Chapter 1

A HISTORY OF SURGICAL COMPLICATIONS

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"Why is my pain perpetual, and my wound incurable, which refuseth to be healed?"

Jeremiah XV:18

Defining a surgical complication before the latter part of the 18th century is not as straightforward a thing as it might appear at first sight. For one might argue that not until after John Hunter's monumental study of pathological processes in his *Treatise on the Blood, Inflammation and Gun-shot Wounds* (1794) did surgeons really come to develop a concept of surgical healing that, by definition, did not assume complications as part of the course of nature, a thing that had to be managed and nursed around, if the strength of the patient allowed, rather than something that could be avoided altogether. For by definition, a *complication*, in any sphere of endeavour, is something out of the norm, and the product of extraneous and unexpected factors. Yet since time immemorial, pain, trauma, haemorrhage, inflammation, fever and infection in all their complex forms had been reckoned as normal in surgery, along with the acceptance of a very high death rate amongst surgical patients.

The Roman medical writer, Aulus Cornelius Celsus, summed up the four characteristic signs of inflammation in more clinically explicit terms, as "rubor et tumor cum calore et dolore" ("redness and swelling with heat and pain"), in Book III.10 of his encyclopaedic treatise *De Medicina* (*c*. AD 30). However, the symptoms that Celsus rounded up into a enduring pithy dictum had been familiar to earlier classical medical writers. For Greek writers such as Hippocrates already had a practised familiarity with these and other aspects of surgical and other types of complications, as would Claudius Galen of Pergamum a century after Celsus in the second century AD.

Indeed, 2000 years before Celsus, the compilers of the Law Code of the Babylonian king Hammurabi (*c*. 1700 BC) were familiar with surgical complication, at least as a category of professional mishap, for the Code stated that if a surgeon took a bronze lancet to a patient who was of high status, and the patient died, then the surgeon's hand had to be cut off! Considering the prevalence of serious infection and postoperative inflammation in any pre-late-19th-century AD surgical environment, however, one wonders who would have been foolhardy enough to have trained as a surgeon in ancient Mesopotamia in the first place. The *Edwin Smith* and *Ebers* Egyptian medical papyri from *c*. 1700–1600 and 1550 BC, respectively (though probably deriving from much earlier originals) display a familiarity with certain surgical procedures. The *Edwin Smith* papyrus in particular deals with no less than 48 specifically surgical conditions, including the setting of broken bones, the treatment of spinal damage, and the diagnosis and treatment of no less than 27 cases of head injury, as well as making reference to various healing salves and religious ceremonies, which were clearly intended to facilitate a speedy and uncomplicated recovery; while at the same time Egyptian operators do not seem to have lived under the fear of dire legal retribution if their cases went wrong. One would, however, like to know what became of the medical practitioners who attended the 18-year-old king Tutankhamun in his final illness. For a recent (2005) CT scan of his mummy, conducted by Egyptian scientists in Cairo, revealed that the Pharaoh seems to have suffered multiple and unhealed fractures of both legs immediately prior to his death, which could well have actually occasioned his death. Did the Egyptian physicians and surgeons attempt to reduce these fractures — the scan showed the presence of embalming materials inside the post-mortem injury, suggesting an open wound — and the Pharaoh die from a subsequent bacterial infection?

It was not uncommon amongst classical and later writers on surgery to associate certain types of complications with the incompetence of the operator, and thereby see a complicated operation as the logical outcome of botching. Hippocrates around 420 BC was very much of this way of thinking, and set a precedent which was to be followed by many surgical writers down the ensuing centuries. In his elaborate discussion of bandaging for orthopaedic cases, for instance, in Book XXXV of *On Joints*, which formed one of the surgical books in his *Corpus*, Hippocrates warned against seeking treatment from surgeons who boasted of their operative dexterity, yet who were really foolish fellows in so far as they did not understand the broader problems involved in surgery or place their procedures within the wider regimen of healing the sick. When attempting to re-set a broken nose, for instance, these practitioners "delighted" in the chance of showing off their skills and made a great display of their elaborate bandaging technique, yet applied too much pressure, in consequence of which the re-set nose dipped down in the middle rather than healed straight. Hippocrates gave similar warnings (*On Joints* XXXIII) against the over-enthusiastic bandaging of a broken jaw, when the two halves of the fracture are not re-set evenly, and the patient ends up with a kink in his jaw-line.

Yet these are not complications in a scientific sense, but the results of incompetence. And as Hippocrates in his practice, teachings and extensive writings did more than any other early Greek to define and professionalise the medical arts, he was at obvious pains to separate the true healers — who were also wise philosophers and religious men — from the empirics and quacks who would have a go at any disease or injury given half the chance.

Incompetence on the part of the operator, moreover, was also alleged by Hippocrates as the reason for complications arising from a trephination of the skull (in *On Wounds in the Head* XV). To ensure healing in such cases, observed Hippocrates, it was essential to ensure complete dryness around the site of the operation. For moisture would attract excess heat to the wound, and this in turn would result in a suppuration. This association of proliferating moisture, usually in the form of pus, heat and discomfort with a suppurating surgical wound would survive as a perceived corollary of surgery down to the great teaching hospitals in the young Queen Victoria's London, and Celsus' "rubor et tumor cum calore et dolore" would ring down the centuries with the inevitability of sunrise.

But what seems to have separated the surgical sheep from the goats over the centuries, as it were, was the possession of not only humane, but also scientific instincts. For when one reads Hippocrates' *On Joints*, *Fractures*, *On Wounds in the Head* and *In the Surgery*, Celsus on surgical procedures, or what Claudius Galen had learned from the management of wounded gladiators, one is immediately struck by what one might call a scientific instinct. For the injury was not just a thing to put right in a purely topical sense, but something to be studied, compared, and seen in a wider context of health. And details concerning the success or failure of the treatment, moreover, should also be remembered, or written in a case book, to act as a guide to the treatment of future patients.

But one major factor separated all pre-19th-century surgeons from their latter-day colleagues, and this was the relative infrequency and sheer diversity in their practice. For even in a large city, such as ancient Rome or medieval Cairo, the number of persons willing to submit themselves to surgical procedures of any kind would have been relatively small at any one time. For all the pre-modern writers on surgery ultimately saw it as the forlorn hope of the medical arts, and a thing to be resorted to when all gentler methods had failed, or else — as in the case of battle and other injuries — a sudden and drastic intervention which offered the only possibility of survival. This must have meant that even the most subtle of hands got out of practice in a way that would be unimaginable to a modern surgeon, who would probably operate several times a week on one specific part of the body; one can only marvel at those men who would amputate an arm, "tap" a dropsical abdomen, and couch a cataract in June, cut for the stone, treat a fistula, and reduce a compound fracture in July, and then drain a dental abscess, struggle with a hernia, and trephine a skull in August! For this was the traditional surgeon's art: operations performed occasionally, diversely and reluctantly, and, in that noble tradition that ran from Hippocrates to University College, London, and Dr Robert Liston, performed *scientifically*. And if a man could not hope to make a consistent livelihood from such occasional heroics, then one must not forget that many surgeons made a bread-and-butter living from phlebotomising the generally unwell who wished to have their humoral balances altered, and from dispensing *materia medica*, especially if they did not hold some salaried appointment.

Yet what was a *scientific* operation? Generally speaking, it was an operation performed by a man who not only had a good eye and an experienced hand, but also worked within an extensive framework of prior anatomical and medical knowledge. A man, moreover, who, in the tradition of Hippocrates, kept a detailed case book, and who passed on his knowledge to capable pupils. For if certain types of complication arose out of ignorance and inexperience, then they might be avoided if the practitioner had a sound understanding of the body's structure and function. And herein lies surgery's long-standing and intimate relationship with academic anatomy. For while a pre-modern surgeon had no reliable way of preventing gangrene or other infections, nonetheless if he possessed a thorough knowledge of what lay below the skin in the region of the body on which he was operating, he *might* be able to contain excessive blood loss, prevent unnecessary muscular laceration, avoid splitting a bone, and inflict minimal collateral damage on the operative site.

Yet why did scientific anatomy only begin with the Greeks? For the Egyptians, after all, had been eviscerating and embalming their dead for over 3,000 years before Herophilus and Erasistratus in Greek-occupied Alexandria began to cut up humans and animals in the fourth century BC. The answer lies, I would suggest, in the nature of curiosity itself. For though the Egyptians did compile books of practical medical and surgical procedures, drugs, prayers and incantations, such as in the *Ebers* and *Edwin Smith* papyri mentioned at the start of this chapter (though it is true that the *Edwin Smith* papyrus contained some astonishingly perceptive one-off diagnoses), there is no real evidence, in the vast surviving literature of their culture, that they thought of the body in what we might recognise as anatomical and physiological terms. The brain, liver, lungs and other organs so carefully removed after death by the low-status embalmers, to be preserved in their correct Canopic jars, were simply seen as being *there*, inside a body. Their precise functions or physiological interrelationships in life were simply not part of Egyptian medical consciousness. For while external injury, poisoning and blindness brought on by accidents, wind-blown sand and snake-bites were recognised as having a physical basis, most illnesses were generally ascribed to divine or spiritual agencies. So while an eye salve, a purge or a bandage for a broken arm might be prescribed because of its predictable physical effect, most remedies were expected to work because the rituals and sacrifices which they entailed were thought to please the relevant deities. In consequence, and in the absence of an organ-based concept of disease, anatomy was an irrelevance, and the embalming of millions of corpses across 40 centuries produced no contribution whatsoever to the advancement of medicine as a physical, scientific discipline.

