General Introduction and History of Hernia Surgery

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Ancient and Renaissance Hernia Surgery

The high prevalence of hernia, for which the lifetime risk is 27% for men and 3% for women [87], has resulted in this condition inheriting one of the longest traditions of surgical management. Descriptive anatomy of the anterior abdominal wall dates back over 6000 years, to the beginning of civilization, the Valley of the Nile and the ancient Egyptian papyri. These texts, often by unknown authors, were written in a time when medicine was magico-religious and the first steps in inductive reasoning were being taken. The Egyptians (1500 BC), the Phoenicians (900 BC) and the Ancient Greeks (Hippocrates, 400 BC) diagnosed hernia. During this period a number of devices and operative techniques have been recorded. Attempted repair was usually accompanied by castration, and strangulation was usually a death sentence. The word 'hernia' is derived from the Greek (hernios), meaning a bud or shoot. The Hippocratic school differentiated between hernia and hydrocele—the former was reducible and the latter transilluminable [88]. The Egyptian tomb of Ankh-ma-Hor at Saqqara dated to around 2500 BC includes an illustrated sculpture of an operator apparently performing a circumcision and possibly a reduction of an inguinal hernia [94] (Fig. 1.1). Egyptian pharaohs had a retinue of physicians whose duty was to preserve the health of the ruler. These doctors had a detailed knowledge of the anatomy of the body and had developed some advanced surgical techniques for other conditions and also for the cure of hernia. The mummy of the pharaoh Merneptah (1215 BC) showed a complete absence of the scrotum, and the mummified body of Rameses 5th (1157 BC) suggested that he had had an inguinal hernia during life with an associated faecal fistula in the scrotum and signs of attempts at surgical relief.
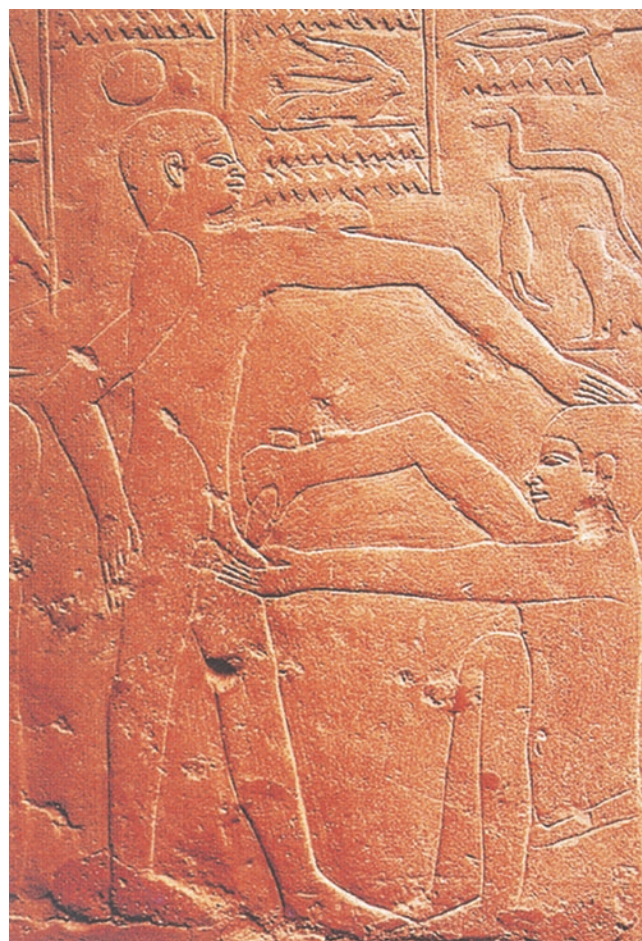
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Fig. 1.1 Egyptian tomb of Ankhmahor (Saqqara). The operator (*bottom right*) rubs in something with an instrument and seems to perform a reduction of an inguinal hernia

Greek and Phoenician terracottas (Figs. 1.2 and 1.3) illustrate general awareness of hernias at this time (900–600 BC), but the condition appeared to be a social stigma, and other than bandaging, treatments are not recorded. The Greek physician Galen (129–201 AD) was a prolific writer and one of his treatises was a detailed description of the musculature of

Fig. 1.2 Terracotta ex voto shows femoral hernia (from Geschichte der Medizin (1922))

Fig. 1.3 Phoenician terracotta figure (female) shows umbilical hernia (fifth–fourth century BC) (from Museo Arquelogico, Barcelona, Spain)

the lower abdominal wall in which he also describes the deficiency of inguinal hernia. He described the peritoneal sac and the concept of reducible contents of the sac.

