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Clinically-Orientated Anatomy: Five exemplars to portray the concept

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SUMMARY

It has become almost a truism that, as for many biomedical sciences courses, gross anatomy tuition for healthcare curricula (including medicine and dentistry) should be integrated with clinical components to improve vocational relevance. Nevertheless, many fundamental questions remain to be answered relating to the content to be taught, who teaches the discipline, how the students react, and whether the students are prepared to integrate the clinical and biomedical components. We additionally need evidence of how the delivery of clinical content is influenced by technical developments such as medical imaging. This article documents some examples, or case scenarios, showing how interactions between professional anatomists and clinicians can be fostered, as well as providing illustrations of different teaching styles. From a review of the literature, as well as from our own experiences, we conclude that, for many branches of medicine, it is essential to have access to human bodies for both anatomical and clinical education and training and that postgraduate anatomical teaching remains important for a variety of specialities. We therefore support the notion that a close relationship between professional anatomists and surgeons can reinforce core anatomical knowledge by deepening the understanding of its clinical importance. Paradoxically, however, there is evidence that medical students do not believe that the teachers of anatomy should necessarily be clinically qualified. Furthermore, while students appreciate the value of using clinical examples, scenarios or case histories in anatomy teaching, they remain ambivalent about their use in assessments or examinations. This article also emphasises that anatomy is important both as a scientific and a clinical, translational discipline and argues that the discipline is crucial for appreciation of the human body, not just in disease, but also in health.

Key words: Clinical Anatomy – Medicine – Dentistry – Gynaecology – Imaging – Neurology – Plastination – Teaching

INTRODUCTION

Competent medical practice relies upon a good, detailed knowledge of human gross anatomy to ensure safe and effective clinical outcomes. The importance of teaching anatomy in a practical manner has been previously reported (Patel and Moxham, 2006; Moxham and Moxham, 2007; Riederer et al., 2015). Furthermore, integration of the anatomical sciences with clinical teaching is often thought to be essential for contemporary medical courses and for all other healthcare courses. Nowadays, anatomy courses are provided for a great variety of students, including sports sciences, pharmacy, radiography, and manipulative therapists such as physiotherapists, osteopaths and

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chiropractors. All such groups require anatomy courses adapted to their particular professional needs and there is no 'one-size-fits-all'. This principle applies equally to anatomy teaching for medical students. At some universities, medical students are taught alongside other groups, for example dental and/or psychology students. Such combinations require careful weighting of the content of the anatomy course to ensure that the needs of all groups are satisfied. If this condition is not met, then such courses delivered to multiple student groups can also meet with resistance from the students taking those courses, because they can feel that the needs of single group are not being fully met (McHanwell, 2015). In the experience of one of this article's authors, when teaching anatomy to a combined class of medical, dental and veterinary students, whenever veterinary clinical examples were provided the medics and dentals uttered farmyard animal noises and whenever dental clinical examples were given moans accompanied by the holding of jaws came from the medics and vet students. Whatever the context of teaching anatomy, several important questions need to be answered with objective evidence:

Is anatomy a scientific discipline in its own right or is it always subservient to medical/healthcare training?

What are the attitudes of students regarding the teaching of anatomy in a clinical context? Because prior learning predicts performance (Chickering and Gamson, 1987; Smith and Naylor, 2005; Gibbs, 2010), how varied is the pre-existing knowledge of medicine that the students bring with them when they start medical school, and does this enable them to make good use of the integrative approach?

Is it necessary for anatomists to be clinicians as well as scientists, or is it sufficient for a clinician with some anatomical knowledge to be responsible for this aspect of medical education?

How necessary is the employment of human cadavers and dissection-based courses to supplement or support the clinical approach?

What are the tools and pedagogic methodologies presently at our disposal to supplement or support clinical teaching?

When might be the best time to introduce clinical concepts and scenarios into the anatomy course, and how best can complex clinical cases that are often encountered in practice be introduced early into courses?

In order to answer these questions, we will commence by providing five examples/case scenarios that demonstrate how professional anatomists and clinicians can interact and how plastination, prosected specimens, radiological anatomy and computer-assisted tools might help document surgical interventions. Furthermore, an example is offered of how clinical anatomy can be introduced into an undergraduate anatomy programme, in this case dentistry, to critically evaluate the conceptual basis of clinical anatomy (also referred to as translational or surgical anatomy) and to review how students perceive the importance of this approach.

EXAMPLE 1: THE COMPLEXITY OF THE PELVIC FLOOR

The pelvic floor is one of the more difficult anatomical regions for students to understand. Over the past decade, combined efforts between a gynaecologist and an anatomist at the University of Lausanne have resulted in several publications on the clinical anatomy of this region (e.g. Spinosa and Riederer, 2007; Spinosa et al., 2007). It is clear that both clinical and anatomical expertise is required to enable the students to obtain relevant and clinically-related knowledge for pre- and postgraduate training (Spinosa et al., 2009). Indeed, with regard to what is taught and at what level, it was suggested that medical students, even at undergraduate level, need to be taught in a clinical context for them to navigate their way through this complex region (Spinosa and Riederer, 2011). A frequently asked question is: in what detail do undergraduate students have to learn the anatomy? In this context it is important to explain early in the curriculum the relevance of anatomical structures for clinical medicine and surgery. However, a gynaecologist will inevitably respond to the question by stating that "all structures are of importance!" Of course, within a congested medical course it is not feasible to teach everything that every specialty regards as important. Some of the 'core' topics to be taught in relation to pelvic anatomy have been identified by Spinosa and Riederer (2011). In particular, several crucial points of gross and neuralgic anatomy were highlighted where knowledge of innervation and topography of a structure(s) is essential clinically, including urinary stress incontinence, faecal incontinence, compression pain, cystocoele or colon cancer with reconstructive surgery, or when placing transobturator slings to improve continence (Delorme et al., 2011) while avoiding damaging blood vessels or producing palsy of the obturator nerve (Spinosa et al., 2007).