Why the Alexandrian Greeks of the fourth century BC began to cut up human and animal carcasses is a good question, but one could perhaps connect it with that wider intellectual curiosity which so characterised the rise of early modern science in Greece. For the Greeks certainly showed a driving concern with getting below the surface appearance of nature, and explaining its innermost connections. Thales, Pythagoras, Euclid and several others had already done this for the great truths of geometry. Anaximander, Heraclitus and Anaximenes did the same for cosmology, while a whole succession of Greek physical scientists from Anaximander's own teacher, Thales around 590 BC to Claudius Ptolemy in the second century AD would do it for mathematical astronomy. As we have seen, Hippocrates pioneered an observational and taxonomic approach to the practice of medicine, while Aristotle, in the half century down to his death in 322 BC, sought out the rational foundations of perhaps a dozen sciences comprising physiology, embryology, meteorology, cosmology and optics, and the human sciences of politics, grammar and logic.

For what fascinated the Greeks was the inner logic of the whole of nature. And while they preserved a deep reverence for the divine order and wonder that ran through nature, they nonetheless de-mythologised the details of its regular workings, seeing *action* and *agency* in nature — be it a solar eclipse or a suppurating wound — not as the consequences of spiritual squabbles, but as the implicit expressions of wider regularities or laws. These regularities or laws, moreover, were amenable to the study of the disciplined, inquiring human intellect, and could, within given limits, be harnessed or predicted. Thus, a combination of prior observation and mathematical analysis could enable Thales to predict the eclipse of 585 BC, and Aristotle's theory of cardiac heat could provide a form of rational explanation of why bloodletting could cool and ease a paralysed patient.

It was this wider context of naturalistic explanation which enabled dissection to make sense to Herophilus, Erasistratus and others. And while Aristotle's extensive writings in many branches of the life sciences contain few examples of regular dissection *per se*, they nonetheless include numerous brilliant examples of careful description: of the scales of fishes, of human and animal teeth, limbs and skeleton bones, and details of the external anatomy of many creatures. Even genetics can trace its first scientific utterances to Aristotle where, in *De Generatione Animalium* (Book IV, 3, 767a), he looks at examples of heredity: how children can resemble one parent more than the other, how it is that a man who has lost a limb in battle can later father children with all of their limbs present as normal, and why parents sometimes produce "monsters," or creatures which resemble neither their parents nor their ancestors. Of course, none of these observations were especially original when Aristotle was conducting his researches around 350 BC, yet he was certainly the first person to discuss them in the wider context of what might be called scientific medicine. He was, perhaps, the first to see structural and functional parallels between humans and animals, as well as being one of the first to develop an integrated and encompassing model for the disease process in a way that amplified Hippocrates' earlier studies of fever types and the association of specific diseases and human temperaments with given geographical and climatic locations, dealt with in *On Fevers* and *Airs, Waters, and Places*.

Indeed, one tends to find that explanations of why wounds go wrong and complicated have always hinged on broader theories of health and disease. And just as the post-Pasteurian explanation for surgical infection has hinged predominantly on the action of microbes, and later viruses, so that of the writers of the classical period turned upon their wider views concerning health. For when reading the classical medical writers, one invariably encounters a set of assumptions about the innate healthiness of the human body. Quite simply, it is *natural* be healthy, for functional efficiency is the teleological end of a body's existence. And when illness in any form supervenes, then it must be caused by some sort of invasion or upset. This model is implicit in the balance theory of health encountered in all the writings of Hippocrates, and given its definitive clinical expression in the four humours — Yellow Bile, Black Bile, Blood and Phlegm — of Aristotle. For in these humours, the four great qualities of nature, the hot, the cold, the moist and the dry, are built up into an over-arching clinical scheme. In a healthy body, all are in their correct balance, but in disease, one or the other predominates over the rest. And humours could be put out of balance by a variety of external factors, including drastic changes of domicile, diet or climate, or an encounter with foul airs, injury or surgical intervention. And in the way that a penetrating wound of any kind, be it a battle injury or the Hippocratic case of a complicating scalp wound following trephination, would invariably upset the body's natural balance, so it would often lead to the generation of excess heat. "Rubor et tumor cum calore et dolore" would set in, and one hoped that, if the surgeon had nourished and nursed his patient gently and well, the superfluous heat would be eased away, and the patient would recover. As the author of the Biblical book *Proverbs* (20:30) wisely summed up, "the blueness of a wound cleanseth away evil", the colour-change indicating that the infected state is passing.

But this balance theory of health, and the heat-attracting concept of surgical infection, paid no more than lip-service to anatomy as such. For it was the classical Greek doctor's self-perceived task to chase imbalances around and out of the body, rather than to associate specific diseases with specific organs. Yes, it is true that Greek doctors had progressed streets ahead of their Egyptian and Mesopotamian predecessors and colleagues in the way they saw the disease process in terms of naturalistic rather than occult agencies, but their knowledge of the operations and functions of the body's interior remained rudimentary. On the other hand, it was the Greeks who developed the first "approximately true" theory of physiology. For did not food ingested by the mouth produce juices in the stomach that somehow led to the liver becoming engorged with blood? And did not this blood, in its heaviest and crudest form, get sucked up into the heart via the vena cava? In the heart, according to Aristotle, it was heated up due to the innate crucible-like nature of that organ, and refined. The lungs then acted like bellows, blowing life-giving *pneuma*, or air imbued with spirit, into the blood, after which the refined and vital juice entered the *veins*, where, after a series of pulsating motions, it arrived at the extremities of the body. Here it not only congealed to become new flesh, but also carried the innate heat of the heart and its very life-force to every part of the living creature. Some blood was even believed to pass through the thick septal wall of the heart into the left chamber, and up through the two carotids in the neck, to refine yet further into those salty-tasting animal spirits which were found in the lateral ventricles and cortical mass of freshly-removed brains.

But this concept of the interior of mammalian bodies was essentially didactic rather than therapeutic in character, for the functions ascribed to organs such as the stomach, liver, heart, brain or veins were either vague or else plainly wrong. And it is no doubt for this reason that anatomy played a relatively minor part in classical medicine — in spite of its otherwise scientific status. It is true that the importance of these organs to the continuance of life had probably been known from time immemorial, and Homer and Old Testament Biblical writers of around 1000 BC had been all too well aware of the incurable nature of spear or arrow wounds that penetrated the liver, spleen or thoracic cavity, even though the precise physiological roles of these organs were not understood. In a running fight described in the Old Testament, for instance (*II Samuel* 2:23 and 3:27), Abner inflicted instant death on his pursuer Asahel by striking him with a spear under the fifth rib, and with such force that the weapon emerged from Asahel's back, before Abner got his just deserts by receiving Joab's avenging spear in exactly the same place. So while none of these men were anatomists, they certainly knew where to direct a weapon if it were intended to strike a fatal blow through a major organ!

On the other hand, and bearing in mind the caveats outlined above, we do know quite a lot about surgery in the ancient world, especially from the time of the Romans. Claudius Galen, for instance, was not only an accomplished operator, but also a flamboyant anatomical demonstrator, especially when working on live animals. One of Galen's party-piece demonstrations showed the central importance of the spinal nervous system. Galen would make a series of decisive severances of the spinal nerves of a well-secured pig, starting from the tail and working towards the head. The still living yet progressively paralysed animal suddenly stopped squealing when its laryngeal nerves were severed, to be eventually despatched when the brain was reached, thereby showing the importance of the spinal cord and the nervous branches which came from it, to the motor functions of different regions of the body. Likewise, tradition has it that Galen got his first main job as surgeon to the gladiators at the amphitheatre at Pergamum in Asia Minor (now Bergama, Turkey), by demonstrating his skill at re-assembling a previously disembowelled monkey. It appears that candidates for the surgeon's job were presented with a specially-eviscerated living primate, and the surgeon had to demonstrate his skill in putting the animal back together again. Galen's monkey lived — presumably making a relatively uncomplicated recovery — and thus began one of the most illustrious surgical careers of all time! It is not for nothing that our internationally-used word for the place where surgical procedures are performed derives from the Latin *theatrum*: a place of public display and ceremonies!

In addition to textual sources, archaeology has added considerably to our knowledge of the sophistication of Roman surgery from the instrumental point of view. There is the beautifully-carved votive relief of a Roman surgeon from the Asklepeion, Athens, showing his folding instrument case, containing scalpels, probes and other instruments. And our knowledge of Roman surgery has been greatly amplified following the discovery of large collections of bronze and steel instruments in archaeological digs in Bingen, Germany, and especially at what has come to be known as the "House of the Surgeon" at Pompeii. Dating from some time before AD 79, when the Roman town was destroyed in the eruption of Vesuvius, these Pompeian instruments include trephines, probes, bone levers, obstetrical instruments, and various types of forceps and scalpels. They are beautifully-made instruments, some containing screw-operated and detachable parts, while a circular trephination saw has a central point (probably detachable before it partly corroded away) of a similar type to the "crown trephine" or *modiolus* described in Celsus' *De Medicina* Book VIII.3. In using this type of instrument to perform a trephination, Celsus recommends, the operator should, upon commencing the operation, place the central pin in a small chiselled nick in the skull to act as a central point for the rotation of the "crown trephine." Once the teeth of the strap- or belt-actuated trephine had begun to bite into the skull, the surgeon would remove the centre pin, and then spin the trephine on its own. In this way, he produced an exact and controlled circular hole in the desired part of the skull, and avoided damaging the pia mater dura mater or meninges which lay beneath.

