Orthopaedic Innovations in Developing Countries

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Edited by

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ACKNOWLEDGEMENTS

It gives us immense pleasure to share the book ***ORTHOPAEDIC INNOVATIONS IN DEVELOPING COUNTRIES*** with our readers.

Our objective will be focused on improving orthopaedic surgery in low & middle-income countries (LMICs). Over the last 35 years, our orthopaedic surgeons have done multiple innovations locally that have never come to the surface. Many surgeons in our world work in a resource-constrained setting and have to use frugal innovation to work their way out. These are the ground realities of working in an LMIC which we would like to share with the rest of the world through this book.

Starting from seeing patients in the clinic and to the operating room, we have set very high standards in our country for others to follow and replicate within their own resources. This book will be a narrative of how we achieved all this and the way forward considering the resource constraints that we have in our LMICs compared to Western countries.

In the end we would also like to thank **Ms Ayesha Jazib**, Content Writer, and **Mr Shariff Charania**, Specialist in the Department of Surgery at Aga Khan University. They both worked tirelessly day and night and made this herculean task possible. We hope you will appreciate the quality of chapters in this book.

Happy reading,

Editorial Committee,
Orthopaedic Innovations in Developing Countries

CHAPTER 1

ORTHOPAEDIC SUPER SPECIALIZATION IN TRAUMA

AKBAR J. ZUBAIRI
AND SYED MOHAMMAD NABEEL NOOR

History of Super Specialization

Orthopaedic science and technology are evolving at a very rapid pace. The future lies in providing focused sub-specialist care to our patients. In the 1800s we only had the general surgeon, who would perform every surgical procedure: abdomen, pelvis, trauma, thorax, head and neck—everything lay within the domain of general surgery. However, the scope and number of procedures offered to patients were limited and rudimentary. So it wasn't unreasonable to expect proficiency in all of the procedures. As the number and technicality of surgical procedures grew, surgeons realized that they can no longer claim to be masters of all, even if they were credentialed for the same. Ophthalmology was one of the first surgical sub-specialties to become distinguished from general surgery. The American Board of Ophthalmology was formed in 1917 (Bruns et al. 2014). Many other specialties followed this approach and the American Board of Orthopaedic Surgery (ABOS) was formally formed in 1934 (Fig. 1-1). The American Board of Surgery—Complex General Surgical Oncology is the latest to become sub-specialized, in the year 2012 (Bruns et al. 2014).

Specialty Board	Year
American Board of Ophthalmology	1917
American Board of Otolaryngology	1924
American Board of Obstetrics and Gynecology	1930
American Board of Orthopedic Surgery	1934
American Board of Colon and Rectal Surgery	1935
American Board of Urology	1935
American Board of Anesthesiology	1937
American Board of Plastic Surgery	1937
American Board of Surgery (ABS)	1937
American Board of Neurological Surgery	1940
American Board of Thoracic Surgery (ABTS)	1948
ABS—Pediatric Surgery	1973
ABS—Vascular Surgery	1982
ABS—Surgical Critical Care	1986
ABS—Surgery of the Hand	1989
ABTS—Congenital Heart Surgery	2006
ABS—Hospice and Palliative Medicine	2008
ABS—Complex General Surgical Oncology	2012

Figure 1-1: List of Specialty Boards in America and their respective years of formation.

The rationale for sub-specialization is that a specialized surgeon has a better understanding of the regional anatomy and biomechanics, and is more familiar with unconventional approaches, ultimately leading to a shorter operative time, less morbidity, and better operative outcomes for the patient. Building on this idea, most developed regions treat trauma orthopaedics and elective orthopaedics as separate entities. Surgeons choose to specialize in elective orthopaedic sub-specialties or orthopaedic trauma. The majority of the trauma cases are managed by specialized traumatologists. However, if the fracture is complex or requires an unconventional approach, the case is then referred to involve assistance from sub-specialists of that body part. Elective surgeons sub-specialize through 1 or 2 years of fellowship post-residency in one of the AAOS recognized sub-specialties which include: arthroscopy, foot & ankle, hand, total joint, hip, knee, pediatrics, shoulder and elbow, spine, and sports (American Academy of Orthopaedic Surgeons 2022). This list is constantly expanding, and several fellowships are in their early stages and are not accredited by the AAOS yet. Sub-specialist surgeons are considered experts in their niche, and usually do not take trauma calls. However, complex trauma cases are referred to them.