As a result of this work, the Department of Anatomy at Lausanne designed training workshops for gynaecologists that employed cadavers to train the clinicians to place slings correctly and to demonstrate how to identify the relationships of pelvic anatomical structures to the slings. In addition, plastinated specimens were used to supplement an appreciation of such critical anatomical relationships. Cases of pudendal neuralgia are not uncommon and, because of the great variability from individual to individual, there is a requirement for precise identification of anatomical structures and relationships. In many instances, the neuralgia results from nerve compression or as a consequence of perioperative nerve entrapment

(Amarenco et al., 1997; Bautrant et al., 2003). In 70% of cases, it is the sacro-spinal/sacro-tuberal ligament grip that results in neuralgia while in 20% of instances it is due to nerve compression in the pudendal canal (Alcock's canal). Because it is essential to localize such compressions, it is crucial to know the specific anatomy and neurological control of the pelvic floor (Vodusek, 2004; Shafik et al., 2005) and to understand how, by applying staged sacral reflexes, the compression site can be pinpointed (Spinosa et al., 2009; Bharucha, 2006).

Knowledge of the anatomy of the sacro-spinous ligament is fundamental for fixation of the vagina after hysterectomy (Richter and Albrich, 1981). Because several nerves pass closer to the spine than to the sacrum (Grigorescu et al., 2007; Lazarou et al., 2008), suspending the vagina at least 3 cm from the spine is recommended. It is clear, therefore, that awareness of the exact location of nerves is essential to avoid post-operative complications due to entrapped nerves.

Fig 1. On a regular dissection table two adjustable leg rests are fixed for positioning the legs in the correct gynaecological position (thus reproducing a surgical approach as well as enabling dissection in the same clinical position).

A dissection table has been designed at the University of Lausanne to allow a fresh cadaver to be placed in a gynaecological position (Fig. 1). In postgraduate master classes, gynaecologists and obstetricians are trained to place slings and other devices around the urethra for improved suspension of the pelvic floor. Under expert supervision, physicians first place the different tapes and then dissect the pelvic floor, the trans-obturator foramen and the ischio-anal fossa to show the relationship of placed devices to important anatomical structures. In order to ensure the success of these ventures, the employment of both a gynaecologist and an anatomist is essential.

In recent years, two Masters students have studied the anatomy of the female pelvic floor using imaging techniques and vascular reconstruction by angiography followed by careful dissection and by preparation of anatomical slices that match the CT scanning images (Riederer et al., 2016). The aim was to design a practical teaching module in the form of a demonstration for medical students during the 2nd year of undergraduate training (Hoffer, 2010; Hugonnet, 2011). By installing computer terminals within the dissection room it has been possible to display CT data sets of whole bodies for the students in order to train them to recognize anatomical structures. Selected CT scans and corresponding slices also provide material for formative quizzes and summative assessments (Fig. 2). The quizzes are greatly appreciated by students, but the use of CT data needs to be integrated into the dissection protocols for a close comparison of virtual images with real anatomical structures.

It should also be noted that, despite both Masters students having already received clinical and imaging training, they reported that they were able to further develop their ability to read CT images through the preparing and comparing of CT images with tissue slices. Having a matched CT scan next to a real body slice markedly aids the identification of individual structures and should be regarded as being essential for learning clinical anat-

Fig 2. CT scan of a female pelvis with angiography of veins and arteries and an anatomical slice at corresponding level. (Courtesy of Iza Hugonnet, Master thesis Hugonnet, 2011).

omy. Given the complexity of the three-dimensional organization of the pelvis, a deep anatomical knowledge is necessary for a clinician. Both Masters students have not only discussed the pelvis anatomy but looked also at possible clinical complications using either the vaginal route or laparoscopy. Furthermore, it was a salutary experience for these Masters students to have contact with undergraduate students to present their work and to see how to better introduce clinical anatomy during the 2nd year of undergraduate training.

To provide one further example of the ways in which basic and clinical anatomy of the pelvis can be integrated, at the University of Padova a workshop for clinical anatomy of the female pelvic viscera has been developed as part of the training programme for the first year residents in gynaecology and obstetrics. Un-embalmed pelvic viscera are available and the residents follow a worksheet that is structured as a guide to the anatomical basis of physical examination through inspection and palpation of the viscera. A topographical test is also administered to the residents, with four radiological images of the female pelvis (one sagittal and one frontal ultra-sonogram, one sagittal MR T2-weighted scan, and two axial CT scans), where the residents have to identify the requested anatomical structure (Macchi et al., 2003).

EXAMPLE 2: PLASTINATION AS TEACHING TOOL

The safe and effective performance of endoscopic procedures to access surgically the frontal cortex or brainstem via the nasal cavity requires a thorough knowledge of the relevant anatomy (May et al., 1994). In order to develop endoscopic training to demonstrate anatomical routes into the nasal cavity and approaches to the frontal cortex or brainstem for surgery, the ethmoidal region has been dissected from several human heads to demonstrate regional sinus anatomy and endoscopic surgical approaches. After preparation, specimens are plastinated by using the gold standard S10 plastination technique. These specimens have been successfully employed in the clinical teaching of sinus anatomy and surgery (Musumeci et al., 2003a, b). For some heads, prior to dissection, maxillary and internal carotid arteries are injected with radio-opaque, red coloured, silicone. For other specimens, the ophthalmic and ethmoidal arteries have also been dissected. The specimens are long-lasting, enable visualization of arteries during endoscopic and radiological examination, and training is possible outside the dissection room (given that plastinates are easy to handle and odourless). However, a disadvantage is that the specimens are rigid during endoscopy (Fig. 3). The incidence of complications such as focal haemorrhages (e.g. orbital hematomas and epistaxis after sinus surgery (May et al., 1994; Sharp et al., 2001)) would be expected to be higher with untrained or inexperienced surgeons (May et al., 1994), providing a strong argument for the use of anatomical specimens during training to ensure a sound knowledge of the relevant anatomy. These specimens would also provide examples to illustrate surgical interventions and for highlighting criti-

