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Review

Surgical experts: Born or made?

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ABSTRACT

The concept of surgical expertise and the processes involved in its development are topical, and there is a constant drive to identify reliable measures of expert performance in surgery. This review explores the notion of whether surgical experts are "born" or "made", with reference to educational theory and pertinent literature. Peer-reviewed publications, books, and online resources on surgical education, expertise and training were reviewed. Important themes and aspects of expertise acquisition were identified in order to better understand the concept of a surgical expert.

The definition of surgical expertise and several important aspects of its development are highlighted. Innate talent plays an important role, but is insufficient on its own to produce a surgical expert. Multiple theories that explore motor skill acquisition and memory are relevant, and Ericsson's theory of the development of competence followed by deliberate self-practice has been especially influential. Psychomotor and non-technical skills are necessary for progression in the current climate in light of our training curricula; surgical experts are adaptive experts who excel in these.

The literature suggests that surgical expertise is reached through practice; surgical experts are made, not born. A deeper understanding of the nature of expert performance and its development will ensure that surgical education training programmes are of the highest possible quality. Surgical educators should aim to develop an expertise-based approach, with expert performance as the benchmark.

1. Introduction

In the context of surgery, experts can be defined as "experienced surgeons with consistently better outcomes" whereby they demonstrate superior performance in multiple skills compared with non-experts.[1]

There seems no reason to doubt that since humans lived on earth, there were people with a particular aptitude to carry out such interventional procedures; they may have displayed an innate instinct for self-preservation amongst themselves.[2] Despite the controversies that exist, the Darwinian concept of "natural selection" and "survival of the fittest" is well established. Such a theory can be used as a starting point to argue the assertion that experts have qualities that allow them to "go further". There is a vast amount of research in the literature attempting to elucidate the attributes of experts and the steps involved in the development of expertise.[3,4] The two questions that must be posed collectively are:

How important are innate abilities in the development of surgical expertise?

Given the appropriate training, can sheer determination, hard work, and practice be enough to turn an individual into a "surgical expert"?

This review will begin by touching upon competence and defining the attributes of surgical experts, followed by elaborating key conceptions in light of educational theory with regards to expertise development and innate talent, and end with a discussion of the implications to modern surgical training, in order to evaluate whether surgical experts are "born" or "made". This paper is an overview of available material, and involves a detailed exploration and critical appraisal of key concepts underpinning the development of surgical expertise.

2. Development of competence

The making of a competent surgeon has always been a priority for our profession and the public. With at least 30%–50% of major

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complications from general surgical procedures being potentially avoidable, there is a role for a formal framework to define, document, and assess surgical competence.[5] Although well-defined and assessed competencies are thought to contribute to safer, more effective patient care, a "universal" definition of surgical competence has been deemed rather unattainable.[6] It is therefore more appropriate to consider the different components or roles of the competent surgeon.[7]

According to the behaviourist approach, competence is assessed by precise measures of performance, generally documented by checklists. The holistic, integrated approach defines it as a complex combination of personal attributes. In the surgical arena, competence is the ability to successfully apply professional, skills, knowledge, and attitudes to new situations and familiar tasks.[8] An important step in assessing this competence is developing robust methodology for its evaluation and certification. This must be distinguished from proficiency, "the level of performance in each of the specific components of competence".[9]

The adage "See one, do one, teach one" is familiar to surgical trainees. It fosters a sense of pride and competition in the profession. However, it creates undue tension for trainees and may inhibit further exploration of a skill particularly following early complications.[10] It is now also neither acceptable nor appropriate for educating trainees to perform complex procedures based on "seeing one" and then "doing one".[11]

Miller[12] introduced his famous "hierarchical" triangle comprised of four levels in 1990, where from base to pinnacle one "Knows", then "Knows how", then "Shows how", before reaching the final stage of "Does". Thus in each step towards competence, the trainee progresses through requisite cognitive and behavioural steps that underlie the subsequent step, building upon the knowledge that eventually underpins the execution of a precise skill. Howell's model[13] constitutes similar phases whereby a novice initially migrates through phases of "unconscious incompetence", "conscious incompetence" and ultimately "unconscious competence".