Celsus (AD 40) was a prolific writer, and although he had no medical training, he documented in encyclopaedic detail the Roman surgical practice: taxis was employed for strangulation, trusses and bandages could control reducible hernia, and operation was only advised for pain and for small hernias in the young. The sac could be dissected through a scrotal incision, the wound then being allowed to granulate. Scar tissue was perceived as the optimum replacement for the stretched abdominal wall. A common method of treating hernia at this time was to reduce the contents of the sac and then attempt to obliterate it by a process of inflammation and gangrene by applying pressure to the walls of the sac through clamping the hemiscrotum between two blocks of wood. The last of the Graeco-Roman medical encyclopaedists, Paul of Aegina (625–900 AD), distinguished complete scrotal from incomplete inguinal herniation or bubonocele. For scrotal hernia, he recommended ligation of the sac and the cord with sacrifice of the testicle. Paul was the last of the great sur-

geons who wrote several books, which gave detailed descriptions of operative procedures including inguinal hernia.

Aulus Cornelius Celsus (first century AD) who first described the importance of surgical closure of the abdominal wall [104]. The procedure was termed 'gastrorrhaphy' originating from the Greek 'gastir' meaning abdomen and 'rhaphy' meaning suture. In fact, what Celsus was describing was a layered closure of the abdominal wall to prevent an incisional hernia. A century later, Aelius Galenus (Fig. 1.2), better known as Galen of Pergamon, a Roman of Greek origin and arguably the most prominent physician of the Greco-Roma period, provided a detailed description of mass closure of the abdominal wall [105]:

In stitching the needle should be thrust from without inwards through skin and rectus muscle, and then from within outwards through the muscle and skin, repeating this until the wound is closed. Some operators include the peritoneum in the stitches, but this is not usual. The dressing should be soft wool dipped in oil moderately warm and cover the space between the flanks and armpit.

It seems that Galen was aware of the risk of incisional hernia following abdominal surgery, and he describes in detail the paramedian incisions, in order to prevent a hernia from developing [105], an incision which was used commonly until the late twentieth century:

> A wound in this situation is less dangerous than in the mid-line, since the thin aponeuroses are lacking. In the mid-line stitching is accomplished with difficulty and the intestines are more likely to protrude and be hard to replace.

The works of Galen were later translated into Latin and helped to form the basis of modern surgery.

The Middle Ages (AD500–AD1500)

In the Middle Ages, the notable techniques of Greco-Roman surgery were largely lost. This was an age of faith and scholasticism. During this period, different types of abdominal wall hernia were rarely differentiated. However, Arnaud de Villeneuve, a French physician and surgeon, described an epigastric hernia in 1285, and another Frenchman, Guy de Chauliac (1300–1368), wrote *De ruptura*, which classified different types of hernias and distinguished between umbilical and epigastric hernia; however in his classification, they were not given these names [106, 107].

The drawing of the Vitruvian Man by Leonardo da Vinci (circa 1487) is considered to be one of the world's greatest works of art. It is da Vinci's representation of ideal human proportions described by the ancient Roman architect Vitruvius in Book III of his treatise *De Architectura*. The left inguinal region of the Vitruvian Man demonstrates a spherical fullness above his groin, above and medial to the pubic tubercle. This corresponds to the classical manifestation of an inguinal hernia. Leonardo da Vinci made the drawing in the coronal plane to illustrate the geometrical dimensions of the human body through the observation of living subjects and cadaveric dissection [108] (Fig. 1.4).

During the dark time of the Middle Ages, there was a decline of medicine in the civilized world, and the use of the knife was largely abandoned, and few contributions were made to the art of surgery, which was now practised, by itinerants and quacks. With the rise of the universities such as the appearance of the school of Salerno in the thirteenth century, there was some revival of surgical practice [94]. At this time three important advances in herniology were made: Guy de Chauliac, in 1363, distinguished femoral from inguinal hernia. He developed taxis for incarceration, recommending the head-down, Trendelenburg position [58]. Guy was French and studied in Toulouse and Montpelier and later learned anatomy in Bologna from Nicole Bertuccio. Guy wrote extensively about hernia in his book Chirurgia principally about diagnosis and methods of treatment (Fig. 1.5).