Although it has been pointed out that classical medical writers thought of the wider disease process *not* in terms of systemic organic malfunctions but in terms of humoral imbalances, it is clear from the writings of Celsus and Galen in particular that they had a good knowledge of the inner layout of the interiors of bodies. It is true that this may have derived from veterinary rather than from human dissections — Galen especially conducting most of his anatomical researches on the carcasses of Barbary apes, Rhesus monkeys and pigs — but in their scientific spirit, they deemed such knowledge essential to a learned medical man.

Book IV, 1 of Celsus' *De Medicina* consists of a carefully-conducted tour of the body's interior, the topic details of which have a strong ring of direct hands-on familiarity. We are told, for instance, that the windpipe is a thick pipe with strong external ridges, rather like vertebrae, though smooth on the inside; that the interior chambers of the lungs are "spongy"; and that descending from the two kidneys are two tubes — called *ureters* by the Greeks — which lead to the bladder. Celsus also speaks of the healthy and diseased appearances of organs, and the special infirmities to which they were prone, in what was a remarkable essay on descriptive anatomy. But it is in Celsus' *De Medicina* Book VII, which deals with surgical procedures, that we first encounter the range and ingenuity of Roman surgery. The causes and treatment of abscesses and fistulae, for example, are discussed with remarkable insight and accuracy of detail. He tells us how to read the stages through which an abscess can pass, and whether to use medical or surgical procedures in its treatment. Celsus also tells us that, while all surgery upon the abdomen is likely to be fatal, it can sometimes succeed: fistulae of the stomach *can* be healed with the right cutting and stitching, while the guts can even be forced back through an aperture in the abdomen wall, and stitched in. A patient who has been thus operated upon, moreover, should lie on his back so that the intestines can re-seat themselves in their natural place. Various types of hernias are also described, along with their prosthetic or surgical treatment.

Yet while Celsus is only too well aware of how gangrene, putrefaction and complication can set in in any wound, he has no coherent idea of what their causes could be, or how they might be prevented. They are simply part of the risks involved in surgery. On the other hand, we today, with hindsight, can see the clinical sense of some of the surgical procedures which he mentions as one of several options. When discussing the detailed technique for "tapping" a dropsical patient to draw off water from the abdomen, for instance, he mentions the especial benefit of using a hot cautery scalpel. For unbeknown to Celsus or to anyone else in that pre-bacterial age, a cautery scalpel killed bacteria and allowed the wound to heal by first intention, without needing to suppurate.

In many ways, however, the final and most enduring opinion, as far as wound treatment, infection and suppuration were concerned, came from Galen. His monumental anatomical and clinical studies, including *On the Use of Body Parts*, *Commentaries on the Hippocratic Oath*, *Aphorisms* and *On the Natural Faculties*, to name but four titles, contain such a wealth of medical observation and insight as to cause their author to become the great authority on matters anatomical for the next 1300 years. And as far as Galen was concerned, any surgeon who operated upon a patient, or attempted to cure a battle or other wound, must take steps to enable the wound to slowly excrete its poisons, from the bottom upwards, during a process of slow closure. For to Galen suppuration was natural and the pus generated "laudable". The ensuing Galenic doctrine of "laudable pus" was to constitute something of a surgical orthodoxy down to the late 18th century, with what we would recognise as a *complicated* wound being seen as a naturally healing wound. One suspects that the gladiators of Pergamum may not have complained, however, as their lengthy convalescences under this regime inevitably kept them out of the arena for a few months, and thereby extended their lives!

In spite of the Roman love of bathing and general cleanliness, at least amongst the comfortably-off classes, one must never lose sight of the fact that Galen, Celsus and their colleagues would have worked in highly septic professional environments. For as they had no knowledge of bacteria, and lacked a coherent theory of inflammation and suppuration, their instruments and dressings must have been just as contagious as those of their Victorian successors who complained about the omnipresence of gangrene in their hospitals. After all, "healing salves" of egg-white, wine and aromatics did not kill germs. So while classical culture gave birth to many of the concepts and intellectual ideals of humane scientific medicine, while it invented the basis of rational medical nomenclature, and developed the necessary relationship between anatomy and physiology and surgery, it nonetheless contributed very little to our modern knowledge of surgical complications as such.

It was in the medieval Arab world that surgery began to develop a scientific medical literature that really took up where the classical writers had left off. And while the greater part of Arabic literature in the healing arts was devoted to medicine, especially disease and drug taxonomies, with figures such as al-Razi [Rhazes], Abu Ali al-Husayn Ibn Aballah Ibn Sina [Avicenna], and Ibn al-Haytham [Alhazen] leading the way, there were some surgical commentators. Indeed, the word "commentator" is a significant one when dealing with early medieval science in either the Muslim or the Christian world, for it was from the translated works — into either Arabic or Latin — of the classical writers that medieval scientific culture sprang. Hippocrates, Dioscorides, Galen and quite a few others became current medical sources to Christians and Muslims alike (though Celsus' works were lost, and not re-discovered until the Renaissance), as these foundation works were first commented upon and *glossed*, and then used as patterns in accordance with which fresh researches could be conducted.

In surgery, however, it was Abul Qasim uz-Zahrawi [Albucasis], living in Spain between AD 936 and 1013, who became the overwhelmingly important Arabic surgical writer. Albucasis pays his intellectual debts to Hippocrates, Galen and Celsus, in whose tradition he saw himself, and in his *magnum opus*, entitled *Altasrif* (known in the West as *On Surgery and Instruments*), he discussed a wide range of surgical conditions and instruments from his own practice. Particularly fascinating is his detailed treatment of eye surgery, where his meticulous accounts of how to operate for *ungula* (*pterygium* to the Greeks) eye growths, and for cataract, carry strong resonances of the descriptions of Celsus and other Western classical authors, whose works he would have known in Arabic translations. His *Altasrif* also discussed most of the other conditions deemed operable by ancient and medieval surgeons, including treatments for wounds and fractures, abscesses and fistulae. It is very clear, moreover, that Albucasis was all too familiar with operations that went wrong, yet, like the figures we have seen already, he seemed to have no consistent concept of a complication as such. His account of the procedure for eye cataract, for instance, contains a meticulous postoperative regimen: the bandages must not be touched until the third day, and after an examination of the eyes by the surgeon, rebound until the seventh day. Without such binding, complications will follow, in the form of the depressed or "couched" lens (or "humour") ascending from the vitreous humour and returning to block out the light. But total immobility of the patient's head on a specially-devised bed could prevent this from happening. Likewise, bad after-care could lead to an abscess forming, and destroying the patient's vision altogether.

Yet what we find here is that long-familiar resonance going back to Hippocrates: surgical complications are a product of professional incompetence. A good surgeon does not overreach himself, does not leap at the chance of showing off his skill, is wise and learned, and imposes a meticulously-supervised postoperative regime. Always willing to see off quacks and incompetents, Albucasis hammers the point home when describing the treatment for fistula, a condition which he ascribes to the poor quality of the patient's blood. But in this case, that of a young man, which he describes in detail, instead of the blood being strengthened, the treatment had been botched. For this man had developed a discharging leg ulcer which became a major fistula. Sinking more and more, as one quack after another poked around in his wound, Albucasis tells us plainly: "Eventually he sought me". At this juncture, Albucasis found that the fistula led down to the necrotic bone. But after two operations, during which the necrotic matter was cut away, the wound healed, and the patient enjoyed a perfect cure. The message was clear: a master surgeon was reversing the complications which the botching of lesser men had occasioned.

Likewise, in skilled hands, even gangrene, a "creeping corruption of a limb, consuming it as a fire consumes dry wood" could be cured, so Albucasis tells us. This will come about by the judicious application of the red-hot cautery iron to the affected part, followed three days later by soothing salves of sulphur and oil. Indeed, the cautery was one of Albucasis' favourite therapeutic devices when treating infection or even cutting the flesh, for (as Celsus had noted) such surgical wounds, while especially painful at the time, stood the best chance of healing by first intention, though no one at the time knew why.

Popular medical mythology tells us that the European middle ages were a period of ignorance and butchery in surgery. But like so many myths, this one vanishes into smoke upon careful examination. And while it is true that high-quality surgical writing does not go back quite so early in Western Europe as did that of Albucasis, one must not forget that Arabic medical and scientific writings, along with Greek books from the Byzantine world, began to be translated into medieval Latin by the late 11th century. Indeed, the arrival of these books — translated from classical Greek writers via Arabic intermediaries, in many cases — became a mighty flood by the 12th and 13th centuries. They provided the vigorous intellectual soil out of which medieval Europe's great universities — Bologna, Paris, Oxford, Cambridge, Padua and Montpellier — sprang. And Latin translations of the great Arab scientists themselves came to be studied in Europe. Alhazen's optical and ophthalmological researches were studied and developed by Roger Bacon in 13th-century Oxford, Rhazes' medical ideas were discussed in Paris, while Avicenna's encyclopaedic *Canon*, or Rule of Medicine, was even referred to by Geoffrey Chaucer in *The Pardoner's Tale* (l. 890).