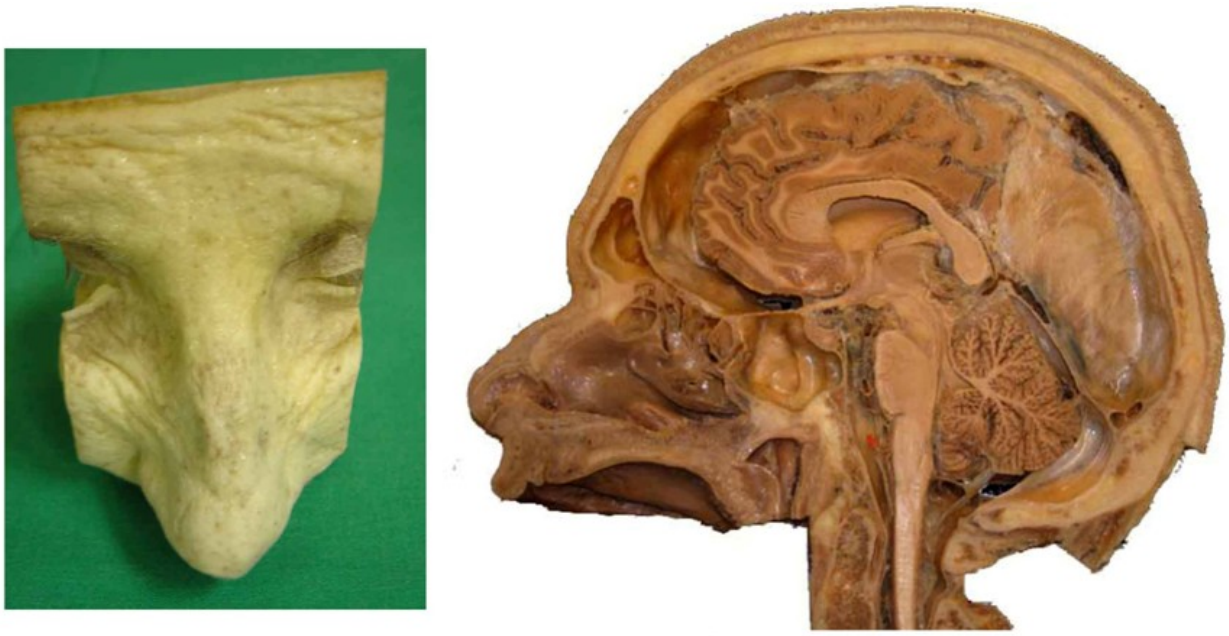

Fig 3. A plastinated ethmoidal block is shown to the left. Special attention was given to the dissection of the cavities and sinus during plastination, especially during curing of silicone, not to have excess of silicone obstructing cavities. The sagittal section through the head provides a nice view of sinus cavities and the route how to reach frontal cortex or brain stem. This image also exemplifies the limitation of plastination, soft tissue becomes rigid and brain tissue has shrunken considerably.

cal features such as the identification of fragile bony structures and the location of arteries.

For further discussion of the use of plastination in anatomical teaching, see Riederer (2014).

EXAMPLE 3: NEUROANATOMY

Neuroanatomy is considered to be one of the most difficult anatomical sciences within the curriculum, since it involves not only learning about numerous structures, but also understanding their spatial relations and their functional correlates (Brewer et al., 2012). This difficulty stems in part from the fact that, unlike gross anatomy, many structures cannot be seen with the naked eye but only in brain sections. Consequently, students are required to integrate two-dimensional information into three dimensional representations if they are to understand the structure of the brain fully - something many students struggle with early on in their studies. A survey of the approaches to teaching the anatomy of the brain and spinal cord reported that, alongside the study of prosected parts and actual brain dissections, combining the study of brain slices in conjunction with CT scans was also effective as a teaching approach (Fitzgerald, 1992). However, there are few studies available on the role of dissection in neuroanatomical teaching. In Padova, we have designed for a selected group of students a practical session on clinical anatomy of the brain that employs a combination of embalmed specimens, intact and prosected and without pathologies, brains plastinated with S10, large slices of human cerebral hemispheres that are fixed in formalin solution, and P40 plastinated brain slices. The session lasts three hours and is divided into theoretical and practical sessions, with 20 minutes dedicated to clinical anatomy during which the teacher introduces three common brain pathologies: hydrocephalus (representative of congenital disease); schwannoma/acoustic neuroma (representative of middle age); primary cerebral haemorrhage (representative of old age). For each pathology, the teacher demonstrates the locations of the structures involved on un-fixed brains. To evaluate the effectiveness of this direct experience of macroscopic brain anatomy and dissection of the brain in terms of improving knowledge of neuroanatomy, tests were undertaken before and after the sessions and also one year later. The results of these tests demonstrate an improved knowledge of neuro-anatomy in 57% of students. Furthermore, one year after the sessions, the students who had attended the course demonstrated better retention of knowledge in neuro-anatomy than a control group of students who did not attend. It was concluded that neuro-anatomical clinical correlations taught alongside exposure to brain specimens helps to reinforce anatomical learning by focusing the students' attention on those structures that are relevant from the clinical viewpoint (Macchi et al., 2007a).

A second optional course was developed for a small group of students. Materials in this course included sections of infant and adult brains that were treated with histological stains (Haematoxylin -Eosin, Nissl, Klüver-Barrera) or labelled immunohistochemically (anti-GFAP, -tyrosine hydroxylase). Clinical correlations were prepared for each session with the aim of correlating the topography of lesions of CNS with the symptoms. For example, in the session(s) on the spinal cord, transverse sections of the spinal cord (C5, T5, L5 levels) were studied in relation to Brown-Sequard syndrome (BSS) and dorsal tabes. In particular, in BSS the hemisection of the spinal cord is responsible for ipsilateral motor paralysis, ipsilateral loss of vibration and proprioception and contralateral pain and temperature sensation deficits, and thus is a particularly good example to choose as the means to understand functional aspects of spinal cord anatomy. The teacher focuses on the three main pathways involved (upper motor neuron pathway of the corticospinal tract, gracilis or cuneatus, and spinothalamic tract), correlating the side of the neural deficit with the level of decussation.