He described four surgical interventions, one of which was a herniotomy without castration, another consisting of cauterization of the hernia down to the os pubis and third consisting of transfixion of the sac to a piece of wood by a strong ligature. His fourth method however was conservative treatment with bandaging and several weeks of bed rest accompanied by enemas, bloodletting and special diet. At the time he was the authoritative expert on hernia.

Franco's book *Traites des Hernies* [61] standardized the practice of hernia surgery at the time and diminished the influence of the itinerant practitioners (Fig. 1.6). Franco popularized the punctum aurium and using this instrument made a small incision in the upper scrotum, isolated the hernia sac from the spermatic cord and then encircled it with a gold thread, thus sparing the testis. He chose gold thread because this was considered to be the best nonreactive material. In spite of the known hazards and high mortality of operating on a strangulated hernia, Franco advised early intervention and rejected the conservative measures employed such as bloodletting and tobacco enemas. As a result he saved numerous patients with life-saving operations. He wrote many up as case reports illustrating his management and surgical techniques. He recommended reducing the contents and closing the defect with linen suture (Fig. 1.7). His beautifully written manuscript was rediscovered and published again in 1925 by Walter van Brunn. As shown in the illustration, the unusual feature of the book was the patients posing in everyday attire as if they were going about their everyday life.

In 1559 Stromayr, a German surgeon from Lindau, published a remarkable contribution to surgery. His book *Practica Copiosa* describes sixteenth-century hernia surgery in great detail and is comprehensively illustrated. Stromayr differentiated direct and indirect inguinal hernia and advised excision of the sac and of the cord and testicle in indirect hernia [96]. Having differentiated and classified the two types of inguinal hernia, Stromayr recommended a testis sparing procedure for the direct type. His operation for high ligation of an indirect sac at the internal ring is illustrated in Fig. 1.8. Stomayr also advanced the technology of trusses, which he designed to be adapted to the rigours of everyday life. The Renaissance brought burgeoning anatomic knowledge, now based on careful cadaver dissection. William Cheselden successfully operated on a strangulated right inguinal hernia on the Tuesday morning after Easter 1721. The intestines were easily reduced and adherent omentum was ligated and divided. The patient survived and went back to work [54] (Fig. 1.9).

Without adequate interventional surgery, some patients survived hernia strangulation when spontaneous, preternatural fistula occasionally followed infarction and sloughing of a strangulated hernia. Cheselden's Margaret White survived for many years 'voiding the excrements