The main drawback to Miller's triangle in this context is that it appears to assume that competence predicts performance. However it is widely accepted that factors outside the surgeon's control can hinder task execution, such as difficulty stopping an acute haemorrhage intra-operatively if the available equipment is inadequate or if there is no available team to help; such experiences represent challenges to every-day skills acquisition. Rethans et al.[14] have thus proposed "The Cambridge Model", taking this into consideration. This model distinguishes competence from performance (i.e. what a trainee shows in an assessment situation as opposed to in real practice), because although performance builds on competence, it depends on other personal or systemic factors (such as peer relationships and hospital policies respectively).

3. Attributes of a surgical expert

It is vital to note that surgical experts are not just mere "technicians", capable of operating successfully when faced with difficult procedures. Modern surgical education aims to cultivate surgeons with the appropriate technical and non-technical skills. These non-technical skills include domains such as knowledge depth, professional values (such as team working and communications skills) and judgement to be members of the multi-professional surgical team.[15]

Elstein et al.[16] highlight the fact that they were unable to establish superior accuracy of peer-nominated best general physicians when compared with undistinguished physicians. In the medical field (compared to the surgical field) it is probably difficult to evaluate outcome and hence expertise is probably more difficult to determine. It is surprising to note that physicians with extensive experience and education did not make better decisions than their less-skilled peers, or even sometimes than their secretaries.[17] Decision-making, especially under pressure, is crucial for surgical experts.

It has also been suggested that experts display greater "movement economy", consistency, and automaticity of performance. In fact several studies have validated movement economy as a skill level discriminator on simulators.[18,19] Having acquired domain-specific memory skills, they are able to rely on long-term memory to expand the amount of information that can be kept accessible during planning and during reasoning about alternative courses of action, allowing them to execute certain tasks "automatically", as well as anticipate adverse events.[20,21] The "automatisation" of action is evidenced by their capability to perform primary tasks with an apparent absence of intentional effort, with the associated capability to multitask with relative ease.

Studies in laparoscopic surgery have demonstrated that experts are better at monitoring and evaluating their own performance in both cognitive and motor tasks, with a well-developed capability to detect and correct errors in their movement production. Non-experts on the other hand appear to primarily depend on feedback from external sources for error detection and correction.[22] Similar observations have been made during open surgical procedures where the ability to detect surgical errors is strongly correlated with increasing surgical expertise.[23] Experts are essentially both effective and efficient at solving operative dilemmas, using forward reasoning to reach diagnoses and treatment options, making fewer cognitive errors.[24,25] Following on from this phenomenon, Hsu et al.[26] were able to demonstrate in a simulation study that highly experienced surgeons were able to reach "automaticity" in surgical tasks as evident by their ability to "do more than one thing at a time" whilst undertaking both an arithmetic task and a simulated laparoscopy procedure simultaneously.

Surgical expertise is closely linked to the relative experience of a surgeon, which in turn raises questions regarding the relationship between surgical volume and operative outcome. Variability in outcomes of surgical intervention of a specific procedure is related to the number of times a surgeon performs it, even when controlling for related variables, such as hospital volume, which illustrates the benefits derived from targeted training and of adequate experience.[4,27] Increased frequency of performing a surgical procedure (i.e. experience) may lead to superior outcome.[28] This raises the possibility that "less able surgeons" might have more initial failures. This in turn may hinder progression with a reluctance to perform further similar procedures. On the other hand, amongst surgeons with high and very high volumes of specific procedures, a very large individual difference in outcome exists, exceeding the variability that would be expected by chance factors alone.[4,29] Those experienced surgeons with consistently better surgical outcomes can be referred to as "surgical experts".