The historical development of surgeons in Britain has been similar. The Royal College of Surgeons is the oldest professional body to represent surgeons, with the origins of the college dating back to the 14th century as the "Guild of Surgeons within the City of London" (Fu 2000). This guild consisted of both surgeons and barber-surgeons. Interestingly, this is the reason for surgeons in the UK dropping the Dr. prefix: because a medical degree wasn't a requirement to become part of that guild. Over time there have been many conflicts between these two groups. In the end, surgeons and barber-surgeons parted ways and the Royal College in London was formed in 1800 by a royal charter. This college was further expanded to all of England, forming the Royal College of England in 1843. The British Orthopaedic Association (BOA) was established soon after the First World War in 1918. The idea was conceptualized by the 12 founding fathers (British Orthopaedic Association 2014), who after witnessing the vast, tragic loss and disfigurement of limbs caused by the conflict felt the need for such an organization. The BOA emphasizes upon systemic research-proven advances in the science and art of orthopaedic surgery. In 2020, the association had just over 5,000 members. The BOA is affiliated with 22 specialist societies, which play a key role in clinical guidance, trauma advisory sheets, and delivery of change in the profession (British Orthopaedic Association 2022).

Our neighbors across the border have had a similar historical progression of surgical specialization. The College of Physicians and Surgeons of Mumbai (CPS Mumbai) was formed in 1913, using the Royal College as a model. It is one of the first examining bodies offering various fellowship and diploma courses at the postgraduate level to meet the shortage of specialist doctors in India. The Indian Orthopaedic Association (IOA) was founded by young surgeons, who trained in the field abroad during or after the Second World War. The BOA served as an inspiration (IOACON 2014, HYDERABAD 2014). At the annual congress of the Association of Surgeons of India (ASI) in December 1955, a formal Orthopaedic Section with office bearers was formed. Currently, the IOA is an independent body, with 16 affiliated sub-specialty societies.

There is a large repository of research showing that specialized or focused trauma care has better outcomes when compared to general trauma care. A review of 569 patients on the Toronto Western Hospital Spinal Program, showed that spine trauma, when managed at a specialized trauma centre, has a significantly lower average mortality than the national average (Kattail, Furlan, and Fehlings 2009). A study comparing the management of ankle fractures between trauma surgeons and specialist foot and ankle specialists showed that when a foot and ankle sub-specialist manages a Weber ankle fracture, they place greater emphasis on preoperative planning with detailed 3-D imaging. They also use a greater diversity of surgical techniques on the synthesis of the posterior malleolus (González-Lucena et al. 2018). These are carried out for a more accurate approximation of fracture in less operative time, and to avoid long-term joint degradation, revision surgery, or infections (van der Vliet et al. 2019). A study compared patient outcomes at a level I trauma centre before and after a full-time orthopaedic traumatologist was inducted as part of the faculty. The presence of a dedicated traumatologist led to improved pelvic fracture outcomes and financials (Testerman et al. 2011). There is a lack of specialized hand orthopaedic surgeons in the US. A systemic review of trauma centres showed that they do not have enough hand surgeons to cover calls every day, and their presence significantly affects patient outcomes. Trauma centres with specialized on-call hand surgeons have a higher likelihood of successfully re-implanting amputated digits (Maroukis et al. 2016). All of this points towards the need to provide specialized trauma care to our patients.

The Current Pakistani Perspective

Pakistan is a developing country with the 5th largest population in the world—more than 220 million. Approximately 100,000 road traffic accidents (RTAs) are reported each year, which leads to 36,000 deaths annually (DAWN 2019). The total number of RTAs is expected to be even higher since cases are only logged if reported to the police, or if the patient reaches an emergency centre (Yahya, Mir and Zafar 2013). Those who survive have significant morbidity issues due to a lack of access to trauma experts for timely intervention. The ratio of members of the population to orthopaedic surgeons is estimated to be 140,000:1, on average, for the country, but in the major cities, the ratio is further skewed to 8,000,000:1. This is due to the concentrated population for which there is a lack of proportional increase in orthopaedic surgeons. Tertiary care trauma centres are limited to the major cities. They not only deal with cases in their city, but also have to deal with the bulk of cases that are referred from areas of the country where tertiary care facilities are not available.

The need for sub-specialization was realized in Pakistan as well. This led to the establishment of the College of Physicians and Surgeons (CPSP) in 1962, with a focus on the promotion of specialist medical practice through the organization of postgraduate medical education, training, and research (College of Physicians and Surgeons Pakistan 2022). The CPSP started with just 2 fellows and 6 specialty programmes, and has now grown to award worldwide recognized qualifications in 73 fellowships from 22 membership programmes. The Pakistan Orthopaedic Association (POA) has recognized the need for further sub-specialization in orthopaedics with its national fellowship programmes. Currently, the POA offers 8 fellowships in: arthroplasty, deformity correction & bone regeneration, hand surgery, orthopaedic oncology, paediatric orthopaedics, sports surgery, and arthroscopy, spine surgery, and trauma.