A variety of other approaches based on dissection have been used in neuroanatomical teaching. De Notaris et al. (2012) used methods that combined virtual dissection of the brain using a 3D dissection model, preliminary exploration of the same specimen using a second 3D model based on a pre-operative computed tomographic scan, and cadaveric anatomic dissection aided by a neuronavigation system as means to train surgeons in the use of endonasal endoscopic approaches to skull base surgery. Skadorwa et al. (2009) used brain dissection combined with magnetic resonance scans and neuronavigation systems to facilitate the understanding of the location of structures and support the transition from structures visualised in two dimensional sections to understanding their relationships in three dimensions. Sundsten et al. (1991) developed computer-based interactive video tutorials created from a database of three-dimensional co-ordinates derived from serial cross sections of the brain. Another approach to neuroanatomy education has been to use simulation models of cerebrovascular circulation (Güvençer et al., 2007; Shimizu et al., 2006) to provide experience for the safe, and ethical, performance of surgical interventions during the intraoperative period. In addition, dissection procedures for the optimal removal of brains and spinal cords of cadavers have been described as the means to yield better specimens for use in teaching and examinations (Felle et al., 1995).

We consider that, in designing teaching courses in clinical anatomy for undergraduate students, the main guidelines in planning a course should be: 1.

Fig 4. A plastinated brain is shown to the left, while a 3-Dimensional reconstruction obtained from CT examination of the brain of a living patient is shown on the right.

the selection of appropriate anatomical landmarks of importance from the clinical viewpoint; 2. identification of pathologies which involve the above anatomical landmarks; 3. relationships between morphology and pathology to enhance anatomo-clinical importance (Macchi et al., 2007a).

EXAMPLE 4: COOPERATION BETWEEN ANATOMY AND SURGICAL DEPARTMENTS

Cooperation between anatomy and hospital surgical departments can promote an approach to anatomy that extends from the basic science of anatomy to its clinical aspects and application. Within surgical departments, the need for professionals in human gross anatomy is uncontested (Fasel et al., 2005). In Padova, this collaboration between basic science and clinical anatomy generates anatomico-clinical research that studies anatomical structures from the new perspectives that are necessary as new and more refined surgical procedures are developed requiring more detailed anatomical knowledge and understanding (Macchi et al., 2005, 2007 b, 2010; Porzionato et al., 2012, Stecco et al., 2010, 2012). For instance, we have studied relationship between the pectoral nerves and the pectoral muscles, describing two different patterns of branching of the medial pectoral nerve, which correlate to the extent of the costal attachment of pectoralis minor. The knowledge of this relationship may be useful when performing elective denervation of the major pectoralis muscle (Macchi et al., 2007c). Moreover, anatomico-clinical research can study the anatomical basis for the design of new surgical procedures, resulting in improvements in surgical practice and an increase in the quality of medical care (Tiengo et al., 2004, 2007). For instance, the blood supply of the gracilis muscle was studied by dissection in order to identify its main and secondary peduncles. Subsequently, the distribution of vessels to the gracilis muscle was identified by CT angiograms in living patients, (Fig. 5), supporting the results of the dissection, and also reporting that these vessels are recognizable during in vivo imaging (Macchi et al., 2008). Based on the anatomical results, a new surgical flap was developed for coverage of a total knee prosthesis that has been called the reversed gracilis pedicle flap (GreSP-flap). This shows that it is possible to study pre-operatively blood vessels and that this detailed anatomical knowledge can be used to plan reconstructive surgery (Tiengo et al., 2010).

EXAMPLE 5: CLINICAL RELEVANCE IN GROSS ANATOMY FOR THE UNDERGRADUATE DENTAL COURSE

The examples so far given in this paper all relate to the teaching of anatomy to medical students or graduates at various points in their training. Dental students also receive grounding in gross anatomy and it is arguable that the teaching of clinically relevant gross anatomy at an early stage in their careers is even more important for this student group. Two reasons for this can be given. Firstly, dentistry is a surgical science and knowledge of

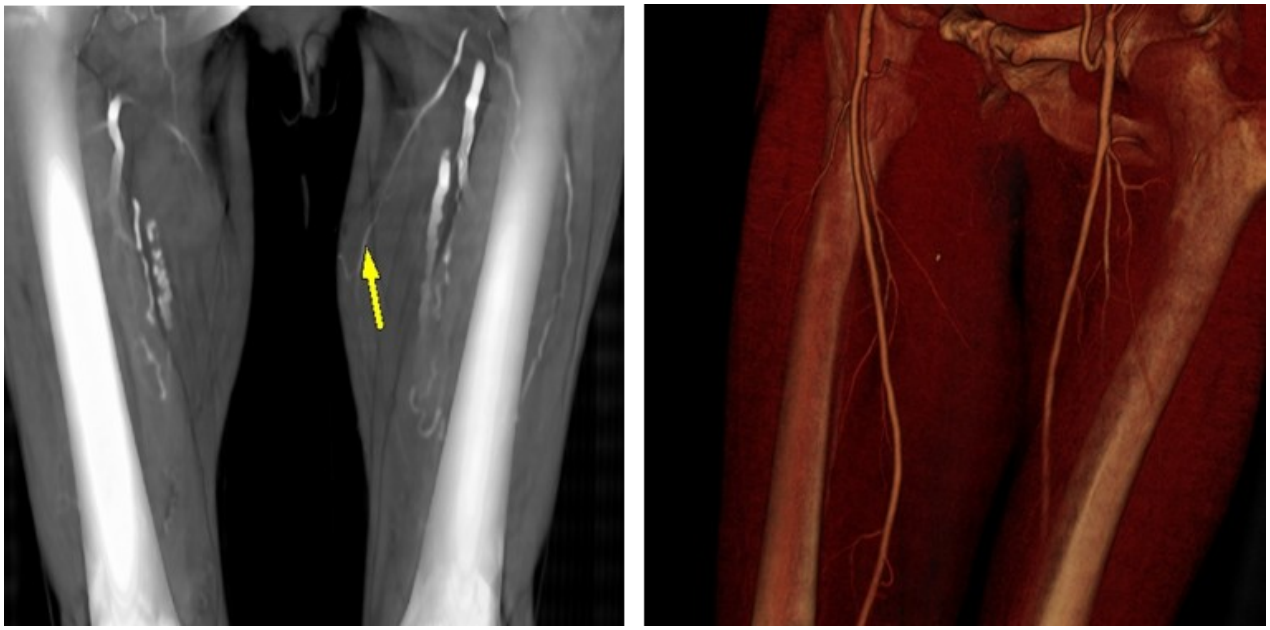

Fig 5. A Maximum Intensity Projection reconstruction (left) and a 3-Dimensional reconstruction (right) of CT angiograms, showing the vascularisation for the gracilis muscle.