Fig. 1.4 Vitruvian Man (from Ashrafian)
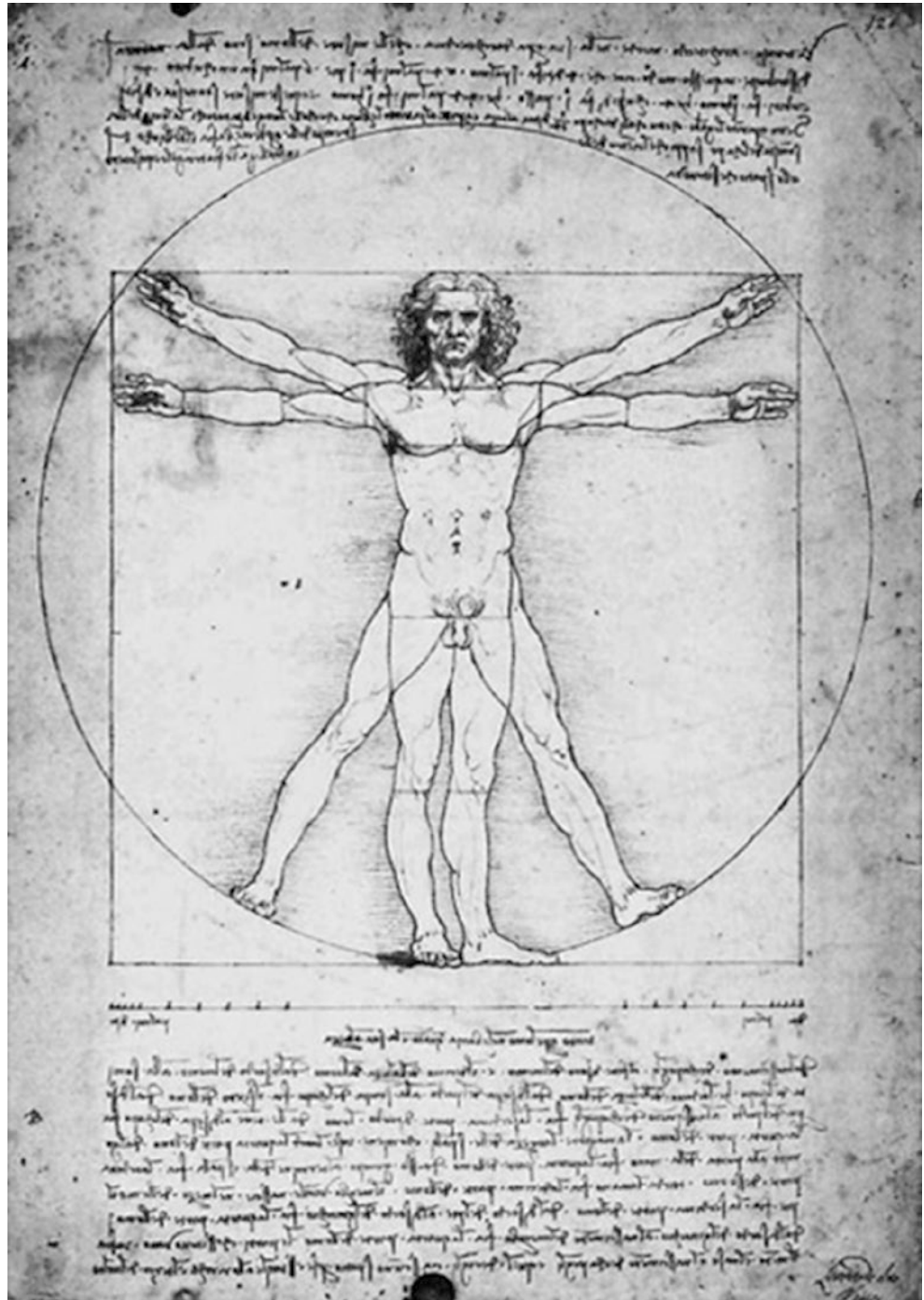
through the intestine at the navel' after simple local surgery for a strangulated umbilical hernia [54]. The closure of such a fistula in the absence of distal bowel pathology was described by Le Dran, who had noted that it was quite common for poor people with incarcerated hernias to mistake the tender painful groin lump for an abscess and incise it themselves. He found that these painful wounds with faecal fistulas required no more than cleaning and dressing. Often the wound would heal, nature preferring

to send the faeces along the natural route to the anus [72] (Fig. 1.10).

The Anatomical Era

The great contribution of the surgical anatomists was between the years 1750–1865 and was called the age of dissection [94]. The main contributors were Antonio Scarpa

Fig. 1.5 The visit of surgical patients in Chirurgia. Guy de Chauliac, fifteenth-century manuscript (from the Bibliothèque Nationale, Paris, France)

and Sir Astley Cooper and few major advances in our knowledge of the anatomy of the groin have been made since this time. The names of these great anatomists are Pieter, Camper, Adrian van der Spieghel, Antonio Scarpa (Fig. 1.11), Percival Pott, Sir Astley Cooper, John Hunter, Thomas Morton, Germaine Cloquet, Franz Hesselbach, Friedrich Henle and Don Antonio Gimbernat.

The Dutchman Camper was a polymath who described a fascia, which is sandwiched in between the skin and deep fascia and can only be separated from this fascia below the inguinal ligament where the space between them accommo-

dates lymph glands and cutaneous vessels of the groin. Below the external ring, Camper's fascia becomes the dartos muscle of the scrotum, which like the platysma is a muscle of the superficial fascia. Camper was the author of the definitive surgical text on hernia. Camper also contributed to anatomical descriptions of the foot, upper limb and axilla. His explanation of the aetiology of inguinal hernias significantly affected surgical practice at the time [109].