Interestingly it has been shown across a wide range of surgical specialties that there is a clear and consistent relationship between both surgeon and hospital volume with outcome. Higher volumes (of surgeon ideally within a high volume centre) is associated with improved patient outcomes, including decreased length of stay, complication rates, mortality, adverse outcome, failure of surgery and improved clinical results.[30,31]

4. Galton and innate talent

Sir Francis Galton is recognized for developing the scientific basis for the view that skill acquisition is based on innate biological capacities, which limit the level of achievement that can be attained. His pioneering book, Hereditary Genius[32] (written in the

19th century), stated that height and body size was determined genetically, arguing that similar innate mechanisms must determine mental capacities.

He also states that relevant heritable capacities set the upper bound for an individual's mental and physical achievements, so that once all the training benefits have been attained through sufficient practice, the immutable limit for performance is subsequently reached. It appears he felt that immutable characteristics that would naturally limit maximal performance could not be affected through training i.e. they were innately endowed. Such arguments for the importance of innate factors in elite performance were quite compelling and, thus, have had a lasting impact on our culture's view of ability and expertise.[4]

There have been some attempts to determine the desirable personality traits of a surgeon with Hoffman et al.[33] suggesting that surgical residents were "highly conscientious, extraverted, and emotionally stable individuals". However, it has not yet been possible to determine what particular personality trait sets give one surgery resident the "edge" and sets him or her apart from the rest of the residents. Differences in this so-called "raw surgical ability" have also been observed amongst surgical novices. It has been demonstrated that there are variations amongst the arthroscopic ability of medical students who had never been exposed to any type of endoscopic surgery.[34] The latter study discovered that the novice subjects clustered into three groups of surgical ability; a group who were innately gifted with arthroscopic skills almost from the outset of the study, a group who were able to reach competency with repeated practice on a simulator, and a group who could not achieve basic competency despite repeated practice. Grantcharov and Funch-Jensen demonstrated similar findings in surgical residents (inexperienced in laparoscopic techniques) and went a step further to suggest that individuals who lacked the innate ability to acquire such technical skills should "choose an alternative professional field".[35] This suggests that some individuals do possess innate abilities that set them apart from the rest. However, the latter studies focused on the effect of task repetition and simulator-based practice on improvement of surgical skills. Therefore, one cannot automatically assume that such individuals are "un-trainable" because they were not receiving any specific training. One may suggest that the testing of innate abilities should be used to identify those who may require extra training, instead of being used as a selection criterion or indeed a reason to end a subject's surgical training.

It has been established that visuospatial awareness and fine motor dexterity are essential skills in minimally invasive surgery.[36] Earlier studies in general surgery have suggested a positive correlation between visuospatial ability and technical skill.[37,38] Murdoch et al. objectively demonstrated a relationship between scores on a "space relations test" and performance on microsurgical tasks.[39] In addition a recent endovascular skill has been shown to correlate strongly with fine motor dexterity.[40] Furthermore, a recent study validated three novel yet simple visual parameters in arthroscopy to assess the level of arthroscopic skill on simulator-based knee task (namely the prevalence of instrument loss, prevalence of lookdowns and the triangulation time).[41] Identification of such useful parameters that strongly correlate with existing methods of skill assessment should be capitalised upon in order to provide powerful and objective means of skills assessment and training.

5. Motor skills: acquisition and retention factors

Although acquisition of non-technical skills (e.g. knowledge, decision-making, and communication skills) is crucial in the development of surgical expertise, there is no doubt that technical skill acquisition and retention remains a priority for surgical training programmes. Although it may seem obvious, it is important to highlight the fact that successful completion of a surgical procedure is dependent on successful acquisition and execution of psychomotor skills. The acquisition of motor skills and the implications of this for surgery have been well described.[42,43] This three-phase theory consists of a cognitive phase (when the skill is being understood and practiced with allowance for making error), an integrative phase (when performance is becoming more fluent) and an autonomous phase (when the motor skills are being carried out without much conscious effort).[44] Reaching this latter – often described as "automaticity", enables surgical experts to perform at a high level in multiple surgical domains (i.e. multitask) with relative ease.[45]

Analogous to this, Dreyfus and Dreyfus identify five levels of skill acquisition in their model, originally derived from studying pilots.[46] The learner starts as a "novice" at level 1, progressing to an "advanced beginner" at level 2 (where situational perception has grown yet remains limited), becoming "competent" at level 3, "proficient" at level 4, and finally an "expert" at level 5 (having developed an intuitive grasp of situations based on deep tacit understanding).