anatomy (including anatomical variation where relevant) is a fundamental requirement for safe and effective practice. Secondly, undergraduate dental students in many courses carry out, at an early stage in their training, irreversible procedures on patients that can cause pain. For many dental degrees, this stage of clinical training usually commences within two or three years of starting a dental degree, although sometimes it can be earlier. While students are intensively supervised during this phase of training, it is imperative that students have a clear and detailed understanding of the relevant anatomy they need before carrying out a procedure in the mouth.

Some of the issues raised in this example are addressed more fully in a review of dental anatomy teaching by McHanwell (2015). Here is highlighted some of the key issues that must be addressed in designing a clinically-relevant dental anatomy course. In particular, attention is focussed upon the dental course at the University of Newcastle (U.K.), where there was a need for careful consideration of the design of a gross anatomy course that was integrated vertically and with appropriate “scaffolding” into the teaching of clinical dentistry. Thus, this example will involve a discussion of the key clinical topics that need to be covered and will also describe some results of a research study on the effectiveness of teaching clinically relevant dental anatomy in Newcastle. The discussion will then be broadened to include some thinking as to when, and how, it is best to deliver the teaching, drawing on the wider literature of the teaching of dental anatomy. Case study approaches such as this have been criticised on the grounds that the use of individual examples limits the generalisability of the findings. However, it has been argued elsewhere that case studies can offer a more granular approach to knowledge that is generalised (Thomas, 2011), something that might be termed ‘exemplary knowledge’.

In Newcastle, as for many dental programmes, gross anatomy is taught primarily in the first year of their studies. The anatomy course focuses upon the head and neck, with some teaching devoted to thorax and abdomen (mainly in support of the relevant physiology). This is in line with most Bachelor of Dental Surgery courses (BDS course) where the anatomy of the whole body is not taught. The course at Newcastle is taught through lectures, practicals, and seminars and has a didactic focus rather than being case- or problem-based. Consequently, if the students are to see the relevance of what they are learning then they need to be engaged to learn and to construct their own knowledge and to appreciate the connectedness of what they are learning both horizontally across subject within a year or semester of study and vertically across years. This is accomplished in Newcastle in several ways: i) reinforcing clinical relevance throughout the course by linking the clinic with the anatomy taught; ii) undertaking clinical practice and presenting selected clinical topics that are co-ordinated with the gross anatomy teaching, and iii) delivering topics by clinical staff within the dental school. In a BDS course there are many opportunities to make links between basic and applied anatomy (Guttman, 2003; Guttman, Ma and MacPherson, 2003), but this needs to be employed selectively and strategically and also needs to be appropriately scaffolded (Olson, 2007) if stu-

Fig 6. Teaching in small groups.

dents are not to feel overwhelmed. Consequently, during year 1 of the Newcastle course, links between anatomy and the clinic focus on the key areas of the anatomy relevant to dental practice and include: the anatomy of local anaesthesia (including variation in the innervation of the teeth), clinical anatomy of the face (focussing particularly on the relationships of the parotid gland), the spread of infection in the head and neck through the teaching of fascial planes, tissue spaces and lymphatic drainage, protective mechanisms during swallowing, and clinical anatomy of the exterior and interior of the skull. The selection of these topics was arrived at in consultation with clinical and non-clinical staff across the dental school and after reviewing some of the key clinical texts in this area (Longmore and McCrae 1985; Dubrul, 1988; Moore, 2001). They were selected to relate to (i) an explanation of the anatomical basis of common procedures carried out in dental practice; (ii) discussion of key anatomical relationships in the head and neck that are necessary for dentists to understand, and (iii) the anatomical basis of commonly encountered serious pathologies that a dentist is likely to encounter in practice. Alongside introducing these clinically relevant topics, the head and neck course for dentists covers the anatomy of several regions of importance to a dentist in significantly more detail than would be the case for undergraduate medicine (Guttman, 2003, Guttman Ma and MacPherson, 2003; Smith et al., 2016a, b). The face, infratemporal fossa, and oral cavity are taught in detail and student learning in these topics is supported through a structured series of formative self-assessments involving anatomy quizzes during practical classes and seminars. The students are allowed to structure this work through self-constructed group work. Practical teaching has been found to be of particular value in supporting the learning of anatomy by dental students (Smith, Martinez-Alvarez and McHanwell, 2014). This theoretical and practical teaching within the basic science components of the course is then supported by two lectures on clinical topics delivered by clinical practitioners who are surgeons; one on local anaesthesia and one on facial fractures. In structuring the course in this way we are trying to ensure as many as possible of the seven principles of learning set out in the OECD project The Nature of Learning (Dumont, Istance and Benavides, 2010) are being fulfilled. In particular, learners are placed at the centre of the learning, by supporting social learning, by challenging students, and by building connections (Dumont, Istance and Benavides, 2010).