By the late 12th century, Hugo of Lucca was both practising and teaching sophisticated surgery, while his pupil Theodoric's *Chirugia* (1267) dealt with the nature of infection. Indeed, in "high medieval" Europe, after about 1180, a remarkable level of sophisticated discussion took place on medical and surgical topics. And just like the Arab medical writers before them, they looked for fundamental guidance back to Hippocrates, Galen and the great classical physicians, seeing healing in all its branches as an essentially conservative art. Yet in this medieval world, one finds active, fresh discussion of how best to treat wounds and manage surgical cases. How should one best treat perforative wounds inflicted by arrows or crossbow bolts? Or, outside the theatre of war, how should one treat nasal polyps, haemorrhoids, accidental wounds, bad burns, compound fractures, cataract, tumours of various kinds, and dental complications leading to jaw abscesses?

Especially relevant, moreover, from our present point of view, was the medieval surgical debate about pus. Was it a natural part of healing or was it a poison, and should a surgeon try to eliminate it altogether? The ancient medical community of Salerno, on the Bay of Naples, arguably the first hospital and medical school in Europe, pre-dating Bologna, Paris and Oxford by the best part of a century, tended to follow a conservative line. Being a major conduit of classical Greek medicine into the West that was in itself fairly independent of the abovementioned Arabic tradition, while at the same time being familiar with Arab work, the Salernitian School followed the precepts of Hippocrates and Galen in particular. Galen's doctrine of "laudable pus" was an orthodoxy, and argued that after the treatment of wounds or the performing of surgical operations, pus formation was a natural part of healing. Wounds should therefore be left open, with drains to enable the pus to rise out, and only closed by degrees as everything became progressively dry.

By the 13th century, however, active medical and surgical teaching, including the dissection of *human* corpses (spasmodic in antiquity and probably non-existent in the Arab world) was under way in Bologna, Montpellier and Paris. Figures such as the abovementioned Hugo of Lucca and Theodoric, then William of Saliceto, his own pupil the Frenchman Lanfranc, and the Norman Henri de Mondeville, were all asking what happened when the skin of the body was broken. And *contra* Galen, they were coming to see pus as *not necessary* for the healthy healing of a wound. For observation showed that a well-managed wound *could* heal aseptically or by first intention. And while none of these men had any coherent idea of infection or surgical complication, beyond the caveats against bad air, putrid blood and incompetent colleagues noted by their ancient predecessors, it is nonetheless strange that the historical period so associated in the popular mind with backwardness should have done so much to advance surgery. For while the Arab world had had brilliant and inspired medical teachers and taxonomists, the peculiar and enduring achievement of medieval Europe lay in its invention of the university as an enduring corporate institution by 1180. What is more, the medical faculties of these universities not only taught and set standards — inventing the Doctorate in Medicine as an internationally recognised benchmark of excellence for a medical practitioner — but also pioneered the scientific study of the human body. In the Italian universities, such as the Papal University at Bologna (but not in the north European schools), surgery was included as a curricular subject, being studied as a branch of medicine.

One of the decisive turning-points in the history of surgery, which was to lead by the late 18th century to the recognition of surgical complication as a clinical and pathological condition within the wider healing process, was the introduction of firearms in warfare. This took place in the early to middle parts of the 14th century, and by 1420 European military surgeons were having to come to terms with battle wounds that were fundamentally different from the relatively clean puncture, slash and contusion wounds which had predominated since the most ancient times. For cannon shot shattered human bodies in a myriad of different ways, while the soft lead musket ball produced wounds of the most frightful complexity. And by the time that Hieronymus Brunschwig wrote his vernacular treatise *Buch der Wund-Artzney* (1497) ("Book of Wound Dressing"), which was one of the first of many treatises that described treatments for gunshot wounds, it had come to be accepted that gunshot wounds were unlike all others in so far as they were automatically taken to be poisoned. The gunpowder, and the lead of the balls themselves, were thought to be highly toxic, and the radical opening up of such wounds to enable the surgeon to remove such projectiles and debridement was taken to be *de rigueur*. And when soldiers on campaign were likely to have been long unwashed, and wearing filthy clothes, and a musket ball likely to carry a trail of garment fabric deep into the wound behind it, we today realise from our modern clinical perspective that such wounds must have been extremely complicated. It is hardly surprising, therefore, that contemporary surgeons regarded gunshot wounds as being poisoned by definition.

These wounds, moreover, led to the writing of a great many books on surgery after 1497, often recording the experiences and practices of individual military and naval surgeons. They represent the first books aimed at a readership of surgeons who were *not* learned university physicians (as had been the case with most Western medieval writers), but were hands-on practical surgeons who had learned their art from vernacular sources and come up through the channel of apprenticeship. The books are not in Latin, but in German, French and English, and while often translated between vernacular languages, rarely had Latin intermediaries.

Giovanni de Vigo laid down what would become an enduring procedure in 1514, when he recommended that debrided gunshot wounds should be cauterised by pouring in boiling Oil of Elder. This would neutralise the poisons, and while the collateral damage inflicted by such an invasive treatment might lead to a slow and painful convalescence, it nonetheless seemed to give the best chance of survival. For while we now know that chemical poisoning was not in reality as great a problem as 16th-century surgeons feared, it was well known by ancient empirical practice that cauterisation seemed to clear away infection. To modern-day understanding, it killed germs. And while de Vigo's method was challenged by Ambrose Paré after 1536, when he discovered, on running out of boiling oil during the siege of Turin, that a mixture of rose water, egg yolks and turpentine had a cleansing without a secondary traumatising effect when treating gunshot wounds, it is not clear whether his patients had a better long-term postoperative survival. Sadly, Renaissance doctors and surgeons invariably spoke of individual cases, and were innocent of longer-term statistical analyses.

Indeed, the English surgeon William Clowes devised an ingenious experiment to test the "poisoned bullet" idea of gunshot wound complication around 1580. Clowes asked a soldier to fire a military arrow out of his musket at a gate post, working on the idea that if the discharge explosion was going to poison the projectile, then it should also burn or singe the arrow. Upon inspecting the embedded arrow, however, he found it quite undamaged and even its feathers unsinged-presumably, so he argued, because the arrow left the gun barrel *before* the flames and noxious sulphurous fumes! I suspect this was probably the first controlled experiment in scientific history to investigate the possible cause of a wound complication.

In addition to the new surgical techniques necessary to treat debrided gunshot wounds, 16th- and 17th-century surgeons made fundamental improvements to amputation techniques. References to major amputations are relatively rare in classical and medieval surgical practice, though they had become commonplace by 1700. What made these operations *technically* possible, however, were the massive advances in *human* (as opposed to monkey) anatomy that began with the public dissections of medieval Bologna, Padua and Montpellier, and which raced ahead after the publication of Andreas Vesalius's monumental *De Fabrica Humani Corporis* (1543). By 1640, in fact, no surgeon would have been able to go through his apprenticeship and — in London — pass the Worshipful Company of Surgeons qualifying examination unless he had attended lectures in anatomy and partaken, if only as an observer, in full-scale human dissections, starting with the subcutaneous muscles and finishing with the details of the skeleton.

For radical amputations of the knee-joint, thigh and shoulder, in particular, demanded a sound knowledge of the whereabouts of the veins and arteries, which would be encountered during the course of the operation, if the patient was going to survive. Amputation "above the knee" or of the thigh, for instance, does not seem to have been known before William Clowes successfully performed one some time before 1588, writing up the case on page 33 of his *A prooved practice for all chirugians*. For the massive blood loss implicit in such an operation meant that the operator not only had to be swift and resolute with his knife, but also fully prepared to ligature or cauterise the large number of blood vessels which he would encounter. Clowes's case was not a victim of war, however, but a "mayde" of "Hygate", London, and a charity patient. We are not told how her leg had become "so greevously corrupted, that we were driven upon necessitie to cut it off above the knee", but Clowes and his colleagues did a thoroughly professional job, with relatively little blood loss, "and so cured her after within a very short time". By first intention, one presumes. Yet the new, radical amputations of the post-gunshot-wound era — even when performed on civilians who had fallen from roofs or been run over by wagons — presented a whole new series of complications for the surgeon: massive haemorrhages, enormous postoperative scars which were prime sites for complex infections, and, of course, appalling trauma. Clowes's "mayde of Highgate" was very lucky indeed to survive. A surgeon facing cases such as these would not only have to be a highly-skilled and versatile anatomist, but also a careful planner, and the head of a well-drilled team of five or so assistants. Men who would know exactly how to hold and restrain the fully-conscious patient, set out the instruments in likely order of use, and have the pre-threaded ligatures or cauteries ready at hand, along with several dozen carefully-rolled absorbent "buttons," "dossils", bandages, blood bowls and finally a bed especially prepared to place the postoperative patient at his maximum ease.

There were many master-surgeons who published their experiences for the guidance of others, especially in England. William Clowes' *A Profitable and Necessaire Booke of Observation* (1596), John Woodall's *The Surgeon's Mate* (1617), Richard Wiseman's *Several Chirurgical Treatises* (1676), a work based upon no less than 600 of his own personal cases, and his earlier *Treatise of Wounds* (1672), which came to be popularly nicknamed "Wiseman's Book of

Martyrs", were four of the most outstanding. It was Wiseman who — without properly understanding its cause — was the first to describe a joint swollen and damaged by tuberculosis: he referred to the lesions as "white swellings". Woodall, moreover, who was writing particularly for sea surgeons, set his surgical knowledge within the wider context of a total medical practice, as was necessary for a man working in the isolation of a warship. Yet what shines through all of these men's writings, in addition to their measured confidence and thoroughgoing professionalism, was their caution. For no surgeon worth his name by the 17th century took up his knife easily, being all too aware of the dangers involved. "For", as John Woodall aptly put it when contemplating a major leg amputation, "it is no small presumption to Dismember the Image of God". And the relative rarity with which even a surgeon of Woodall's standing — being senior surgeon at St. Bartholomew's Hospital, London — exercised that "presumption" is brought home in the 1639 edition of the *Surgeon's Mate*. For in this work, Woodall tells us that he had performed a little over 100 amputations in 24 years. On the other hand, his success rate could have been the envy of many senior surgeons of two centuries later, for out of the 100 add amputations, he had only 20 fatalities.