In an ideal scenario, elective and trauma services should be running parallel with specialized trauma and elective surgeons. However, due to the high population to orthopaedic surgeon ratio, we do not have this luxury. Orthopaedic surgeons have to perform elective surgeries and cover trauma calls. It is not uncommon for a foot & ankle specialist to have to deal with paediatric trauma and vice versa. Sub-specialist surgeons have an ecosystem around them which enables them to provide better outcomes. This includes instrumentation specific to their sub-specialty, and a greater familiarity with regional variances, whether that is smaller paediatric instrumentation or a niche instrument for unconventional approaches. Their staff have been trained to give them the expertise in pathologies that they regularly deal with. There is a delay in referring complex trauma cases to sub-specialists, which leads to poor outcomes for the patient. In areas where higher-level centres are not easily accessible, patients may not be referred at all. The American College of Surgeons recommends a minimum number of annual cases for trauma surgeons to have outcomes similar to the national average (Konvolinka, Copes and Sacco 1995). When elective surgeons take general trauma calls, they are performing a few cases of every specialty but not enough cases to meet the minimum requirement in any particular sub-specialty.

The Trauma Super Specialization System

Keeping Pakistan's resource constraints in mind, we have a proposal for a super-specialized trauma call system, to allow the same resources to be used in both elective and trauma situations. A hybrid system where trauma calls are subdivided under different sub-specialist consultants:

- Foot & ankle
- Paediatric orthopaedics
- Hand & wrist
- Pelvis & acetabulum
- Application of Ilizarov apparatus for open fractures of long bones not amenable to IM nail or plate osteosynthesis (Ilizarov)
- General trauma.

We recommend a minimum of 3 surgeons for each sub-specialty, who have accreditation in that particular sub-specialty. The on-call days will be divided. The number of surgeons can be more or less depending on the patient load and resources available. Given that we will have 3 sub-specialist surgeons, each sub-specialist will be on-call 10 days a month. The sub-specialists on call will perform surgeries in their areas of expertise and subsequently will have higher volumes in their niche. At any given time there will be one specialist on call for each sub-specialty and one general trauma surgeon on call. If the patient has an isolated sub-specialty-specific trauma, the case will be managed by the appropriate sub-specialists on call only. If there are fractures of multiple body parts, then the patient will be managed by the general trauma surgeon on-call and assisted by sub-specialists on call for a particular fracture as needed. The general trauma surgeon will deal with isolated trauma that does not fall under any of the sub-specialties. This will mainly include long bone fractures, hip fractures, periarticular fractures (other than ankle and wrist), and all others.

The trauma super specialization call system will allow the surgeons to further build up their expertise by developing their specialized experience. The number of surgeries performed by a particular surgeon will more or less be the same; however, the surgeries that they are performing will be focused on the sub-specialty that they have trained to become experts in. We hypothesize that this will lead to a shorter and more efficient surgery with a decreased hospital stay. Patient outcomes and quality of care will improve as a result of specialist care. This will also bypass the need for referral, since cases are already managed by the appropriate sub-specialists. There will be huge potential to have rapid and focused research when a surgeon has a narrow spectrum and larger patient volumes. In addition, if a surgeon has fellows training with him, they will also have a more focused experience in the area that they are training to become future experts in.

A potential downside of the system may be that the surgical exposure of the general traumatologist will be reduced, and it could be argued that a general traumatologist from this system will not be able to work in a remote setup. However, we believe that the potential benefits are far greater.