However, it is also clear that simply exposing students to clinically relevant applications of gross anatomical knowledge early in their dental careers does not enable them reliably to solve real-life clinical problems encountered during their clinical years (Durham et al., 2009). This study demonstrated that students in their final year of clinical

training struggle to solve even straightforward clinical problems requiring an understanding of the relevant anatomy. This should not be the occasion for surprise. It is not reasonable to expect a student exposed to a gross anatomy course in the first year of a five-year dental programme to be able to retain that knowledge throughout the five years without further reinforcement of that knowledge, no matter how good the teaching was they originally received. Indeed, a further issue is raised that the understanding of how to solve clinical problems requires two things to be brought together simultaneously, namely sufficient basic knowledge plus clinical experience. Early on in a course, students lack the clinical experience to appreciate real-life cases but can be expected to have a good grasp of the basic science. At this stage, they can be given simplified cases. At later stages, they have a more developed clinical understanding but cannot resolve clinical problems through a lack of basic knowledge (Hendricson, 2012). This is a very real issue of ensuring that a course is properly scaffolded in the sense originally defined by Bruner of not simply revisiting topics, but revisiting them in a more elaborated form (Olson, 2007). One solution appeared to be the delivery of a course during the final year that is taught by basic scientists and clinicians, in which basic anatomical knowledge is revisited and then immediately applied to the solving of problems. This has been taken a step further in Newcastle through the delivery of a short anatomy course at the start of clinical training, where the focus is upon the anatomical relationships of teeth in the widest sense of their relationships to their innervation, and to soft and hard tissue structures, fascia and tissues spaces. This course is designed to help students develop an understanding of the anatomical relationships that need to be taken into account when working upon any individual tooth (DuBrul, 1998).

In conclusion, helping students to understand how to apply anatomical knowledge to clinical problems requires a longitudinal approach in which knowledge is appropriately scaffolded at each stage of their education (Olsson, 2007). A case study example of how this is done in one dental school has been given.

DISCUSSION AND CONCLUSIONS

The five different examples/case scenarios provided suggest that a combination of expertise is necessary for the teaching of gross anatomy in the contemporary environment to students on healthcare courses, whether they be undergraduate or postgraduate. The example describing how to approach the teaching of the pelvic floor demonstrates how collaboration between anatomists and clinicians can support surgical training while at the same time providing a resource for more effective undergraduate teaching. The examples describing approaches to teaching neuroanatomy and to the teaching of anatomy to dental students both demonstrate the value of integrating clinical examples into undergraduate teaching, and describe how this can be achieved through co-operation between anatomists and clinicians. Modern surgical techniques continue to develop and, in so doing, require ever more detailed anatomical knowledge as demonstrated by the examples provided with respect to teaching pelvic floor anatomy, the anatomy of the ethmoidal region, or the examples given for muscle anatomy. Here, the collaboration goes in 'the other direction', with anatomists helping to underpin surgical advances. It should be borne in mind that gross anatomy is not just a tool for the physician to practise medicine, but it is its very foundation and, as such, should be taught by anatomists. On the other hand, there is a demand for clinical anatomy that seems to be either intrinsic or relevant for many aspects of treatments in all healthcare professions. It could be argued, therefore, that a close relationship between anatomists and clinicians enhances and reinforces core knowledge of gross anatomy by appreciation of its clinical importance in whatever context it might need to be applied (Fasel et al., 2005; Turney, 2007). This may consequently help to address the shortages in anatomy teaching by attracting teaching staff that hitherto have not been recruited to the task.

That gross anatomy should be taught to medical students as clinical anatomy (see Winkelman, 2009; Regan de Bere and Mattick, 2010) has become a shibboleth for virtually all anatomists, medical educationalists, and authors. Indeed, hardly any contemporary textbook of anatomy is without the word "clinical" in its title. There is little agreement, however, about what should be included (or excluded) from an anatomy course, or what might be appropriate as clinical scenarios, largely because core anatomical knowledge in a clinical context has yet to be defined with universal acceptance. This is hardly surprising, given the fact that anatomical terminologies (e.g. Terminologia Anatomica, 1998) have also yet to gain general approval. Recognising this as an issue, the Anatomical Society within Great Britain and Ireland commissioned its Education Committee to develop a core regional anatomy syllabus for undergraduate medicine (McHanwell et al., 2007). As the examples above illustrate, these syllabuses cannot be allowed to stand still but must be subject to periodic review. Consequently, after nine years in use it was deemed necessary to look again at this syllabus, resulting in a revised core regional anatomy syllabus being published by Smith et al. (2016b), using Delphi methodology as the research tool to validate its content. At the same time, the International Federation of Associations

of Anatomists (IFAA) is using Delphi methodologies to help develop a series of core syllabuses in the anatomical sciences (Moxham et al., 2014). To date, IFAA core syllabuses for Head and Neck Anatomy, for Neuroanatomy, and for Embryology and Teratology, all within the medical curriculum, have been published (Tubbs et al., 2014; Tubbs and Paulk, 2015; Moxham et al., 2015; Fakoya et al., 2017). The IFAA syllabuses are being formulated and disseminated in ways which are specifically intended to facilitate periodic review as our knowledge continues to develop.