Yet one still looks in vain in the writings of these men, and of their contemporaries, for any coherent sense of a "surgical complication" as we think of them today. For as in the days of Hippocrates and Celsus, there were good, bad and bogus surgeons who cured, mauled or killed their patients; there were great wounds that could go wrong because of the patient's unique humoral imbalance; Divine Providence might cause a ligatured artery to burst and kill the patient; while, as Woodall reminds us, gangrene might proceed "by reason of an inward cause" to necessitate a second operation or else kill the patient. And as Woodall further reminds his reader, when dealing in particular with ulcers and fistulae — which only serves to emphasise the fundamentally unknowable nature of illness and wound complication, in his mind — "the malignity of the humour or other evill disposition of the body changeth itselfe into a rebellious *Ulcer*, *concavous*, *fistuleas*, or unto any the like height of malignity". One might almost draw the rule: very sick people develop complications which kill them; less sick people get better!

But in spite of very high and generally accepted death rates, especially in major surgery, it is clear that the repertoire and frequency of operations was increasing by 1700. And some highly-skilled surgeons, who liked to specialise in a particular procedure wherever possible, could achieve remarkable success rates. Thomas Hollier, the lithotomist of St. Thomas's and St. Bartholomew's Hospitals, London, who removed a stone the size of tennis ball from the bladder of the fully-conscious Samuel Pepys on 26 March 1658, was one of them. Hollier (who operated on Pepys not in hospital but privately in the house of a relative) prepared for the ordeal like a general preparing for battle, with every contingency covered, and had the stone out within a few minutes after the first incision. The cleansed wound healed by something approaching first intention, and the 25-year-old Pepys was on his feet again within 35 days and lived another 45 years. Indeed, Hollier must have been a truly virtuosic operator, for an oft-repeated story, passed down through the 18th, 19th and 20th centuries in various narratives, and appearing in Thomas Hollier's entry in *New Dictionary of National Biography* (Oxford, 2004), has it that in one single year he performed no less than 30 lithotomies without a single fatality. On the other hand, Hollier did have his fatalities, for in a letter to his patron, Lord Montagu, dated 3 December 1659, Pepys mentioned a visit to the Jewish Synagogue in London, where he heard "many lamentations made by Portugall Jewes for the death of fferdinando the merchant, who was lately cutt (by the same hand with myselfe) of the stone".

Indeed, by the 18th century, feats of prodigious surgery came to be reported on a fairly regular basis, often in the pages of the *Philosophical Transactions* of the Royal Society. The rapid burgeoning of London's private medical schools and great public and teaching hospitals, and abundant wars to act as "nurseries" for up-and-coming surgeons, and the growth of scientific societies and a scientific press, all colluded to produce that proliferation of surgeons, students and learned audiences keen to witness the dissection of corpses. Even Samuel Pepys, the scientifically-minded senior civil servant who would be elected F.R.S. in 1665, attended on 27 February 1663 the dissection at Surgeons' Hall, London, of one Dillon, a sailor who had just been hanged.

In his detailed *Diary* entry recording the event, Pepys says how he was hosted at the dissection by Dr Charles Scarborough and other medical friends. A sumptuous dinner for the doctors and their friends was laid on as part of this conspicuous piece of medical theatre, and then, after the meal was over, Pepys was taken for a private view of the cadaver, where he saw "the Kidneys, Ureters, yard [penis], stones [testicles] and semenary vessels" laid out for his inspection, so as to "show very clearly the manner of the disease of the stone and the cutting and all other Questions that I could think of". Indeed, Pepys's own ordeal of five years earlier had given him a lifelong fascination with diseases of the urinary tract! The *Diary* entry does not record whether Thomas Hollier was present at this somewhat macabre feast, for the lithotomist who had saved Pepys's life also went on to become the Pepys's family doctor and a good personal friend.

A good example of this proliferation of learned medical and surgical culture, with its combined surgeon, hospital and fascinating case write-up format, came in 1735 when Claudius Amyand F.R.S., the eminent Huguenot surgeon at St. George's Hospital and Serjeant Surgeon to King George II, treated an 11-year-old boy with a hernia complicated by the presence of a scrotal fistula. When Amyand and his colleagues decided to operate on 8 December, they got more than they bargained for in so far as one complication now followed upon another. In the process of trying to relocate the falling gut, for instance, they found that not only had the *Appendix Coeci* descended into the scrotum, but that a "Pin incrusted with Stone" which the boy must have swallowed was poking through it. The attempt to replace the gut and close the fistula eventually resulted in a complex "Dissection" of the intestines of the courageous 11-year-old Hanvil Anderson who "bore … with great Courage" his fully-conscious half-hour ordeal. As Amyand had placed a ligature around the inflamed appendix before excising it, he became the first surgeon to perform, albeit inadvertently, an appendectomy. What is more, young Hanvil Anderson made a spectacular recovery, being discharged a month later simply wearing a "Truss, which he was ordered to wear some Time, to confirm the Cure".

Claudius Amyand later spoke of the operation as "the most complicated and perplexing I ever met with, many unsuspected Oddities and Events concurring to make it as intricate as it proved laborious and difficult". Of course, he is using the term "complicated" to indicate the sheer range of problems that descended one after the other as he tried to "Dissect" his way through the mess of living intestines, and close the fistula. But very clearly, as indicated by the patient's well-nigh miraculous recovery, no postoperative complications could have arisen. Amyand wrote up the case for the *Philosophical Transactions* of the Royal Society in 1736, along with several related ones, including a case where he had operated on and cured a soldier with a gunshot wound in the abdomen.

Eighteenth-century Britain — London, Edinburgh and Glasgow — along with Paris, became the world centres of excellence in anatomy, diagnostics and surgery, with figures like William Cheselden, Percival Pott, Alexander Monro (primus), Louis Petit and others winning enduring fame as medical scientists. It was Pott in particular who showed that a surgeon could not simply look at a surgical case in isolation, but must do so in the wider context of the environment, occupation and underlying disease conditions. It was Pott, for instance, who in 1775 first recognised the connection between high levels of scrotal cancer amongst chimney sweeps and the particular circumstances of their occupation. And more significant was his recognition in 1779 that hunchbacks with suppurating vertebral abscesses displayed a syndrome of complications that appeared to have links with tuberculosis — Pott's Disease, in fact. And while none of these conditions were specifically surgical complications in themselves, they were recognised as being the products of wider complicating conditions that the surgeon was called upon to treat.

But it was one man, a Scotsman brought up in Glasgow, yet whose surgical training and creative career was entirely based in London, who was to take the medical sciences down a new road, and was to become, in many respects, the first person to study surgical and wound complications as a branch of science in their own right. This was John Hunter.

Though he never ceased to be an active operating surgeon, John Hunter's contemporary and enduring fame rested on his scientific studies of bodily growth, change, decay, putrescence and response to invasion by foreign bodies. He was a brilliant and inspiring teacher who built up a very substantial income from pupil fees drawn from his successive domestic and teaching establishments in Golden Square and Jermyn Street, in addition to St. George's Hospital, and from the 1760s down to his death in 1793, Hunter shaped the careers and attitudes of hundreds of young men who would go on to become the medical and surgical élite of the late Georgian and early Victorian periods in England.

Hunter was an astute observer and a natural diagnostician, who saw connections which other men had missed. His independent scientific career began after working for several years as his older but less famous brother's assistant in London. Then during the Seven Years War in the early 1760s, John Hunter became a surgeon in the British Army, and was struck by the way in which untreated bullet wounds in soft tissue healed faster and more naturally than those which had been enlarged and probed by the surgeons. His later studies of teeth transplantation, platelet bone growth in piglets, fractures, and the nourishing role of a healthy blood supply, enabled him to draw profound conclusions about the life process. And much of this, passed on in papers or taught to students, was set out systematically in his monumental yet sadly posthumous *Treatise on the Blood, Inflammation and Gun-shot Wounds* (1794). For while Hunter died still innocent of any knowledge of the role of either cells or bacteria to the life process, he was the first surgical scientist to explore the process of *complication*, and see it not as an Act of God, an accident, or a result of incompetence, but as the product of a very specific set of biological factors. And at the heart of these studies was Hunter's work on inflammation. From scores of meticulous case studies, he concluded that suppuration is not a natural or necessary part of the healing process, and abandoned the still prevalent doctrine of "laudable pus" and bodily balances. Suppuration, rather, is the result of some prior inflammation, and the way to resolve it is to prevent or remove the source of inflammation. Hunter later specified three main types of inflammationary reactions: adhesive inflammation between parts; suppuration with pus formation; and ulceration, where tissue is lost through absorption. And in the Second Section of his monumental *Treatise*, moreover, he not only saw blood as conveying nutrition around the living body, but noted that when that blood was somehow defective or inadequate in supply or systolic force, its deficiency allowed inflammations to take told. Hunter perceived a connection, for instance, between valvular defects of the heart and the weakening of blood supply to the extremities, which could result in leg ulcers.