6. Can surgeons be made?

It is interesting to note that in 1918, Jasper Halpenny, a Canadian surgeon in Winnipeg, presented his paper "The Training of the Surgeon" at the Hamilton Medical Week.[47] This paragraph strikingly sets the scene:

> "As to surgery, surgeons are made, not born. The making process we call education. Education should commence when the child begins to use its hands. It should be taught to use both hands equally well, as nearly as possible. As it grows, it should have its reasoning power developed, its ability to observe and record its observations, and its mechanical ability should be encouraged."

Before one becomes an expert, he or she must develop competence. It can be argued that much before true expertise develops, one must achieve competence. Some may naturally achieve this due to innate talent, still requiring adequate practice, and otherwise may require much more practice in order to achieve that same level of competence.

But what if simple practice does not result in achievement of such competence? In a follow-up to their study investigating the innate arthroscopic abilities of novices, Alvand et al.[48] provided medical students with specific arthroscopic training in order to determine whether or not all of these subjects could be trained to a predefined level of competency. They discovered that despite such attempts, there were individuals who were unable to achieve basic competencies. A similar subgroup of individuals was identified by Eversbusch and Grantcharov[49] in a randomized study using a virtual reality laparoscopic trainer. One could argue that such studies are limited by the type and duration of training that can be provided and can only be considered as a "snapshot" view of a very complex and multifactorial environment. Nevertheless, they confirm that the existence of differing learning curves amongst individuals is a reflection of their innate technical abilities. The key challenge for the modern-day surgical educator is to devise training programmes that can address these shortfalls for every individual - regardless of his or her innate ability.

7. Deliberate practice

It can thus be seen that expert performance represents the highest level of technical skill acquisition. Through extended experience, it is the final result of a gradual improvement in performance. This concept is best elucidated by Ericsson, who believes most professionals reach a stable, average level of performance and maintain this status-quo for the rest of their careers.[4] "The fundamental theoretical challenge is to explain how most people and professionals reach a stable performance asymptote within a limited time period, whereas the expert performers are able to keep improving their performance for years or decades". Repeated practice is thus crucial to gain expertise. Although Ericsson's work largely stems from observational work in domains outside medicine, he has shown that practice must be deliberate, sustained over many years - over ten years according to Simon and Chase,[50] and underpinned by a determination to improve.

This is where the concept of "Routine" vs. "Adaptive" experts is useful. Routine experts are highly skilled technicians within their domain, who have learned complex and sophisticated sets of routines, capable of applying them effectively at work. However, when faced with a novel problem, they tend to pursue their existing routines, trying to adapt the problem to the solutions they are comfortable as opposed to adapting their solutions to the novel problem. Thus any additional learning tends to focus on improving efficiency by refining specific aspects of established routines. On the contrary, adaptive experts will use a new problem as a point for departure and exploration; they consistently seek challenges to stretch the boundaries of their knowledge and competency. Adaptive experts are thus characterised by their flexible, innovative and creative competencies within the domain rather than in terms of speed, accuracy and automaticity of solving familiar problems.[51,52] Their 'reinvestment in progressive problem solving' as they reach automaticity is a useful way of looking at expertise development.

It seems logical to state that regular practice is hence an important determinant of outcome.[53] However, it is apparent that volume alone does not account for the skill level among surgeons because variations in performance have been shown among different surgeons with high volumes of cases. Intra-variability (for the individual surgeon) may also become smaller with high case load volumes. Ericsson[3] also argues that the number of hours spent in deliberate practice (with the specific intention and motivation to improve), rather than just hours spent in surgery, is an important determinant of the level of expertise. Thus deliberate practice is a critical process requisite for the development of expertise, or mastery.