Adrian van der Spieghel (1578–1625) was educated at the University of Padua, and he occupied the chairs of anatomy at the University of Modena and later Pavia. He was Flemish

Fig. 1.6 Frontispiece and surgery instruments in Traités des Hernies (by Pierre Franco, Vincent, Lyon [61])

and another polymath. He was privileged to have two of the most accomplished anatomists of that period, Fabricius ab Aquapendente and Yulius Casserius, as his teachers. He first

described Spiegel's lobe (caudate lobe) of the liver and the linea semilunaris (Spiegel's line) on the lateral side of the rectus abdominis muscle. Spigelian hernia (lateral ventral

Fig. 1.7 Woman with femoral hernia. In Die Handschrift des Schmitt- und Augenartztes. Caspar Stromayr (by Walter von Brunn (1925))

Fig. 1.8 The dissection of the sac and cord in an indirect hernia, carried to the level of the internal ring (in von Brunn (1925))
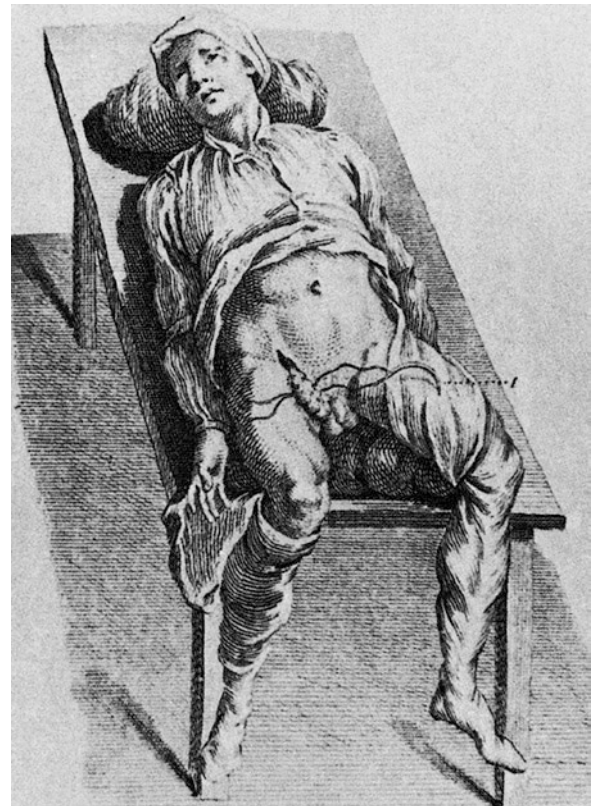
Fig. 1.9 Ligation of strangulated omentum in a strangulated right scrotal hernia. The wound then granulated. The patient survived and the hernia did not recur (operation by Cheselden in 1721 [7])

hernia) was named after him. He was a renowned physician in his time and was the first to give a detailed description of malaria. He made significant contributions as a botanist: the genus *Spigelia*, which has six species, is named after him [110].

Sir Percival Pott described the pathophysiology of strangulation in 1757 and recommended surgical management (Fig. 1.12): 'I am perfectly satisfied that the cause of strangulated hernia is most frequently a piece of intestine (in other respects sound and free of disease) being so bound by the said tendon, as to have its peristaltic motion and the circulation through it impeded or stopped' [86]. Pott was trained at St Bartholomew's Hospital and wrote the manuscript *A Treatise on Rupture*. This publication brought him into conflict with the Hunters who accused him of plagiarism for his description of congenital hernia, which they claimed to have described 2 years previously. He emphasized that the hernia sac was peritoneum continuous with the general peritoneal

Fig. 1.10 Development of a preternatural colon fistula (colostomy) after strangulation of an umbilical hernia. The wound was trimmed. The patient survived many years 'voiding' the excrements at the umbilicus (operation by Cheselden about 1721 [7])