Injuries which did not break the skin, however, such as simple fractures or simple contusions, seemed to heal more directly, without inflammation setting in if the patients were vigorous and had efficient hearts. Hunter also recognised the natural therapeutic importance of scab formation, and came to see scabs as natural protective layers that facilitated the repair process, and protected that process from interference from outside. To remove such natural scabs and insert irritant powders as a way of bringing about suppuration came to be seen by Hunter as inducing complications where they did not naturally exist. In some ways, one might say, Hunter realised that the less the surgeon interfered with a wound of any kind, the fewer the complications that occurred. And all of these results, moreover, came not from the application of one of those all-embracing theoretically-based medical "systems" so beloved by 18th-century physicians, but from meticulously-conducted experimental investigations.

Hunter's colossal legacy to medicine was the bringing about of a sea-change in what surgeons did. More than any other single individual, he broke down many ancient and enduring "truisms" of medicine, and did this on the back of meticulously-recorded experimental researches, and that vast collection of specimens which was later bought for the nation and lodged at the Royal College of Surgeons as the Hunterian Museum.

Hunter's scientific legacy was international. Henry Clift, John Abernethy, Robert Knox, Charles Bell and Sir Astley Cooper were amongst some of his greatest British disciples. Men who, even if not studying under him directly, modelled their approach to their profession in accordance with Hunter's teachings and principles. Hunter's experimental approach to the study of life and decay processes further influenced the researches in continental Europe and America. John Collins Warren, for instance, who performed the world's first scientifically-monitored operation to use an anaesthetic at Boston, Massachusetts, in 1846, had been a "grand pupil", as it were, of Hunter, having studied at Guy's and St. Thomas's in the late 1790s, where the Hunterians Henry Cline and Astley Cooper ruled the roost. Warren, indeed, was one of several American medical men who took the Hunterian approach to the New World at the outset of what would turn out to be a distinguished surgical and medical career.

By 1846, Warren was Professor of Surgery at Harvard, and Surgeon to the Massachusetts General Hospital, when, on 16 October, he became the principal player at one of the greatest discoveries in the history of surgery. For on that day, in the Massachusetts General Hospital, he operated on a man who had been rendered insensible by sulphuric ether, administered to him by the dentist Dr William Morton. The success of that operation had reverberated around the world by Christmas 1846, for the mercy of anaesthesia promised to remove a set of problems from surgery which hardly anyone had thought of as a complication before they were removed, for their very presence had been seen since time immemorial as simply synonymous with the surgeon's art: pain and trauma. By the new year of 1847, in Boston, New York, London, Paris, Berlin, Vienna and the other great medical centres of America and Europe, surgeons found themselves working in a wholly new environment. Patients, knowing of the power of ether, no longer approached surgery as terrified lambs going to the slaughter. Powerful restraining assistants were no longer necessary; the patient's screams no longer drove young medical students out of the profession, as they had done to the medically-aspiring Charles Darwin at Edinburgh in 1827; while the postoperative patient was no longer a traumatised wreck who stood in need of months of convalescence if he survived at all. Surgeons, quite simply, did not fully realise what a major complication pain and fear had been until they vanished. For their sudden disappearance opened up wonderful new therapeutic prospects which would have been unthinkable before October 1846. Speed ceased to be a surgical prerequisite, and more complex operations could be planned and attempted on patients in deep anaesthesia which might even last for 20 or 30 minutes.

Post-1846 surgeons also found that other side effects of surgery which went back centuries could be drastically reduced and controlled. William Clowes, John Woodall, Richard Wiseman, Astley Cooper and Robert Liston (who was the first Briton to operate on an anaesthetised patient) had all been aware of the grave dangers stemming from massive haemorrhages, especially if working on the thigh, for no matter how good the surgeon's anatomical knowledge was or how well-disciplined his assistants were, pints of blood were easily squandered when a patient's convulsions made it impossible to seize and ligature the arteries. Yet when a patient was in deep anaesthesia, haemorrhage control became so much easier, and another complication was greatly reduced.

And once anaesthesia had been demonstrated as a medical reality, the hunt was immediately on for better anaesthetic substances with fewer side effects than ether. Sir James Simpson in Edinburgh, with a group of colleagues, began the systematic inhalation of various new chemical substances, and was delighted to discover the superior anaesthetic properties of chloroform — a new chemical preparation originally isolated by Soubeiran and Liebig in 1832 and already used in pharmacies — in 1847. Then in addition to powerful inhalants intended for operating theatre usage, Victorian chemists and doctors began to search for other types of pain-killing drugs, from those to control severe postoperative pain at one end of the spectrum, to sedatives and relatively mild analgesics at the other. It seemed that once the concept of efficient chemical pain control had sunk into the thinking of the medical and scientific communities, then the race was on. Crude opiates gave way to the power of the new analytical chemistry to produce morphine by 1805 and heroin by 1898. Then there was cocaine after 1885, which opened up entire new vistas for ophthalmic surgery, where the need for patient cooperation during surgery precluded the use of a general anaesthetic. Chloral hydrate became medicine's first "safe" sedative and sleep-inducer after 1871, while 1900 saw the isolation and wholescale manufacture of that drug which would be marketed as Aspirin. The mode of administration of pain-killing drugs also fundamentally changed in the latter half of the 19th century. For half a century after its chemical isolation from poppy juice by Friedrich Sertürner in 1805, morphine had been administered orally, as drugs had been since time immemorial. But in 1855, Alexander Wood of Edinburgh invented intravenous administration by hypodermic syringe, whereby a much more exact and physiologically specific dose of the drug could be given. Likewise, following their entry into medicine, cocaine and heroin came in turn to be delivered by hypodermic. And by the end of the century, the mass manufacture of pure, laboratory-produced pharmaceuticals, by firms such as Bayer and Merck, and the development of machines which could manufacture pills of exact dosage, were essential to the launch of the ubiquitous Aspirin and other tablets by 1900. Pain, one of surgery's most enduring complications, therefore, had been removed on the primary operative level, and rendered controllable at the secondary.

Surgery went through a honeymoon period in the years following 1846. Longer and more complex operations were now being tried, though surgeons were beginning to notice that postoperative infection and inflammation could ruin good work done in theatre.

For centuries surgeons had had their own chosen "antiseptics", without any coherent concept of what sepsis was or how it could be prevented, and long-standing favourites had included vinegar, turpentine and wine (or alcohol distilled from wine). Indeed, the great 14th-century French surgeon Guy de Chauliac had recommended "biting wine" or early brandy for such purposes. Yet none of these substances were used in accordance with any proper system quite simply because no one knew how sepsis occurred in the first place, and empirical attempts to mop up "putrefied blood" and then swill out the wound with turpentine or brandy were hit and miss in the extreme.

The overcoming of the next great surgical complication — gangrenous infection — had to wait until the 1860s. After the introduction of anaesthesia, surgeons, especially when working in hospital theatres as opposed to the homes of private patients, were alarmed to find that gangrenous complications tended to be on the increase. We now recognise, however, that the larger and more complex operative sites made possible by anaesthesia, and the much longer duration of anaesthetic operations, quite simply provided more opportunities for infection to occur. Several solutions to the problem of "hospital gangrene" were being actively sought during the period 1846–1866, and all seemed to offer some kind of success. A drive towards what was considered to be "cleanliness" was one of them, especially in the wake of Florence Nightingale's return from the Crimea in 1856, when it became clear that her nursing regime had undoubtedly improved the survival rates of wounded soldiers. Floors, walls, furniture and fittings were now regularly scrubbed, and the new breed of Nightingale nurses looked smart and well-starched. And because bad air, or "miasmas", were thought to hang around places where the unwashed poor were huddled together — in workhouses, prisons, military barracks and the Charity Wards of great hospitals — the encouragement of a brisk "through ventilation" was deemed necessary to remove them, thereby dictating the high ceilings and lofty architecture of our Victorian hospitals. And as mentioned above, varying degrees of trust were placed in the liberal application of "antiseptics". Turpentine became a favourite in the early 1860s, and was used extensively in the hospitals of the American Civil War. Yet none of these substances or procedures offered real or enduring success.

It was not until Joseph Lister, the young Regius Professor of Surgery at Glasgow, read Louis Pasteur's recent researches into fermentation in 1865 that a solution to the abounding complications of hospital sepsis in its various forms began to take shape. For while the concept of airborne sepsis was implicit in the miasmic theory, Pasteur's researches had shown that it was not the air itself which caused sepsis, but rather the presence of micro-organisms contained in the air, for as the Frenchman had demonstrated, if those micro-organisms were destroyed, such as by heating, then the air would lose its power to turn soup putrid or produce decomposition in meat.

One of Lister's brilliant insights was his recognition of the connection between putrescence and surgical sepsis, and as soon as he had read Pasteur's paper, he began to look for ways of applying its scientific principles to surgery. Though he could not remove bacteria from the air around and inside a wound with heat, he realised that one might be able to do so with chemicals. We have already seen that "antiseptics" had already been around on a hit and miss basis for centuries, but Lister chose a dilute preparation of a relatively new chemical substance which had already proved its worth in the treatment of sewage: carbolic acid, or phenol.

The class of surgical complication on which he began his antiseptic researches was an all too common one at the time: compound fractures. Why did even a bad fracture which did not penetrate the skin heal without septic complications, whereas one which only slightly penetrated the skin often became infected, gangrenous, and finally required amputation? The scenario was not a new one, and clearly harked back to John Hunter's observations concerning the different healing tendencies of punctured and non-punctured wounds. But Joseph Lister came to see that it was not the air itself which was the culprit, but Pasteur's microbes being carried in the air, as well as — as he later realised — microbes on the surgeon's hands and instruments.