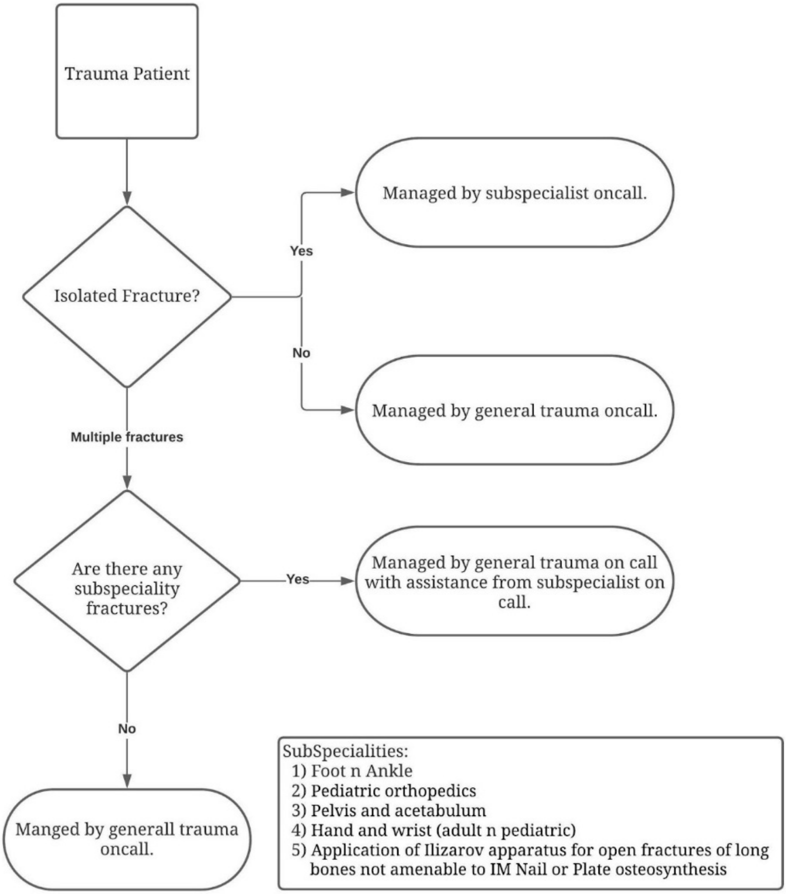

Figure 1-2: Trauma Cases Assignment Algorithm

Pilot study

Karachi is one of the major cities of Pakistan. In 2018 the reported population of Karachi was 16.6 million, but this is a gross underestimation as it does not account for the large undocumented peri-urban settlements. The Aga Khan University Hospital (AKUH) is a tertiary care teaching hospital located at the heart of Karachi. The Aga Khan University Hospital has 560 beds, 17 operating rooms and provides state-of-the-art treatment in 22 different disciplines. Currently, there are 12 full-time orthopaedic surgeons at this hospital. The trauma super specialization call system was implemented at The Aga Khan University Hospital as a pilot, which started in June 2018. We have parsed the data of the first 2 years of its operation (Fig. 1-3).

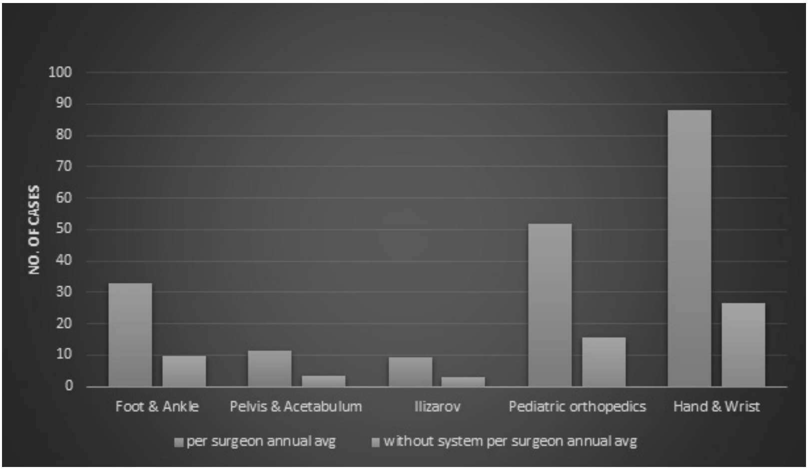

Figure 1-3: Annual surgical volume before and after implementation of the system.

There is a three times increase in sub-specialist volume per surgeon across all sub-specialties. Particularly in Ilizarov and pelvis & acetabulum surgeries, where previously a surgeon would be performing only 3 surgeries annually, now these procedures are performed by sub-specialists, and their volume has increased to 10 surgeries per year. Paediatric orthopaedics and hand & wrist operations have the most significant increase in volume. This pilot will be run for 5 years after which patient outcomes will be compared.

Conclusion

With this super-specialized trauma call system, we hope to see improvements in patient outcomes including but not limited to: length of surgery, rates of complications, perioperative infection, and length of hospital stay. Depending on the outcomes we plan on expanding this system by adding further sub-specialties. This could include shoulder-elbow and hip-knee. As previously stated, a limitation of this setup is that the scope of general orthopaedic trauma surgeons is decreasing and that surgeons who are accustomed to this setup may not be able to cater to the needs of a rural trauma setup. However, we believe that this system overall will benefit the patient, and if this setup is widely adopted, then the narrow scope of one surgeon will not be an issue. Ultimately we want to challenge the status quo. The problems faced by the developing world are unique to us. We cannot just copy systems from the developed world and hope that they will work perfectly. Those systems should be used as inspiration, but then should be adjusted according to our needs and resource constraints.