Few studies are available to assess students' opinions about the efficacy of teaching gross anatomy in a clinical context. Moxham and Plaisant (2007) and Moxham et al. (2011) used Thurstone and Chave's (1951) analyses to evaluate first-year medical students' attitudes at Cardiff and at the Sorbonne, and reported that these students much appreciated the great importance of gross anatomy to their clinical studies. Similar results were reported for final year students at Cardiff and Paris (Moxham and Plaisant, 2007) and for medical students at Imperial and Nottingham Universities (Kerby et al., 2011). Similar attitudes were shown for dental students (Olowo-Ofayoku and Moxham, 2014). Indeed, regardless of the nature of the anatomical courses undertaken, anatomy was regarded as having considerable value and purpose in an undergraduate medical course. Furthermore, this applied regardless of geopolitical and cultural backgrounds. Moxham et al. (2011) also reported that medical students appreciated the integration of anatomical material with clinical medicine. Nevertheless, they valued the use of clinical case histories as motivational tools and insisted that anatomy is a "foundation subject" and a scientific discipline in its own right that is more than just a device for studying clinical situations. They were also ambivalent about the use of clinical scenarios for assessments and examinations at the early stages of the course. Indeed, Regan de Bere and Mattick (2010) suggested that "anatomy may require its own custom-built approach to teaching and learning". Furthermore, Mattick and Knight (2007) reported that students found that acquiring anatomical knowledge was qualitatively different to other closely related biomedical subjects, requiring a different approach to learning more dependent upon memorisation. The findings of these studies indicate that, while students do prefer anatomy to be made explicitly relevant to clinical needs, their understanding of the clinical, scientific and cultural aspects of anatomy is aligned with the view that anatomy should not be subsumed or totally integrated into clinical studies. The two examples relating specifically to undergraduate teaching provided in this article show ways in which clinically-relevant examples can be integrated into basic science teaching of undergraduate medicine or dentistry while retaining the sense of anatomy as a subject. This has relevance to the question of the positioning of anatomy in medical and healthcare studies courses. It is becoming commonplace to argue, without evidence, that gross anatomy teaching should extend beyond the early years of the medical course. However, in the report of Moxham et al. (2011) it was acknowledged that 77% of the medical students surveyed believed that anatomy forms the basic knowledge of the human body needed before it can be utilised in a clinical situation; and just over 60% believed that anatomy teaching should occur at the beginning of the course with only 20%, expressing the view that it should be extended throughout the course. Of course, a well-planned reinforcement of anatomical knowledge is likely to be beneficial and, in well-planned spiral curricula, topics will be revisited and elaborated at the same time (Olson, 2007). Nevertheless, care must be taken to ensure that core anatomy is taught at an early stage, so that fragmentation of the subject can be avoided and the important professional skills that anatomy can deliver are not lost by dissembling courses and losing exposure to dissection and examination of cadavers. A further issue that must be considered is the increasing tendency to place important anatomical material in "optional" or "elective" courses. Entwistle (2009) has argued that more effective student learning is likely to occur where there is coherent syllabus design and both the delivery of parts of anatomy courses either in later years or through elective teaching will militate against this coherence. Moxham and Pais (2016) have argued that, particularly for the teaching of regional anatomy, "until core material is defined (and generally agreed) in the medical curriculum then optionality has conceptually no real foundation". Furthermore, it is worrying that the diversity of elective courses (including content, teaching methodologies, assessment, admissions, and outcomes) detracts from the important educational principles of consistency, reliability and transparency. Indeed, medical education worldwide is already fractured by a high degree of diversity such that there is difficulty in appreciating the standards set (and thus the quality of future medical practitioners) once they have completed their medical degree. Furthermore, in our increasingly consumerist societies, laypersons (patients and potential patients) are the consumers and they will increasingly expect appropriate standards to be achieved and consistency between institutions and medical curricula to be applied. In this regard, Moxham et al. (2016) have reported that laypersons believe that their medical practitioners should have a high level knowledge of gross anatomy.

With respect to the use of clinicians for the teaching of anatomy, Regan de Bere and Mattick (2010) reported that this was "key to keeping teaching grounded in relevant application", but sadly it seems that, for a variety of reasons, anatomists

with clinical qualifications are, in many parts of the world, not choosing to follow careers in the basic biomedical sciences (including anatomy). However, training programmes for newly appointed anatomists without clinical qualifications are being established (e.g. Fraher and Evans, 2009). Moxham et al. (2011) however reported that over 50% of the medical students in their survey were of the opinion that anatomy need not be taught only by clinicians (11% were strongly of the opinion that it can only be taught by clinicians; 14% strongly held the contrary view). That said, given that clinically-qualified teachers of anatomy are becoming fewer in number, collaboration between anatomists teaching the subject at undergraduate or postgraduate level and practising clinicians is ever more important and the five examples described in this paper show different ways in which this might be achieved, and argue for some of the benefits that can ensue from such collaborations.

Looking at this aspect from a different perspective, students are often expected to take responsibility for their learning and not rely upon their teachers. It is instructive to note that, on a voluntary basis, only 34% of students were involved in medically-related reading beyond the recommended anatomical texts. This finding may reflect the lack of interest or time available to the student for self-integration of material, and/or is related to the perceived requirements of their examinations, and/or is a measure of the lack of emphasis or direction provided by the teachers. Whatever the reason may be, it should be acknowledged that many students choose a surface or strategic approach to their studies and not the deep approach that many teachers would wish (Smith and Mathias, 2010). While it is the case that deep learning cannot occur without surface learning having taken place (Hattie, 2009), and that the burden of surface learning is high in a content-rich subject such as anatomy, surface learning by itself will not be sufficient in situations where clinical problem-solving is needed.

A further issue relating to the teaching of anatomy as clinical anatomy stems from an appreciation that medical students could already have a reasonable knowledge of medicine before they enter medical school. Although such knowledge could derive much benefit to the medical course, medical schools usually make the assumption that a new medical student is a tabula rasa and has little or no knowledge of clinical medicine. Consequently, students are taught medicine *de novo*. Indeed, it is now becoming commonplace to argue that until a student has experience of the clinic she/he cannot appreciate the significance of studying anatomy or any other basic science. Thus, early, and generous, exposure to the clinic is advocated long before exposure to anatomy and the basic sciences. In view of this belief, Moxham et al. (2011) tested the hypothesis that students “have a significant knowledge of medicine before they commence their education and training at medical school“. Their findings supported this hypothesis. Using musculoskeletal, cardiovascular and respiratory medicine as signifiers of their medical knowledge, while many students claimed little or no knowledge, the tests suggested that they do bring a significant amount of medicine with them to medical school. This being the case, teachers should not only focus upon the clinical relevance of anatomy but should appreciate that their students are not ignorant of medical conditions. Consequently, benefit can be obtained by encouraging students to impart their existing knowledge and by their recounting the “stories/narratives” whereby their knowledge of medicine was obtained. This approach would foster clinical relevance in their biomedical sciences studies and would improve staff-student interactions. Presently, there are trends in medical education that bring students into the clinic before they start their studies into biomedical sciences, the belief being that by exposure to clinical situations they can only then appreciate the need for learning anatomy and other biomedical sciences. By no means should one argue against the need for early clinical exposure. However, it is clear that students are already well aware of the importance of anatomy to clinical medicine and that they already bring with them a significant knowledge of medicine. Furthermore, a contrary argument can be made that without a foundation in basic sciences complex clinical scenarios cannot be understood. Again a well-designed spiral curriculum will attempt to address these difficulties through revisiting topics and elaborating detail Olson (2009).