His first attempt at antiseptic healing in the light of the Pasteurian discoveries was on a Glasgow road accident victim, a boy named James Greenless who, in August 1865, was run over by a wagon. The reduced fracture was meticulously cleansed with carbolic solution, and the whole wound site wrapped in carbolic-soaked lint. James Greenless's leg healed by first intention, and he walked out of the hospital six weeks later.

Lister began to refine the technique and, crucially, developed a precise antiseptic system for compound fracture cases, often wrapping a treated limb in tinfoil to prevent evaporation from the chemical dressings. Lister's technique was streets ahead of what had been done before, not because phenol was a magic drug in surgery, but because it was used in accordance with a precise method rather than just splashed around a wound site, as had been the case with earlier antiseptic substances. Then in the 16 March 1867 number of *The Lancet*, he published an account of 11 compound fracture cases in which he had used his method, all of which had healed without sepsis: an unprecedented run of success for the time.

But applying the method to elective operative surgery seemed more difficult, and still working with the idea of airborne bacteria, Lister devised a spray machine which would produce a carbolic aerosol atmosphere around the operating site. The ensuing results were decisive. He found that his fatalities for amputation cases fell from 45.7% for 35 persons operated upon without antiseptics between 1864 and 1866, to 15.0% for 40 antiseptic cases for the period 1867–1870.

Yet Lister's results, decisive as they seem to us today, still left many doubting, and the decisive Achilles heel of Lister's method was his inability, at the time, to show which particular microbes caused which complications. Surgery, let us not forget, has always been the most pragmatic of all the healing arts, and tends to attract persons of a pragmatic turn of mind to its practice. And as British science in particular was deeply Baconian in the 19th century, and its practitioners concerned with using experiments to establish precise cause and effect relationships in nature, Lister's theory was easy to shoot down from a cause and effect perspective. Why did wounds sometimes heal by first intention even without "Listerianism", especially if performed upon private patients in their own homes in rooms that had been well scrubbed in advance? Were hospitals dangerous places in which to perform surgery simply because the poor folk who inhabited their wards were less vigorous or fundamentally degenerate?

Although we know that Lister was correct, one must not write off powerful critics of his method, such as Robert Lawson Tait or John Hughes Bennett, as dinosaurs: indeed, the anti-Listerian Lawson Tait — who had, from purely empirical criteria, developed a form of aseptic surgery — was almost a generation younger than Lister himself. For quite simply, if one adhered to the new yet pre-Listerian doctrines of cleanliness, good ventilation and competent nursing, a surgeon stood to have higher survival rates for his patients than a colleague who employed the older and dirtier methods, quite apart from the use or otherwise of Lister's techniques. For to many, there seemed no proven connection between the creatures seen under the microscope in pus or fluid specimens from wounds and the occurrence of surgical gangrene, septicaemia or pyaemia. Indeed, even Robert Hooke and Antoni van Leeuwenhoek, the discoverers of the "animalcules" of bacteria back in the 1660s, 1670s and 1680s, had pointed out that one found them wriggling about everywhere: in plant moulds, teeth scrapings, saliva and blood; and by the age of the high-power compound microscope in the 1860s, it seemed that creepy crawlies were everywhere! So why was Lister's method significant?

In many ways, the turning-point in the intellectual acceptance of antisepsis came from Robert Koch's researches during the 1870s which showed that a specific inflammatory or infectious disease could be connected with a specific bacterium. What mattered, therefore, in the avoidance of inflammatory complications in surgery, was the absence of specific strains of bacteria from the site of the operation, and not necessarily *all* bacteria. Koch's researches, first published in 1879, were to produce the key pieces of Baconian "proof" for the correctness of Lister's idea of protecting the surgical site from microbes, though by the time that Koch's work on the connection between specific bacterial strains and specific diseases was coming to win over doubters to the germ theory in general in the 1880s, surgery itself was going beyond Lister's chemical method. For one thing, Koch demonstrated that heat, rather than chemicals, was more effective in killing bacteria. And while no one suggested that the entire operation had to be performed at sterilising temperatures, it was found that if surgical instruments and dressings could be heat-sterilised before operating, then the wounds stood a good chance of healing by first intention even without Listerianism.

After 1865, surgery forged ahead in a way which would have been unimaginable in 1840, for once the monumental obstacles of operative and postoperative pain had shown themselves to be amenable to control, and Lister had demonstrated the same for septic infections, a foundation had been established upon which one innovation after another would be built. By the 1890s, for instance, many surgeons in Europe and North America had gone beyond Listerian carbolic methods to develop aseptic, as opposed to antiseptic, techniques. Theodor Billroth, William Halstead, the surgeons of the new Johns Hopkins research school, the Minnesota brothers Charles and William Mayo, and others had come to see the operating theatre not as a carbolic-soaked place, but one in which germs were not so much killed as excluded from entry. For aseptic conditions could be achieved if the surgeon and his assistants were well scrubbed, wore the new thin flexible gloves developed by the Dunlop Rubber Company, and were aseptically gowned rather than merely aproned. Their instruments, moreover, were re-designed, losing their traditional black bone handles, and were stripped down to the steel, so as to be capable of sterilisation in high-temperature autoclaves.

The old problem of haemorrhage came to be controlled not just with advancing anatomical knowledge and ligatures, but also with special locking forceps, and with special clips. And then, one might say, the old complication of haemorrhage found its ultimate solution after 1900 when Karl Landsteiner's researches opened up the possibility of using transfusion as a way of replacing lost blood. Landsteiner came to his discovery after studying why previous transfusions had failed, and the patient's and donor's blood had coagulated and produced an allergic reaction, which often resulted in death. Laboratory experiments led Landsteiner to realise that antigen reactions were at work between different groups of red blood cells, and by 1900, he was able to isolate distinct blood groups which he called A, B, O and later AB. When blood from a compatible donor was given to a surgical or accident patient, blood loss caused by haemorrhage could now be replenished. Most of these early transfusions were direct between donor and patient, but the establishment of the first blood banks in the late 1930s opened up all kinds of possibilities for surgeons, and by definition, reduced complication.

Although the number of surgical operations performed increased dramatically after 1846, and they became progressively safer in the wake of Lister's work in the middle and late 1860s, the actual repertoire of operations still remained fairly fixed. Yes, it is true that a military surgeon, working on extreme battlefield injuries and attempting whatever procedure, just might save the patient's life, be it replacing abdominal viscera or trying to remove projectile debridement from the cranial or thoracic cavities — sometimes with success; but what would be considered operable within the context of a hospital theatre remained much more conservative. For elective surgery remained deeply cautious for many years to come after 1865. Joseph Lister's own repertoire of operations, conducted in his capacity as professorial surgeon at three of Europe's greatest university teaching hospitals — Glasgow, Edinburgh and King's College, London, successively — did not change much over the decades. Orthopaedics, attempts at repairing damage occurring in tuberculous joints (especially the wrist), and the excision of external tumours and growths remained his essential stock-in-trade, as they did with scores of his colleagues. What changed drastically were the chances of patient survival, and of wounds healing by first intention.

The abdomen was the first traditional "no go" area of the human body to be worked on electively by surgeons using the new techniques of anaesthesia, antisepsis and asepsis. And while cases were on record of abdominal operations where the patient had survived, these had all been performed in emergency or unexpected contexts — such as Claude Amyand's 1735 hernia operation on the boy who was found to have a pin stuck through his appendix. Quite simply, abdominal operations seemed replete with complications, even after anaesthesia, as infection, muscle damage and blood loss made them too dangerous.

Yet curiously enough, some surgeons had been opening the abdomen with varying degrees of success since 1809, when Ephraim McDowell, an Edinburgh-trained surgeon of Danville, Kentucky, removed an ovarian tumour weighing 23 1/2 pounds from one Mrs Jane Todd Crawford. This radical ovariectomy healed by first intention. Mrs Crawford was up and making her own bed five days after surgery, "and in 25 days, she returned home as she came [on horseback] in good health which she continues [1817] to enjoy". Jane Todd Crawford lived for another 31 years, dying in 1842, and outliving her surgeon by 12 years. McDowell performed over eight ovariectomies before he died in 1830, and in most of these cases the patient lived. Of course, while the 1809 operation on Mrs Crawford was elective, it was in reality just like a severe gunshot wound — a forlorn hope, for as McDowell told his courageous patient, she would die if she did not risk it. During her 25-minute, fully-conscious ordeal, Jane Todd Crawford sustained herself by singing *Psalms*. Ovariectomy was also practised with varying degrees of success by surgeons on both sides of the Atlantic, both before and after anaesthesia and antisepsis came on the scene. By 1880 Spencer Wells in London had clocked up his incredible 1000th operation, and while not adopting Lister's techniques until around 1878, his concern with overall cleanliness and exact procedures meant that he had a mortality rate of only 25%.