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CHAPTER 2

ANIMAL MODELS FOR SIMULATION-BASED TRAINING IN SPINE SURGERY: A LOW- AND MIDDLE-INCOME COUNTRY PERSPECTIVE

AKBAR JALEEL ZUBAIRI
AND MOHAMMAD HAMZA BAJWA

I. Simulation-based training models

The volume-outcomes model is the most prevalent structure for surgical residency training across the world. PGY-1 trainees are quickly inducted in a learning curve-based training programme with graduated competency levels. The standard teaching model follows a three-step approach: "watch one, do one, teach one" (Halsted 1904). Trainees develop their surgical skills through careful observation of surgical techniques in the operating room (OR) and develop the capabilities to take on the first assistant's role. If a trainee shows adeptness at assisting and is confident enough to carry out procedures, a consultant can then place them in centerfield to take on more responsibility in the OR. After considerable trial and error, the trainee becomes more adept in operating independently, and is given the task to train junior residents in similar techniques, thereby assessing their own understanding of surgical supervision. Simply put, a surgical resident's number of cases logged and procedures performed is seen to correlate with improved training, spatial and anatomical awareness in the OR, and an understanding of the dynamics of a surgery (Pham et al. 2019). Ultimately, patient outcomes are decided by how well a surgeon has been trained through a structured residency programme.

Technical proficiency on the other hand, is defined by multiple parameters. With a base in anatomical and surgical field knowledge, the real test of a surgeon's abilities is hand-eye coordination and understanding the objectives of the surgery (Reznick and MacRae 2006). With a scalpel and retractor in hand, can the resident accurately understand where an incision is needed; what needs to be anticipated; and can they respond in real-time to every inevitable surgical complication and case-by-case variation? These skills are not as standardized as one may expect, as anatomy and pathology never are. However, they have their base in a very real grounded knowledge of why we perform certain procedures the way we do, and how one can attain so-called "muscle memory". In fact, until one performs a certain procedure the way it has been standardized till each and every step is imprinted in one's brain, there is no way to ensure that the surgical trainee can truly graduate into the real world – where a mentor is not always available to guide one's hand to the correct tool or guard against egregious error (Sharif and Afsar 2018). Therefore, the learning curve exists to separate the uninitiated from those who have a firm footing in the fundamentals of surgical skills, and are ready to push the boundaries of surgical care (Sclafani and Kim 2014).

In order for a resident to attain the title of "First Assistant", or someday, "Primary Surgeon", they must be trusted with basic surgical skills. We see the current surgical residency model in our setup as inefficacious for developing safe and trusted surgeons, as there is no room for residents to make mistakes, learn from them, and improve at the very start of their learning curve (Nadeem et al. 2013; Zubair and Zubair 2020). This is simply because "teaching on the patient" is an incredibly unethical practice; certainly, none of us would wish to be test dummies for a resident's first suture. Therefore, we propose simulation-based training as an adjunct to surgical training. This has been justified all over the world, particularly with an incredible buy-in from high-income countries (HICs), where state-of-the-art virtual simulators are finding their way into the operating rooms and surgical skills and anatomy labs are expected from high-volume, high-quality training programmes (Kalun et al. 2018). This allows residents to learn in a safe and controlled environment, where their limitations and misconceptions of surgical practices can be explored, modified, and adjusted by trained hands. This acceleration through surgical simulation is precisely what is needed in order to train the surgeons of tomorrow (Wang et al. 2011).

Particularly in low- and middle-income countries (LMICs), the surgical burden of disease is beginning to outmatch the availability of surgical specialists to provide coordinated, multidisciplinary care (Mukhopadhyay et al. 2017). Global surgery bodies mandate that safe surgical practices pervade the surgical landscape. Residency programmes have begun to quickly fall behind improved hospital protocols and guidelines, as surgical care is becoming centralized. Residents often report fewer opportunities to take over procedural steps, and once graduated, report lower rates of confidence in their independent surgical skills (Mattar et al. 2013). As a result, the number of years post-residency surgeons take in instructorships, consecutive fellowships, and allying themselves with senior surgeons as "backup", become a barrier to independent surgical practice. With the overwhelming burden of surgical disease and complexity of procedures being developed, there is soon to be a gap in surgeons who can deliver safe surgical procedures (Ashraf 2020).