The future of clinical anatomy is assured but its context is important. Anatomy remains a central scientific and cultural element in the medical curriculum that requires its own pedagogic direction and principles. Clinical anatomy requires that anatomists and clinicians fully understand what core clinical anatomy is. We remain some way from such an understanding and consequently it is not surprising that, for example, the Royal College of Surgeons in London has expressed concern about the future of anatomy in the undergraduate and postgraduate medical and surgical curriculum. However, a return to the extensive and extended anatomy courses of the past, without regard for clinical context, is not an option. In another context, this is what Morley (2003) has termed teaching knowledge ‘just in case’ it might be required for a professional courses. The Anatomical Society core syllabus (McHanwell et al., 2007) and its later revision (Smith et al., 2016a, b) were developed partly to provide a necessary balance between teaching anatomy ‘just in case’ and teaching it ‘just in time’ while keeping a sense of the discipline as a whole. Putting aside aspects relating to the skills

based on training in anatomy, and also the admonition from the General Medical Council in "Outcomes for Doctors" (GMC, 2015) that a doctor must be a "scientist and a scholar", without a generally accepted "core syllabus" in clinical anatomy we can hardly predict what is 'just in case' let alone what is 'just in time'!

While overall we would argue that anatomy must be delivered in a clinical context, we have concerns about just what is meant by "clinical context". The French philosopher, Michel Foucault, whose father was a professor of anatomy, wrote in *The Birth of the Clinic*: An *Archaeology of Medical Perception* (London, 1973) about the culture of medicine and how it has changed with history. He concluded that the rise of anatomy had a profound effect upon the culture of medicine, shifting the emphasis from a concentration on disease towards an understanding of health. This is instructive, since there is a great danger that our present emphasis on disease scenarios and pathology for the teaching at an early stage in medical training may shift the culture of medicine away from health. And yet, we should not forget that medicine must remain focused on health and disease. Consequently, doctors are expected to be advocates for health as well as diagnosticians of disease. An understanding of the science of anatomy is important in this respect and it is no wild conjecture to state that lay persons/patients are under the belief that anatomy is an essential aspect of medicine and that their doctors are well-versed in anatomical knowledge (Moxham et al., 2016). Should anatomy continue to be downplayed in the medical curriculum one fears not just for the culture of medicine but also for the standing and reputation of the medical profession as seen through the eyes of the lay person. In our view, the future of clinical anatomy relies upon an understanding of the descriptor "clinical" in terms of both health and disease.

In summary, and returning now to the questions initially posed as a consequence of adopting an integrative, clinically-orientation approach to the teaching of gross anatomy:

Is anatomy a scientific discipline in its own right or is it subservient to medical/health care professional training? Traditionally, anatomy has always had feet in both camps, but it should never accept subservience to a disease-based model for healthcare professions. The newer, functionality-based model being adopted by the WHO accords better with the need to maintain health and with the culture of medicine that sees equal validity for the understanding of both health and disease. Nonetheless, we would continue to argue that an appropriate balance is struck between the basic science of anatomy and its clinical applications. If students are to acquire an appropriate foundation in anatomy that can be built upon in later years in a spiral fashion then anatomists must ensure that basic anatomy remains a key part of the early curriculum. Indeed, should there be an over-emphasis on clinical context it could be argued that this might impinge significantly upon the amount of time available for anatomical studies and therefore decrease the depth to which anatomy could be taught. Bergman et al. (2008) have highlighted the fact that student performance is related to total learning time for anatomy and consequently introducing significant clinical content might affect disciplinary integration. As Gibbs (2010) has observed in other contexts, time on task is a crucial predictor of learning effectiveness.

What do students think of the importance of teaching anatomy in a clinical context and what knowledge of medicine or health care issues to they bring with them to enable them to make best use of the integrative approach? For medical students, there is evidence that many students bring significant knowledge to their courses and that this should be acknowledged, and built upon, so that integrative or case-based studies are best fostered. In addition, students seem to like clinical scenarios as motivational devices but not as the primary means of instruction or assessment. The examples relating to the teaching of neuroanatomy to medical students and gross anatomy to dental students provide examples of how clinical examples can be integrated into anatomy teaching.

Is it necessary for anatomists to also be clinicians or is it sufficient for a clinician with some anatomical knowledge to be responsible for this aspect of medical education? Clinical knowledge is essential, not least for providing motivational and contextual instruction. However, present evidence suggests that training courses for anatomists who are not clinically qualified can be beneficial and, furthermore, that many medical students do not see the absolute necessity for their anatomical teachers to be clinicians. Alongside training courses the development of close links between anatomists and clinicians and, where appropriate, team teaching and team development of course materials can be beneficial as this paper illustrates in all five of the examples given.

How far are human cadavers and dissections necessary to supplement a clinical approach? Although Winkelmann (2007) showed from a meta-analysis of 14 surveys that there is only a slight advantage of dissection over prosection when anatomical knowledge is tested (see also Bergman et al., 2011, 2014), dissection by students nevertheless provides the greatest range of learning opportunities and the provision of the greatest range of skills sets (Patel and Moxham, 2006; Moxham and Moxham, 2007; Kerby et al., 2011). This is important in the development of 'professionalism'.

Furthermore, laypersons also expect their doctors to have dissected (Moxham et al., 2016).

What are the different tools presently at our disposal in order to supplement clinical teaching? The use of cadaveric material, via demonstration of prosections as well as dissection by students, affords a wide range of teaching tools that are presently unavailable by means of other tools such as e-learning and teaching (e.g. skills development, understanding of biological variation and 3-dimensionality, appreciation of issues relating to ethics, professionalism, team working, and mortality).

Overall, therefore, we strongly support the teaching of anatomy in a clinical context, provided that it encourages an understanding of health as well as disease and using cadaveric material not just for the acquisition of anatomical knowledge but for the development of important, professional skills sets. We would also argue that it is important that students receive anatomy teaching in a disciplinary context in order that they may have access to the 'powerful' discipline knowledge (Young, 2011) that allows an adequate foundation in anatomy to be established. One possible way of teaching anatomy and clinical anatomy is implementing spiral anatomical education (Olson, 2007; Louw et al., 2009) where general anatomy is introduced early in the medical curriculum to be followed later in the curriculum by advanced clinical anatomy. This approach obviates the problem of having clinicians 'invited' as guest teachers early on when they may not be able to set detailed clinical content in an appropriate basic science setting.

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