lateral ventricles, tela choroidea
5. the components of basal ganglia (basal nuclei)
6. the regional anatomy of the basal ganglia
7. the regional anatomy of the internal capsule
8. the connections of the corpus striatum – afferent fibres
9. the circuits between the basal ganglia and the cortex
10. the common syndromes of the basal nuclei - Parkinson's disease
11. cerebral white matter – commissures
12. cerebral white matter - association fibres

Reticular Formation and Limbic System

A medical student should have core anatomical knowledge of:

1. the general arrangement of the reticular formation
2. the limbic system
3. the hippocampal formation
4. the connecting pathways of the limbic system
5. the functions of the limbic system

Blood-brain barrier

A medical student should have core anatomical knowledge of:

1. the structure of the blood-brain barrier
2. the functional significance of the blood-brain and blood cerebrospinal fluid barriers
3. drugs and the blood-brain barrier

Cortical areas and lobes

A medical student should have core anatomical knowledge of:

1. frontal lobe localisation and functions
2. parietal lobe localisation and functions
3. occipital lobe localisation and functions
4. temporal lobe localisation and functions
5. the vestibular area
6. association cortex localisation and functions
7. cortical localisation of language
8. cerebral dominance
9. consciousness
10. sleep
11. lesions of the motor cortex
12. muscle spasticity following lesions of the motor cortex
13. lesions of the frontal speech areas (incl Broca's area)
14. lesions of the temporal speech areas (incl Wernicke's area)
15. combined lesions of the motor and sensory speech areas
16. lesions of the prefrontal cortex
17. lesions of the sensory cortex
18. lesions of the primary visual area
19. lesions of the primary auditory area
20. epilepsy
21. the arterial blood supply to cerebral hemispheres
22. anterior cerebral artery syndrome
23. middle cerebral arterial syndrome
24. posterior cerebral arterial syndrome

Ventricular system and the formation and fate of the cerebrospinal fluid

A medical student should have core anatomical knowledge of:

1. the lateral ventricles
2. the third ventricle
3. the cerebral aqueduct (Aqueduct of Sylvius)
4. the fourth ventricle
5. the central canal of the spinal cord and the medulla oblongata
6. the subarachnoid space
7. cerebrospinal fluid and its functions
8. formation of cerebrospinal fluid
9. circulation of cerebrospinal fluid
10. absorption of cerebrospinal fluid
11. the extensions of the subarachnoid space
12. raised cerebrospinal fluid pressure, the optic nerve and papilledema
13. hydrocephalus
14. cerebrospinal fluid of the spinal cord

The Autonomic Nervous System

A medical student should have core anatomical knowledge of:

1. the general organisation of the autonomic nervous system
2. sympathetic efferent nerve fibres (sympathetic outflow)
3. sympathetic afferent nerve fibres
4. sympathetic trunks and ganglia
5. parasympathetic efferent nerve fibres (craniosacral outflow)
6. parasympathetic afferent nerve fibres
7. the major autonomic plexuses
8. parasympathetic autonomic ganglia
9. preganglionic transmitters
10. postganglionic transmitters
11. higher control of the autonomic nervous system
12. the functions of the autonomic nervous system
13. the autonomic innervation of the eye, upper eyelid and iris
14. the autonomic innervation of the salivary glands
15. the autonomic innervation of the lacrimal gland
16. the autonomic innervation of the heart
17. the autonomic innervation of the lungs
18. the autonomic innervation of the stomach and the intestine as far as the splenic flexure
19. the autonomic innervation of the descending colon, pelvic colon, and the rectum
20. the autonomic innervation of the medulla of the suprarenal gland
21. the autonomic innervation of the involuntary internal sphincter of the anal canal
22. the autonomic innervation of the urinary bladder
23. the autonomic control of erection of the penis and the clitoris
24. the autonomic control of ejaculation
25. the autonomic control of the visual reflexes
26. the autonomic control of the accommodation reflex
27. the autonomic control of the cardiovascular reflexes

Meninges

A medical student should have core anatomical knowledge of:

1. the general arrangement of the meninges of the brain
2. the dural venous sinuses
3. the functional significance of the meninges
4. intracranial haemorrhage and the meninges: extradural, subdural, subarachnoid and intracranial haemorrhages in infants

Blood vessels of the brain

A medical student should have core anatomical knowledge of:

1. the internal carotid artery (anterior circulation)
2. the vertebral artery (posterior circulation)
3. the basilar artery
4. arteries to specific brain areas
5. the external cerebral veins
6. the internal cerebral veins
7. the dural venous sinuses

Imaging

A medical student should have core anatomical knowledge of:

1. CT & MR SCANNING of the brain, and vertebral column/spinal cord
2. the radiographic appearances of the intracranial cavity and the vertebral column
3. cerebral angiography