Deliberate practice per se involves repeated practice along with coaching and immediate feedback on performance by the trainer. The attained level of expertise has been shown to be closely related to time devoted to deliberate practice in the performance of chess players, athletes and expert musicians.[44] In an apprenticeship-based model of surgical education, there are fewer opportunities for deliberate practice. This is where simulation can play an important role, as shall be discussed later.

8. Memory in the context of motor skills development

It must be noted that motor performance is linked to perception, memory and communication skills, in addition to the managerial processes involved in surgical procedures.[54,55] It has recently been shown that distributed practice (weekly vs. monthly) on complex motor skill acquisition may result in improvement and retention of a newly acquired surgical skill, independent of weekly or monthly practice schedules.[56] It seems prudent to capitalise on distributed practice to aid in memory and skill retention.

Scrutiny of a surgeon's intra-operative motor function (and therefore technical dexterity) is relatively easier than many of his or her non-technical skills. It is more difficult to understand the thought processes involved in controlling the surgeon's hand movements and flow of thinking, and communication between team members. Experts have a vast "vocabulary" of domain-specific knowledge stored in their long-term memory. Such working memory enables the surgeon to maintain elite performance during tasks. There is evidence to suggest that such experts' knowledge is integrated into "encapsulated" wholes, as memory is organised around practical schemas, in which diagnostic accuracy and quality grows as expertise develops.[57] Reasoning strategies thus form a core component in many clinical tasks such as diagnosing and decision-making. Schmidt and Rikers[58] argue that acquiring expertise requires the formation of "illness scripts", which develop only when one is practising as a physician and treating patients. It becomes apparent that interventional procedures require continuous problem-solving and decision-making, which become more difficult in complex and urgent cases. Integration between reasoning and motor skills is most important, particularly because these aspects of surgery are inter-related. This supports the argument that surgeons are made, since this integration is a process that needs to be learned and practised. It is here where experts who have "a vast experience under their belt" may excel, reemphasising the importance of deliberate practice and feedback in the development of that "experience".

9. Other non-technical considerations

There are also other novel aspects to surgical training that have recently been recognised. It is known that effective debriefing is a key educational technique for optimising learning in surgical settings. Given a lack of a debriefing culture within surgery, a recent study identified an "SHARP" intervention as an effective and efficient means of improving performance feedback in the operating room, and recommended its routine use to foster a positive culture of debriefing and performance improvement within surgery.[59] Another topical domain in surgical training is that of human factors. A recent review has highlighted that despite increased awareness of safety, errors routinely continue to occur in surgical care.[60] Disruptions in the flow of an operation, such as teamwork and communication failures, contribute significantly to such adverse events. Although it is apparent that some incidence of human error is unavoidable, there is evidence in both medical and non-medical fields that systems can be designed better to prevent or detect errors before a patient is harmed. The complexity of factors leading to surgical errors requires collaborations between surgeons, perhaps surgical experts, and human factors experts to carry out robust prospective and observational studies. Ultimately such useful interventions should be identified and implemented into surgical skills training programmes.

It has also been noted that in order to optimise the delivery of patient care, surgical leaders must play an important role. It has been advocated that while great leaders are required to have expertise and be results-orientated, they should also exemplify a set of personal qualities and attributes.[61] The concept of leadership in surgery is vast and beyond the scope of this paper; it has however recently been elegantly described in a recent review.[62] The requisite skill-set of surgical leaders has been summarised into professionalism, technical competence, motivation, innovation, emotional competence, teamwork, communication, decision-making, resilience, effective teaching and business acumen[62]; it can thus be seen that such qualities share core components of that of surgical experts.

10. Implications for the delivery of modern day surgical education

A shorter working week for residents in the USA and UK and the stress of increasing operating room efficiency contribute to an overall reduction in educational opportunities in learning surgical skills.[63,64] In addition, the increased complexity of surgical caseloads and the greater awareness of medico-legal implications may prevent junior trainees from achieving technical proficiency within a "normal" working day, unless an improvement in teaching surgical skills is achieved.