Simulation-based training has begun in LMICs and reports from countries all over Asia, Africa, and South America have shown the importance of these training mechanisms to develop and take root (Tansley et al. 2016). The success of residents in learning and performing techniques can be measured through validated tools, i.e., OSATS (objective structured assessment of technical skills) and Likert scale-similar questionnaires. These evaluations assess the time taken to complete tasks and surgical decision-making when faced with complications (Traynor Jr et al. 2021).

Ultimately, the goal is to catch up on the learning curve: orthopaedic residents, under the ACGME guidelines, must perform 15 spinal decompression surgeries as the primary "supervised" surgeon (ACGME 2017). This means being responsible for surgical planning, execution, coping with intra-operative complications, and expecting the unexpected ultimately. Residents in LMICs need to be able to develop surgical skills in safe environments. Surgical simulation-based training (SBT) is the solution to covering the main surgical skills before reaching the OR.

II. Training models for surgical residencies

SBT encapsulates various approaches, as discussed below:

a. Human cadavers

The earliest and most obvious examples of SBT have been cadaveric models. Since the 1500s, anatomical examination and surgical dissections have been a part of doctoral training in universities (Hayashi et al. 2016). Surgical models are anatomically accurate; provide similar feel to the operating room conditions in dealing with surgical planes and approaches; and can be preserved for elaborate dissection and instrumentation according to the surgical technique to be explored (Shiwani 2010). This allows for teaching on models which are nearly in-sync with what the trainee will see in the OR.

Cadaveric labs have a considerable history of facing legal and practical difficulties: procuring specimens requires jumping through ethical hoops; and handling and storage requires large, well-ventilated laboratories. Historically, bodies of criminals after capital punishment or those unclaimed would be donated to medical institutions for the purposes of anatomical dissection and surgical research (Ghosh 2015). However, socio-political and religious factors have resulted in drastic legislation limiting the use of human cadavers. Even within HICs, human cadaveric labs require large starting costs and maintenance of models through continual renewal of preservation fluids and storing capacity.

Despite these difficulties, human cadavers remain the gold standard for teaching in surgical training. A trainee can be given the time and space to understand intricate anatomy while establishing surgical approaches, understanding structures and spatial awareness in real time, and studying the biomechanical forces at play when inserting implants (Stoffel et al. 2007). Many well-known procedural workshops across the world employ human cadavers in order to showcase what it must feel like to perform live surgery (Tjalma et al. 2013). The only disadvantages exist because of the cadaver itself. It cannot simulate the true feeling of “live surgery”, which may include risks of bleeding, tissue quality during dissection, and intraoperative injury.

b. Animal-based models

Wet Labs

Using animal models seems to be the next logical progression: animal wet labs consist of simulated live surgeries performed on anesthetized animals. These have been previously used in teaching cranial aneurysm techniques, cardiac procedures, and capsulorhexis (Graham, Sweet and Sheehan 2021). Porcine and other mammalian models afford similar features to human surgery: tissue control and quality, haemorrhage, and iatrogenic injury are all real-time concerns for the trainee, thereby affording closer simulation of surgical conditions (Deonarain et al. 2020). The disadvantages of these models are ethical concerns regarding pain and suffering experienced by the subject; costs for housing; and ensuring safe, ethical conditions may be prohibitive. Stark differences in anatomy may also not completely translate into accurate training models.

Dry Labs

Our own centre's solution to the conundrum of finding a suitable model for simulation in surgery was to look towards readily available animal-based "dry" models. These are procured through local butcheries to circumvent any unnecessary wasteful sacrifice and to essentially find a "waste-free" solution, i.e., using materials that are already scheduled to be discarded. Ethically and socially, these models are more acceptable in many parts of the world and are significantly cheaper to procure. Anatomical similarities, particularly of bony structures and ligaments, mean that surgical handling of tissues is better on these models in comparison to non-cadaveric models that may show variability. The skills developed on this model can be further translated to human surgery and are easily accessible for residents, in terms of the "give" of a certain selected model. The only drawback we identified was an obvious difference in some anatomical considerations and proportions for human cadaveric models. However, the significant benefits from a dry, animal model come from their adaptability from already existing, cheaply available materials; an absence of ethical conundrums; and accuracy in the biomechanical simulation of surgical procedures (Riley III et al. 2004). The greatest benefits come from the affordability of these materials and the recycling through which newer models can be afforded and help in developing sustainable and continual simulation training labs.

c. (Non-cadaveric) simulation

With the need for newer and more sustainable models for training, many companies have sprung up to provide simulation-based models without the ethical and logistical dilemmas associated with cadavers in many countries. These models are often based on targeted and goal-directed sections of anatomy, directed towards teaching specific skills to trainees. Models can either be purely anatomical replicas and therefore, have utility in teaching near-perfect anatomical considerations, or be augmented with virtual reality tools (goggles, headsets) in order to achieve improved simulation conditions. These AR/VR (augmented reality/virtual reality) models are the cutting-edge innovations in surgical training and have even helped toward developing patient-based models and augmenting surgical strategies in the OR (Louis et al. 2021).

