The Future of Surgery

Data: Visions of the past, present and future

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Two patients sit in a clinic. The first, a young man with no other comorbidities, is coming to find out about coronary artery bypass grafting. When it comes to discussing the risks and benefits of surgery over and above percutaneous intervention, the surgeon refers to two sources. The first shows the long-term results of a randomised controlled trial comparing long term outcomes between the two treatment modalities [1] in order to demonstrate the advantages of surgery over stenting. The second is the EuroSCORE calculator to determine the patient's risk of in-hospital mortality [2], which is estimated at 1 – 2%. The patient chooses surgery.

The second patient is older, with a slew of other medical conditions and a strong smoking history, who requires at least two valve replacements. The cardiologists were unable to perform a coronary angiogram, so undertook an ECG-gated CT to assess the coronary arteries instead. This shows a lesion of indeterminate severity that might also need grafting – the resolution of the CT isn't good enough to say for certain. What the CT does demonstrate unambiguously, however, is the mixed-density spiculated lesion in the lung. There had been no indication of its presence until the chance decision to perform a CT for some other reason, but on further questioning the patient admits to having coughed up blood – and so the heart operation is put on hold to investigate these new findings in more detail.

The future of surgery is personalised medicine. One-size-fits-all approaches are no longer relevant to diseases that sit on complex spectra and co-exist with other conditions. In order to tailor management plans to individuals, dynamic and real-time data underpins the decision making processes. Just as retailers can modify offers available to customers as they shop, healthcare providers will be expected to collect and process data on the fly, with anonymous integration into large population-based prediction algorithms. This data will need to examine the factors influencing disease processes from patients' histories, modify their treatment plans in the moment and predict potential outcomes and complications in order to best inform patients of how to proceed.

Understanding the past

The availability of reliable and accessible data is fundamental to this vision. The first patient in the vignette was typical and uncomplicated: his profile matched with thousands of patients in existing studies and he could be compared with them effectively. To within a fraction of a percent, clinicians can be confident that the information offered to such a representative patient is accurate. For the second patient, however, whose predicament may well also have been encountered hundreds or thousands of times before across the globe, the data existed at some point but had not been collected, assimilated and published. In medical archives across the world, the formulae to guide the management of such patients has been lost. As electronic patient records become more widespread, the quality and availability of this data for analysis should improve. With better healthcare prediction models for more diseases, patients in such situations need face less uncertainty. But in order to achieve this, more data – much more data – is required.

Technology has provided the means to collect incomprehensible volumes of data. Wearable technology, point-of-care testing and ubiquitous imaging techniques mean that not only are more metrics generated per patient, but at a greater frequency and for swelling population sizes. Had the NHS National Programme for IT been successful, the data from every patient might have made the largest, most comprehensive and complete medical database in the world. Nonetheless, other commercial companies, including Google, have already begun to make forays into the industry of healthcare data [3]. Such enterprises have the resources required to store and process the scales of data required for detailed healthcare analytics.

Predicting the future

Much of the data collected, of course, will be irrelevant and sifting the wheat from the chaff brings with it logistic difficulties, including harnessing the computing resources to undertake the necessary calculations. With computer chips doubling their speed every eighteen months or so [4], the processing power required to make Big Data healthcare predictions dynamic and contemporaneous will soon be within reach. Older, static, logistic regression methods, such as the 19 year old EuroSCORE calculator from the examples, could be replaced by continuously adjusted prediction models based on neural networks or other forms of machine learning. As improvements in the technology and techniques of surgery make operations safer, the calculators would no longer become outdated or obsolete, but rather would recalibrate, adapt and update accordingly.

Risk and benefit conversations will utilise survival curves that are not just *adopted* from the literature according to the patient's disease, but also *adapted* dynamically for their age, gender, ethnicity, lifestyle and other relevant factors. The pre-operative decision making on surgical technique will be correlated with outcomes for body habitus, surgical anatomy and genetic profiles. Prosthetic implants may well be tailor made – perhaps from their own stem cells - following detailed cross-sectional and 3D imaging, to exact specifications. Only data will make all this possible, before the patient even steps into theatre.

Addressing the present

The surgical methods we use now may someday look archaic to surgeons of the future. Archaeologists examining ancient civilisations occasionally find evidence of humankind's early efforts at operating. A cranial burrhole in prehistoric skulls; a branch of fir embedded in a fractured bone as medullary fixation; wounds stapled shut with the jaws of termites... the surgeons of antiquity found ingenious solutions to the dilemmas of their times but the principles have remained not dissimilar. Technology has been the principle actor for progress in the evolution of our surgical techniques. For millennia it was only sepsis and consciousness that held back the development of surgery, but with the discovery of ether and carbolic acid [5,6], the floodgates of opportunity opened and the specialty flourished.

In the last two centuries since the birth of anaesthesia and anti-sepsis, developments have been exponential. Where, once upon a time, an apprentice surgeon might have looked for inspiration to ancient tomes, there is an expectation that today's surgeon will evolve their technique based on the contemporaneous work of others. By the end of their career, a typical surgeon today might be performing operations that were unheard of when they trained, using technologies that could not have been conceived.

In theatre, despite the wealth of information at hand, a myriad challenges face the operating surgeon. Where once a plain x-ray might have been all the guidance a surgeon might have had to identify the position of a lesion, complex computations aggregate the data from millions of such images to form three-dimensional cross-sectional computerised tomography (CT) images. Whereas such imaging pre-operatively might localise a lesion, that road-map is often only accessible before getting scrubbed. Once sterile, the surgeon must rely on their recollection of the surgical anatomy, or wander away from the operating field to a nearby workstation in order to refresh their memory. Future technologies will bring these to the table, both literally and metaphorically. Sterile or voice activated consoles are a possibility today and projected holographic images have become a reality, but are still in their infancy.