The acquisition of surgical skills can be considered more complex than mastering basic motor skills alone, partly because of the greater degree of cognitive involvement required. An expertise-based approach for surgical training, however, has great potential for new approaches to surgical skills education, with expert performance as the benchmark.[1,44]

The hallmark of current surgical training appears to be sheer volume of exposure, rather than specifically designed curricula.[65] Simulation has proven to be an excellent adjunct to surgical education, offering a safe environment where trainees can repeatedly practise a range of clinical skills without endangering patients.[66] In fact, the UK's Chief Medical Officer explicitly stated that simulation will be of central importance in healthcare education, especially for surgery and related craft specialities.[67] There is ample evidence to support the use of simulation in the acquisition of technical skills.[68–70] A landmark meta-analysis has highlighted enhanced surgical performance in simulator training when the training procedure incorporated characteristics of deliberate practice such as goal-directed training, repetition, reflection and feedback, where feedback appeared to be the most important factor.[71] As opportunities for surgical education through day-to-day work with patients have reduced, there has been a rise in simulation facilities with formal curricula, specifically designed to teach skills, where trainees can receive structured feedback. This on its own, however, is unlikely to be sufficient to address the current problem. This is because there is a widely held view that surgical training should be based on progressive acquisition of knowledge and operative skills, from simple to more complex levels.[70,72] However, other qualities such as the surgeons ability to function effectively in a team setting, which are as important, are much harder to define than technical skill. In fact, they are invisible when working well, and only surface when things go wrong.[72] Yet, if simulation is to be effective, it must address these complexities and render them visible. A more satisfactory conception of simulation may therefore highlight it as a spectrum of resources alongside clinical care in order to complement its richness.[70,72] Simulation thus offers the opportunity to abstract from a complex reality, to generalise from the particular, and to create suitable conditions for self practice, minimising patient harm. This can help learners think like expert clinicians, and not simple technicians, while preserving the centrality of the optimal patient care. It is important that advances in practical skills teaching are based on our understanding of educational theory.[73]

Educators with the widely held view of expert professional development (acquired experience on a background of innate talent) have focused on identifying and selecting trainees who possess the necessary innate talents that would allow them to reach expert levels with adequate experience and practice. Therefore, it is not surprising that such reputable professional organisations nearly always rely on extensive testing and structured interviews in order to select those applicants who are most talented, which inevitably requires expert standard-setters.[74]

11. Conclusion

There is a requirement to identify reliable measures of expert performance in surgery. That would inevitably require a thorough understanding of the mechanisms of acquisition of surgical expertise.

This review has highlighted that there are several theories applicable to the acquisition of surgical competence and expertise. These involve domains such as psychomotor skills (which are refined with sustained deliberate self practice), memory and deep learning. Given the fact that non-technical skills (which include communication and decision-making skills) are also a core component of the development of surgical expertise (i.e. technical dexterity is only one component), it is logical to propose the notion that there are a combination of factors that help "make a surgeon". These are potentially made easier if the surgeon was born with innate capabilities and a "framework" to succeed. Those surgeons who are labelled as "very technical" at a young age may potentially require fewer hours of deliberate self-practice, creating debate on this important and topical issue. The same argument applies to the development of expertise in the non-technical skill domains. However, this aspect still needs to be explored in greater depth, in order to optimise the education of the next generation of expert surgeons. The most effective methods to deliver this training are still in debate.

The study of surgical expertise has been a focus for medical education researchers for some decades. The purported value of such research enterprise appears self-evident.[38] If the nature of expert performance and its development in individual surgeons can be understood, surgical education training programmes can be modelled towards developing more effective and efficient experts in a shorter space of time. It is hoped that supporting those capable trainees to effectively develop expertise, we can nurture adaptive experts with the ability to excel in a wide range of challenging situations. It appears therefore that although innate abilities play an important role in the development of surgical expertise, given the attributes of the modern day surgeon, the literature suggests the surgical experts are in fact "made", not born.

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