In surgical simulators, we can find prime examples of mannequins (used for tourniquet tying, basic surgical skills, identifying regional anatomy), sawbone models (meta-tarsal, humerus, femoral procedural simulation), and other 3D models of regional sections for hands-on practice. These models provide certain benefits of anatomical accuracy, better feel and provisions for grade-wise training, and allow repetitive manoeuvres/practice sessions for the lifetime of the model. Eventually these models are limited due to a lack of available regional anatomy correlations, expense, and their inability to be used for any purpose besides the one for which the model was created. Anatomical landmarks are missing from most region-specific models. Thus, trainees can practise region-specific procedures in a step-wise fashion to achieve a certain level of proficiency. However, whether this translates into real surgical skills or not still depends on the user acquiring greater exposure and developing spatial knowledge of surgical tissue handling.

Recently, the development of augmented reality tools for surgical training has led to various companies bringing these simulators into labs and ORs. They provide tactile feedback for trainees and surgeons, and can be modified to include a limitless array of feedback simulations and goal-based surgical training scenarios. Virtual reality/artificial reality tools are definitely the future of surgical training and developing surgical tools for improved learning. Unfortunately, as this technology is currently still under study for real-world efficacy, patient safety, and requires enormous start-up costs in foreign countries, it isn't practicable in LMICs. Only a few companies have begun preliminary workshops and efficacy trials in LMICs with a long road ahead for developing training capacity (Joos, Zivkovic and Shariff 2021).

III. Developing models for training in an LMIC

Surgical training platforms have started springing up in LMIC surgical centres. This is understandable due to the development of surgical societies, well-established specialized centres, and structured residency programmes coming into the mix. What is lacking is the basic infrastructure needed for starting up large-scale labs. Therefore, most of these workshops and labs use cadaveric and animal-based models. Unfortunately, recent legislative measures motivated by socio-political reasons have made procuring human specimens exceedingly difficult. Regardless, the shift has logically been towards developing animal-based models wherever feasible.

Table 2.1: Cadaveric models used in various surgical sub-specialties for simulation training

Specialty	Procedures
General Surgery	Animal gut → anastomosis and repair techniques Vessels → vascular repair and embolectomy
Cardiothoracic Surgery	Bovine heart → trauma repair and valve replacement procedures, coronary bypass procedures
Ophthalmology	Capsulorhexis, cataract surgery, corneal procedures
Neurosurgery	Goat/bovine brain → microsurgical dissection, subpial resection techniques

Similarly, other orthopaedic specialties have taken up surgical training models.

Table 2.2: Cadaveric simulation models in orthopaedic specialties classified by region and skills assessed

Region simulated	Skills assessed	Currently available
Flexor tendons of hand	Laceration repair Assessing biomechanics (annular pulleys, core suture tension, tendon motion) Comparison of tendon repair techniques	Hand model simulators Mannequins Equine and canine cadavers
Achilles tendon	Repair with comparison of stitch techniques (double loop knot, Kessler stitch) Tendon graft preparation Comparing minimally invasive technique with open technique	Rat and rabbit cadaveric models Simulator models
Knee joint	ACL reconstruction Arthroscopic techniques	Simulators
Trauma (Open fracture)	Debridement External fixation	Sawbone models

Spine surgery simulator

In comparison to other orthopaedic procedures, spine surgery faces the terrifying possibility of causing a change in permanent neurological function. The field has developed into a complex, interdisciplinary realm, garnering attention and input from both neurosurgeons and orthopaedic surgeons; even after a spine fellowship, surgeons can go on to take further specialized training in complex reconstruction, spine tumour surgery, and other sub-specialties. Currently, cadaveric labs employing human models to study spinal biomechanics dominate as the gold standard in developing spine surgery simulations.

Our own experience with developing a focused spine surgery anatomy lab showed promising results. Porcine models were unavailable, and bovine anatomical dimensions did not synchronize with our goals of surgical simulation. The most suitable model we were able to agree was on goat spine models. In spine surgery, we set out to train residents in bread-and-butter procedures in spinal disorders: spinal decompression and pedicle screw fixation. We used goat cadaveric-spine models as shown in Figures 2.1–3.