Crucial to the development of abdominal surgery, however, was the seeming increase of what had once been called the *Illiac Passion*, which by the 1880s had become known as *Typhilitis*, and after Reginald Heber Fitz in Boston in 1886, as *Appendicitis*. John Woodall in 1617 had left a detailed account of this frightful condition, which appeared to be connected with total constipation and blockage of the gut, and which, *in extremis*, led to the voiding of the faeces from the mouth shortly before death. Hunter had done a classic study, in which he noticed massive inflammation of the peritoneum and blockage of the gut by adhesion in *post mortem*. By the 1880s, however, several surgeons were attempting the opening up of the abdomens of living people with this condition, and it is hard to be sure who was first, for Robert Lawson Tait in England, Ulrich Rudolf Krölein in Germany, Reginald Heber Fitz in America, and so on, were all attempting operations for typhilitis in the early 1880s. Generally speaking, they were not trying to remove the whole *veriformis appendix* so much as drain away the infection and separate the adhesions, and even as late as June 1902, when the Prince of Wales, soon to be crowned King Edward VII, went down with appendicitis, his surgeon, Sir Frederick Treeves, only drained the site rather than removing the appendix altogether. For massive septic complications could all too easily set in, and as late as 1907, Mair, the 17-year-old daughter of the future British Prime Minister David Lloyd

George, died from the complications of an appendectomy. However, when [Sir] Winston Churchill went through a similar ordeal on 19 October 1922, he was just about back on his feet, though looking skeletal, within a month. Charles Mayo, of the celebrated clinic which bore the name of that family of surgeons at Rochester, Minnesota, was to develop the appendectomy as well as several other abdominal procedures into something of a routine between 1890 and the 1930s.

Some surgeons, however, in spite of the inherent dangers involved, became so eager to open up the abdomen by the mid-1880s that one almost hears the Hippocratic alarm bells about rash surgery ringing in one's ears. Sir William Arbuthnot Lane, for instance, was so obsessed with the pernicious effects of constipation, and the supposed absorption thereby of "poisons" into the bloodstream, that he became the virtuoso of the radical colotomy, where substantial pieces of the patient's gut would be removed in the hope of speeding up bowel action. Some surgeons were coming to see themselves as heroes of the knife!

Indeed, by the 1880s, surgery was developing rapidly, and the massively influential Theodor Billroth was to train up in Berlin, Zurich and Vienna a whole new generation of surgeons who would establish his methods on both sides of the Atlantic. For Billroth took surgery out of the operating theatre, seeing that it had to be matched by meticulous laboratory work if its full curative effects were to be realised. Pathological specimens had to be examined in the laboratory, and the pre- and post-surgical state of the patient carefully monitored. Carl Wunderlich's mid-19th-century researches into medical thermometry were seen by Billroth as having a direct surgical relevance, as Billroth related degrees of inflammation to thermometric readings, thereby showing how a surgeon might measure the occurrence and response to treatment of a complication. And Billroth's methods were not reserved for surgery on any one part of the body, but could be applied to any kind of procedure: to amputations, tumour, and liver, renal or abdominal surgery, not to mention the first tentative openings of the cranium and the thorax. What mattered was that the practitioner of the new surgery saw his work within a context which included the laboratory, instrumental monitoring and statistical analyses. And of course, the sheer scope for surgical complications was now expanding at an unprecedented rate, for with each new procedure attempted on the human body, the things that could go wrong increased. On the other hand, these complications could be seen as part of a wider biological and pathological whole, with new scientific methods developed for their control and elimination.

At the same time as some surgeons were risking opening up the abdomen, others were taking the ancient procedure of trephination several stages further, and trying to treat conditions of the brain. As early as 1879, Sir William Macewan in Glasgow successfully removed a tumour from the *dura mater* of a patient, while in the 1880s Eugene Hahn in Germany and Sir Rickman Godlee in England successfully removed potentially malignant growths, or else drained abscesses, from the surface coatings of the human brain. Yet the surgery of the brain and its deeper glandular structures really began to take off with Harvey Cushing in America after his successful removal of the pituitary gland from an acromegalic patient in 1909, based as that operation was on a meticulous study of that gland by Cushing over the previous four years.

It was not really until after World War I, however, that a surgical approach to the human heart was made, although there was an abundance of material in the historical medical literature recording chest and even heart injuries from which the patient had sometimes recovered. But it was that Napoleon of abdominal surgery Sir William Arbuthnot Lane, who first resuscitated a heart which had suddenly stopped during surgery. This feat was reported in *The Lancet* in 1902, where it was told how, when he was removing the appendix of a 65-year-old man, the patient's heart stopped beating. Having the patient already open before him on the operating table, however, the redoubtable Arbuthnot Lane simply thrust his arm into the upper abdominal cavity until he could feel the motionless heart through the diaphragm wall. Then "he gave it a squeeze or two and felt it re-start beating". The patient recovered from both his abdominal and his unplanned cardiac surgery!

Of course, as Arbuthnot Lane was all too well aware, he had not actually *entered* the thoracic cavity, so much as used the elasticity of the diaphragm to enable his hand to feel and squeeze the heart. For in 1902 invading the thorax and tampering with the pericardium, heart and other structures was too much of a closed domain to risk entering. Even so, Arbuthnot Lane became the first surgeon to face the complication of death on the operating table with a new and successful solution.

But it was the sheer volume of battle injuries sustained in World War I, assisted by diagnosis with X-ray machines, which really brought home to surgeons what a living human heart could take and survive. In his paper "The

Surgery of the Heart", in the 3 January 1920 number of *The Lancet*, Sir Charles Ballance described the case of a French infantryman who was found, 70 days after his original medical examination, to have a 1.5 cm piece of steel from a German grenade lodged in his right ventricle. It was subsequently removed in a Paris hospital where the operating surgeon found, to his surprise, that "The heart could not be held in the gloved hand, from which it slipped like a live fish". Other World War I surgeons reported embolic rifle bullets lodged in the aorta and carried with the blood current, penetrated chest walls, damaged pericardia and other conditions which the patients sometimes survived. But as Sir Charles Ballance emphasised in his 1920 *Lancet* paper, sepsis was the killer complication of all such surgery.

As far as I am aware, however, the first elective, as opposed to battle wound, surgery to be performed on the heart had to wait until 1925, when Henry Sessions Souttar of the London Hospital attempted a radical procedure on a young woman whom he believed to have mitral stenosis, a case which he reported in the 1925 *British Medical Journal*. Souttar made a large flap in the region of her left breast, cut through three ribs, and entered the ventricle via the mitral valve, and in a couple of minutes seemed to have cleared away some of the stenosed material, so that when his finger was removed, the blood flow seemed better than before. The one-hour-long operation appears to have been complication-free, as "her condition had never caused the slightest anxiety" and she recovered after six weeks of bed rest and rural convalescence, though remaining short of breath upon exertion.

Regular thoracic and cardiac surgery took a long time to develop, however, for the complications involved could be so enormous, with patient mortality rates of over 70%. Drugs and a severe body-cooling regime (surrounding the anaesthetised patient with ice) were tried as ways of reducing the heart-beat rate in surgery to make the organ more amenable to handling, though sepsis still remained the overwhelming problem. It would take a Second World War, and the whole cascade of new surgical and medical techniques which came from that, before cardiac surgery could become remotely safe. By the 1950s, however, cardiac surgery began to advance rapidly, especially with the development of biomedical technology, and extracorporeal circulation machines of the type used for Charles Lillehei's operations at the University of Minnesota, which made possible complex surgical procedures on living human hearts.

Yet the most powerful surgical tool and combater of septic complication derived in fact from an essentially medical discovery: antibiotics. Antibiotics research really began in World War I, when the young [Sir] Alexander Fleming had been studying wounds and resistance to infection. This was at a time when the concept of the body's immune system, and the role played therein by enzymes, were first coming to be explored by medical scientists. Then in 1928, Fleming noticed how a penicillin mould had destroyed a staphylococcus culture in his laboratory at St. Mary's Hospital, London, and published his results a year later. However, it was Howard Florey, Ernst Chain and Norman Heatley at the Oxford University Dunn School of Pathology a decade later who began work on isolating the active ingredient in *penicillium notatum*, and succeeded in 1940. Though much of the research for the mass-production of penicillin was undertaken in the USA after 1941, research also continued in England, and by the D-Day invasion of Europe in June 1944, penicillin was already in such abundant supply as to transform the prospects of the Allied wounded. And after the War, penicillin and other antibiotics made it possible for surgeons to electively open up the abdomen, cranium and thorax with a much higher likelihood of the patient not succumbing to a lethal postoperative septic or pulmonary infection. An assault upon the causes of sepsis which had been begun by Lister in 1865 had developed beyond recognition by 1945, and would continue doing so in a fairly exponential fashion, at least up to the late 1980s, when antibiotic-resistant strains of bacteria began to emerge.

Although surgical complications have no doubt been around since the stone age, when primitive men first used pieces of sharpened flint to chisel holes in injured heads or perhaps to open painful ulcers or tumours, it was really not until the late 18th century that those complex pathological changes which can take place inside wounds, were studied scientifically. For in the last two centuries, surgery and medicine in all of their branches have changed, both conceptually and technically, beyond recognition. Conditions which had hitherto been seen as "natural" — such as inflammation, pus, pain, haemorrhage, fever and high mortality — were increasingly perceived as essentially extraneous factors which could be eradicated from the surgical environment if not yet, at least at some stage in the not too distant future. And while post-Renaissance anatomy and the experiences gained in the treatment of gunshot wounds had made the surgeon much more confident in so far as he now knew exactly what he would encounter beneath the surface whenever he took up his knife to operate, it was really not until after 1846 that this vast treasury of accumulated body knowledge began at last to reap a sweeping therapeutic harvest in terms of new and increasingly safe operations which eventually extended into every cavity area and organ of the human body. And ironically, one might say that nowadays the range of potential surgical complications is greater than ever before; but this is only because the modern surgeon can confidently address problems within the human body which would have been unimaginable 25, 50, 100 or 200 years ago, yet by the judicious use of that vast armamentum of clinical techniques available today, he stands a very good chance of stabilising and overcoming such complications as and when they occur.

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