Dynamic intra-operative localisation also already exists, but is predominantly limited to proximity sensors (such as the Geiger counters used to locate pre-operatively radio-isotope marked breast tumours) or planar imaging (such as ultrasound or fluoroscopy). 3-dimensional imaging techniques have become available in recent years (such as intra-operative trans-oesophageal echocardiography) but at present the technology lacks the fidelity required to distinguish stenoses in small, distant blood vessels or localise structures through gas-filled viscera. Eventually, though, the resolution and ionising safety of cross-sectional imaging will be of sufficiently high calibre to bring into the operating room and use dynamically as surgery progresses.

Such imaging techniques would, eventually, be able to demonstrate not just anatomical topography, but also quantitative measures and physiological assessments of organs. In the same way that functional magnetic resonance imaging provides indication of brain activity, future imaging techniques would be able to delineate complex stenoses in coronary arteries, quantify flow down the vessels and assess the contribution of collateral flow. These measurements would be able to guide treatment far more effectively than the current methods of visual estimation [7].

Where less than a decade ago, semi-quantitative angiography was the gold standard in diagnosing coronary disease, a variety of additional modalities are now available to provide precise measures of stenosis. Current thin-slice helical CT scanners are approaching the resolution required to provide this information non-invasively but due to the heavy equipment required and the amount of radiation delivered, these are not presently suitable for use in hybrid theatres. Intra-operative fluorescence imaging allows some indication of the patency of grafts and the quality of anastomoses to native vessels, but this system, too, is fraught with limitations.

Radiological imaging alone, however, is better suited to non-invasive and percutaneous treatments. From coronary stents and trans-catheter valves to endo-vascular repairs, the technologies that have promised to make surgery redundant have yet to achieve the same outcomes as open methods. Though such innovations are still in their infancy and have great potential to reduce the burden of disease that requires surgery, the length of time for their maturation is not known. In the meantime, radiological imaging must be supplemented in the operating room with improved visual optics.

Loupes and operating microscopes have been available for centuries to facilitate fine needlework and these have required ever more ingenious light sources. From theatre lamps, to reflective headwear and through to instrument-mounted light sources, the surgical field has never been better illuminated. Even when not opened, high quality fibre-optics allow high-definition images of body compartments – including 3D stereoscopic views – to be magnified and transmitted to the surgeon, their local theatre staff and the wider global theatre who might be in attendance elsewhere on the planet. With these technologies, image stabilisation and orientation is possible and non-visual-spectrum recordings may also be possible.

In addition, newer technologies allow cross-sectional imaging modalities to be integrated with augmented reality viewers and spatially-oriented instruments to give a "heads-up display" super-imposed image in the surgeon's field of view. With the possibility of intra-operative imaging being processed real-time and parsed to viewing devices, such technologies could provide the resources required to prevent damage to adjacent structures and to localise disease accurately for surgical intervention.

Such innovations will be necessary as surgeons iterate towards truly minimally invasive surgery. At present, minimally invasive surgery is really still just "less-invasive" surgery. Patients are frequently peppered with multiple 5-10mm "port" sites along with larger "utility" incisions to insert instruments or remove tissues. Eventually these will all be replaced by single ports with concurrent instruments through them that have multiple points of articulation. Robotic devices are strong contenders for this purpose – and these will require high resolution, probably three dimensional stabilised imaging in order to facilitate their use. With smaller incisions and reduced exposure, the use of accessory technologies to improve safety and minimise the risk of iatrogenic complications will need to increase.

Patients are unlikely to accept increased risks in surgery in order to assist in the development of newer technologies. Anatomic and physiological data from real patients, will therefore be of importance in developing training tools for surgeons of the future. High fidelity simulators using virtual reality environments, complete with tactile feedback, will be necessary to ensure that training is fit for purpose, and will provide their own metrics on performance and areas for development back to the surgeons. Such tools are already in use, along with 3-D printed patient-specific models, to allow surgeons today to have "dry-runs" or intra-operative templates with which to benchmark their procedures. Flow dynamic simulators have already been used to determine whether, in the presence of particular configurations of stenoses, the planned coronary bypass grafts are likely to have competitive flow and increased risk of graft failure. Such information could prevent the anastomosis of redundant grafts.

Although these examples have focussed predominantly on the future of cardiac surgery, the principles for all forms of surgery are likely to be similar: visualising the outcomes before surgery to make the correct decisions; visualising the operative field during the operation; and integrating the data from multiple sources into easy-to-interpret forms that can be assessed, analysed and updated at any point in the patient journey.

Conclusion

Big Data is an important theme in the future of surgery. Prediction models, simulators and enhanced multi-modal imaging with dynamic intra-operative quantitative assessments will be central to the delivery of personalised medicine.

The future of surgery is lit brightly with imaging tools – visualising not just the visible spectrum, but the plethora of other information that lies hidden beneath the surface that can guide surgical treatments. Harnessing the power of such vast arrays of information will require acquiring, processing and presenting this data in increasingly invisible ways. The behemoth task of making this happen will require multiple iterative steps of integration, bringing individual nodes of information together into a single usable form. As medical technologies grow and merge, this science fiction increasingly becomes a reality.

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