Residents were given real operating room tools for developing hand-eye coordination and surgical techniques on our model. They were first taught the indications for each procedure, ideal patient selection, and a few cases to illustrate the necessity of the procedure. From thereon, a fellowship-trained and accredited spine surgeon was able to show the anatomy of the spine and ligaments, and the various approaches that could be made. After teaching sessions, residents were given the freedom to practice independently on models to go through the various surgical procedures necessary in order to achieve successful decompression or screw fixation. These were further assessed by the session faculty, who ensured procedural success, achieving the goals of surgery, and understanding of ideal equipment choice.

Approaches:

1. Posterior approach to lumbar spine
2. Posterior decompression through partial/complete laminectomy

Procedures:

1. Making a posterior approach to lumbar spine
   a. Identifying anatomical landmarks through plane dissection
2. Laminectomy and central decompression
   a. Skills with rongeurs
3. Foraminal decompression
   a. Use of high-speed drill on bone
4. Pedicle screw placement and instrumentation
   a. Identifying correcting landmarks
   b. Measuring length, understanding average pedicle diameter

   c. Checking medial border of pedicles with a probe for breach
   d. Placement of pedicle screws and rods
5. Lumbar discectomy

Tools required:

1. Ideal room setup
   a. Table with flat top
   b. Operating microscope for microsurgical technique
   c. OR lighting
2. Surgical instruments
   a. Rongeurs
      i. Bone nibbler
      ii. Kerrison rongeurs
      iii. Pituitary rongeurs
   b. Self retaining Retractors
   c. Penfield dissector
   d. Pedicle Awls & probes (Lenke/Gearshift)
   e. Screwdriver & Tap for pedicle screw placement
   f. Pedicle screws of various sizes

Materials required: Goat lumbar spine (freshly procured and preserved in freezer)

Skills assessed:

1. Hand-eye coordination and tactile feedback with laminar decompression and screw placement
   a. Angling of screw
   b. Understanding of bone quality and required force for optimum surgical procedure
   c. Ensuring no damage is done to adjacent structures
2. Awareness of microsurgical anatomy and ability to achieve tasks under microscope
3. Developing surgical techniques through step-by-step coordination and using correct tools

Fig. 2.1 Posterior Approach

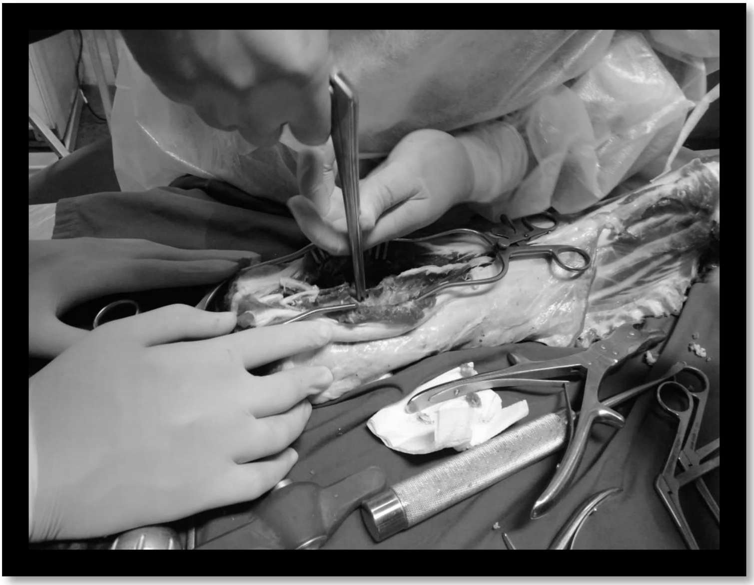

Fig. 2.2: Decompression with Kerrison rongeur

Fig. 2.3: After inserting pedicle screws and decompression

Pros: This model showed accuracy in terms of the step-by-step surgical considerations needed to achieve the goals of decompression and screw fixation. The bone quality is very similar to human spine models – cow spine differs due to larger vertebrae and ligamentous structures. However, laminar decompression was easily achieved using the Kerrison rongeurs and screw placement as well. Particularly under the microscope, anatomical landmarks are nearly exact to what is seen in the operating room:

- Pedicle starting points were similar to what is seen in humans; the starting point according to the intersection method was slightly caudally biased
- Pedicle breaches can be visualised easily, particularly with anterior breaches – this affords better spatial awareness to catch trainees' procedural errors
- Due to the size of the model, a C-arm can be used with ease
- Lumbar soft tissue dissection similar to approaches made in spine surgeries
- Similar anatomical landmarks