Fig. 1.11 Antonio Scarpa (1752–1832) professor of surgery and anatomy in Pavia, Italy
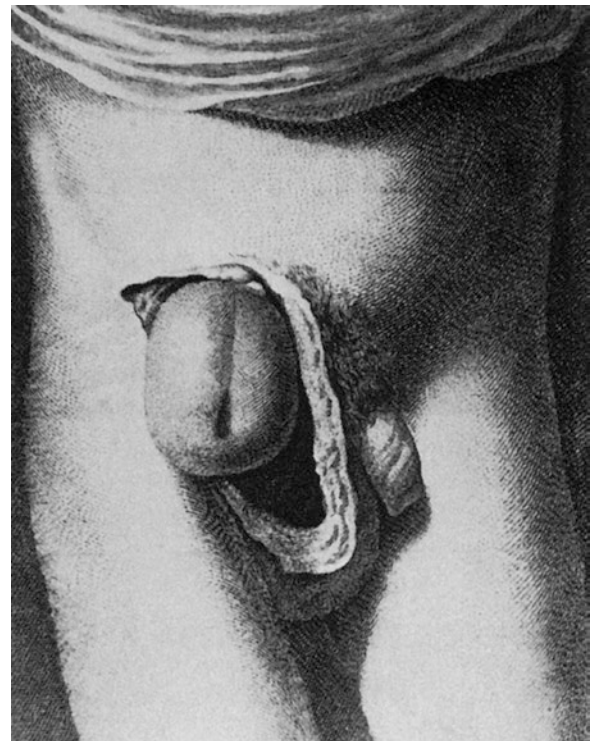
Fig. 1.12 Intestine strangulated by the 'tendon' so that the venous circulation through it is stopped, leading to gangrene (described by Pott in 1757 [9])

cavity and had not been in any way ruptured or broken, which until that time was the popular theory of causation of hernia.

Fifty years later Astley Cooper (Fig. 1.13) implicated venous obstruction as the first cascade in the circulatory failure of strangulation: 'By a stop being put to the return of blood through the veins which produces a great accumulation of this fluid and a change of its colour from the arterial to the venous hue.' Nevertheless ligature, the insertion of setons and castration remained the mainstays of treatment prior to the publication of Astley Cooper's monograph in 1804 [56] (Fig. 1.14). Sir Astley Cooper (1768–1841) trained at St Thomas' Hospital, London, and became a surgeon at Guy's Hospital and from 1813 to 1815 was Professor of Comparative Anatomy of the Royal College of Surgeons. Cooper published six magnificent books, two of which covered the subject of hernia, which were liberally illustrated by his own hand from dissections he had performed personally. Cooper was a charismatic lecturer and socialite and had an
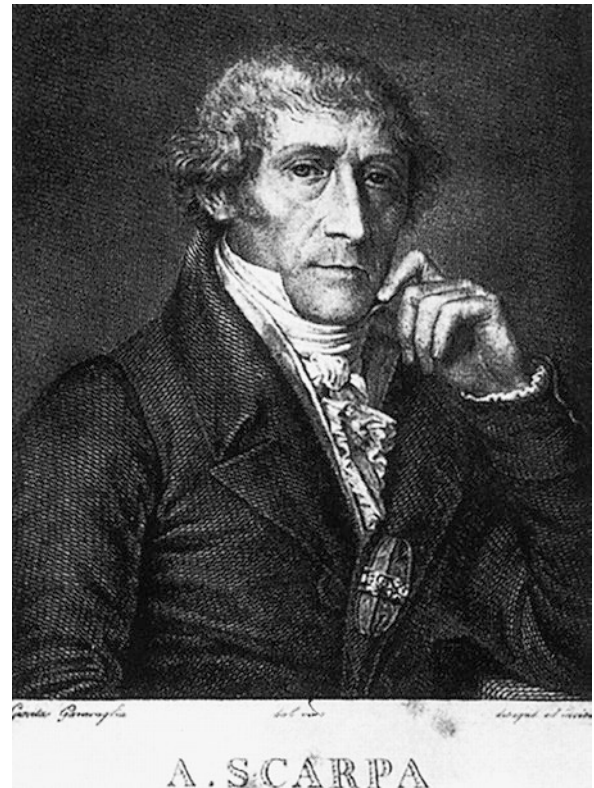
Fig. 1.13 Sir Astley Paston Cooper (1768–1841). Surgical anatomist, London, England

Fig. 1.14 Anatomy of the fascia transversalis. Cooper [56] demonstrated the fascia extending behind the inguinal ligament into the thigh to be the femoral sheath. He first recognized the fascia transversalis and its importance in groin herniation

extensive surgical practice, which included being sergeant surgeon to King George IV. Cooper's recognition of the transversalis fascia positions him as one of the most important contributors to present day surgery which emphasizes this layer as being the first layer to be breached in groin hernias.