Table 3. Core neuroanatomy syllabus for dental students devised by the authors

DEVELOPMENT OF THE NERVOUS SYSTEM
Early development – Neurulation
THE NEURON
Neurotransmitters at synapses
Actions of neurotransmitters
THE PERIPHERAL NERVOUS SYSTEM
Spinal nerve and nerve roots
Sensory ganglia
Autonomic ganglia
Peripheral nerve plexuses
RECEPTOR AND EFFECTOR ENDINGS
Basic and motor unit
Anatomy of the flexor reflex
Jaw reflexes
Motor unit
DERMATOMES AND MUSCULAR ACTIVITY
Segmental innervation of skin (dermatomes)
Segmental innervation of muscles
SPINAL CORD
Meninges of spinal cord – dura, arachnoid and pia mater
Functional localisation in neurons of the ventral horn
Functional localisation in neurons of the dorsal horn
The reflex arc
Upper motor neuron lesions
Lesions of the lower motor neuron
Parkinson's disease
Cerebrospinal fluid of spinal cord
MEDULLA OBLONGATA
Gross anatomical appearance of medulla oblongata
PONS
Gross anatomical appearance of pons
Trigeminal nuclei
Control of mastication, swallowing and speech (including rhythmic generator)
CEREBELLUM & 4TH VENTRICLE
Gross anatomical appearance of cerebellum
Gross anatomy of 4th ventricle (roof and floor, lateral boundaries)
CRANIAL NERVE NUCLEI AND THEIR CENTRAL CONNECTION
Motor nuclei of the cranial nerves - somatic motor and branchiomotor nuclei
General visceral motor nuclei
General sensory nuclei of the cranial nerves
Olfactory nerves – central connections
Optic nerve - central connections - optic chiasm, optic tract and lateral geniculate body, geniculo-calcarine tract
Neurons of the visual pathway and binocular vision
Direct and consensual light reflexes
Accommodation reflex
Corneal reflex
Lesions of the visual pathway
Trigeminal cranial nerve nuclei – central connections
Trigeminal neuralgia
Abducent cranial nerve nucleus
Lesions of oculomotor, trochlear and abducens nerves
Facial cranial nerve nuclei central connections
Facial nerve lesions and Bell's palsy
Vestibular nuclear complex
Cochlear nerve
Glossopharyngeal cranial nerve nuclei central connections
Carotid sinus reflex
Vagus cranial nerve nuclei central connections
Accessory cranial nerve central connections
Salivation and swallowing reflexes
Hypoglossal cranial nerve nucleus central connections
Clinical tests for examining cranial nerves
MIDBRAIN
Location and external features
Aqueduct
Crus cerebri
DIENCEPHALON AND PITUITARY GLAND
General arrangement of diencephalon
3rd ventricle
Location and relationships of thalamus
General functions of the thalamus
Location and relationships of the hypothalamus
General functions of the hypothalamus
Optic chiasma
Location and relationships of the pituitary gland
Division of pituitary into adenohypophysis and neurohypophysis
Control of the pituitary and general principles of neuroendocrinology
CEREBRAL HEMISPHERES
Structural components of cerebral hemispheres
Anatomy of main sulci and gyri of cerebral cortex
Lobes of the cerebral hemisphere
Internal structure – lateral ventricles, tela choroidea
Components of basal ganglia (basal nuclei)

Regional anatomy of the basal ganglia
Regional anatomy of the internal capsule
Connections of the corpus striatum – afferent fibres
Circuits between basal ganglia and cortex
Common syndromes of the basal nuclei - Parkinson's disease
Cerebral white matter - commissures
Cerebral white matter - association fibres
Cerebral white matter - projection fibres
CORTICAL AREAS AND LOBES
Frontal lobe localisation and functions
Parietal lobe localisation and functions
Occipital lobe localisation and functions
Temporal lobe localisation and functions
Vestibular area
Association cortex localisation and functions
Cortical localisation of language
Cerebral dominance
Consciousness
Epilepsy
Arterial blood supply to cerebral hemispheres
RETICULAR FORMATION AND LIMBIC SYSTEM
General arrangement of the reticular formation
Limbic system
Functions of the limbic system
VENTRICULAR FORMATION AND THE FORMATION AND FATE OF THE CEREBROSPINAL FLUID
Lateral ventricles
Third ventricle
Cerebral aqueduct Aqueduct of Sylvius)
Fourth ventricle
Central canal of the spinal cord and medulla oblongata
Subarachnoid space
Cerebrospinal fluid
Functions of the cerebrospinal fluid
Formation of cerebrospinal fluid
Circulation of cerebrospinal fluid
Absorption of cerebrospinal fluid
BLOOD-BRAIN BARRIER
Structure of the blood-brain barrier
Functional significance of the blood-brain and blood cerebrospinal fluid barriers

THE AUTONOMIC NERVOUS SYSTEM
General organisation of the autonomic nervous system
Sympathetic efferent nerve fibres (sympathetic outflow)
Sympathetic afferent nerve fibres
Sympathetic trunks and ganglia
Parasympathetic efferent nerve fibres (craniosacral outflow)
Parasympathetic afferent nerve fibres
The major autonomic plexuses
Parasympathetic autonomic ganglia
Preganglionic transmitters
Postganglionic transmitters
Higher control of the autonomic nervous system
Functions of the autonomic nervous system
Autonomic innervation of salivary glands
Autonomic innervation of heart
Autonomic innervation of lungs
Autonomic control of visual reflexes
Autonomic control of accommodation reflex
MENINGES
General anatomy of the meninges of the brain
Dural venous sinuses
Functional significance of the meninges
Intracranial haemorrhage and the meninges: extradural, subdural, subarachnoid and intracranial haemorrhages
BLOOD VESSELS OF THE BRAIN
Internal carotid artery (anterior circulation)
Vertebral artery (posterior circulation)
Basilar artery