John Hunter (1728–1793) was born in Glasgow but became a pupil at St Bartholomew's Hospital to Percival Pott and later served as a surgeon at St George's Hospital where he established his well-known anatomy lessons and later the Hunterian museum which is now housed in the Royal College of Surgeons of England. Hunter's contribution was to define the role of the gubernaculum testis that directed the descent of that organ with the spermatic vessels into the scrotum around the time of birth. Thomas Wharton (1813–1849) also a London surgeon working at the North London Hospital, in his short life wrote three anatomical texts, two of which were the subject of inguinal hernia and the groin. He first gave an accurate description of the conjoined tendon of the internal oblique and transversus muscles and their termination and attachment to the outer portion of the rectus sheath.

The first accurate description of the iliopubic tract, an important structure utilized in many sutured repairs for inguinal hernia, was made by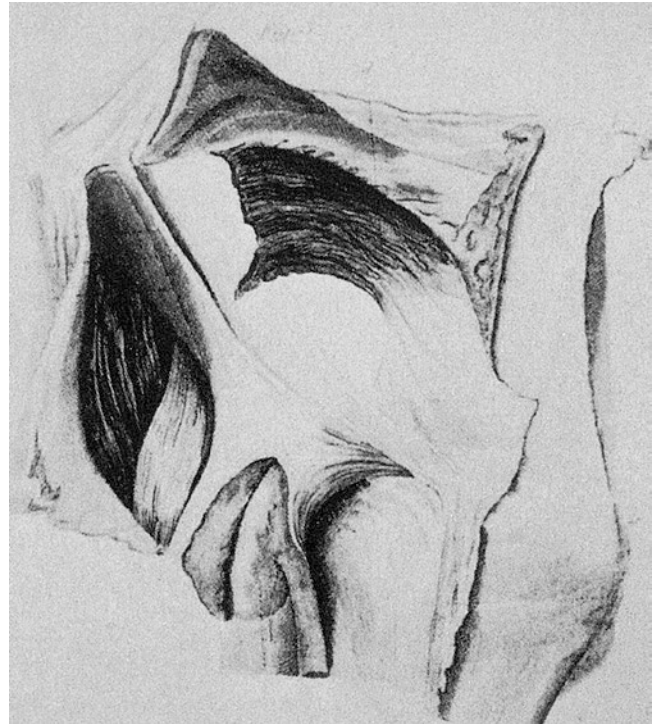 Jules Cloquet (1790–1883). Cloquet was Professor of Anatomy and Surgery in Paris and surgeon to the Emperor. Cloquet researched the pathological anatomy of the groin in numerous autopsy dissections and their reconstruction in wax models. He was the first to observe the frequency of patency of the processus vaginalis after birth and its role in the production of a hernia sac later in life. Franz Hesselbach was an anatomist at the University of Wurzburg who described the triangle now so important in laparoscopic surgery which originally defined the pathway of direct and external and supravesical hernias (Fig. 1.15). The triangle as defined today is somewhat smaller. Friedrich Henle (1809–1885) was another German latterly working in the University of Gottingen. Henle described an important ligament running from the lateral edge of the rectus sheath and fusing with the pectineal ligament. This structure when present could be utilized to anchor sutures in herniorrhaphy. Finally Don Antonio Gimbernat (1742–1790) was a Spanish surgeon working in Barcelona and also surgeon to King Charles III and President of the College of Surgeons of Spain. Gimbernat not only defined the lacunar ligament as a distinct anatomical structure but also showed how its division in strangulated femoral hernia was usually the point of obstruction and allowed reduction of the contents of the sac. His publication *Nuevo metodo de operar en la hernia crural* was translated from Spanish into English by Thomas Beddoe 2 years later with additional plates for his new method of operating on femoral hernia.

Fig. 1.15 The triangle of Hesselbach described in 1814, and as understood today. In Hernias (by Skandalakis et al. (1983))
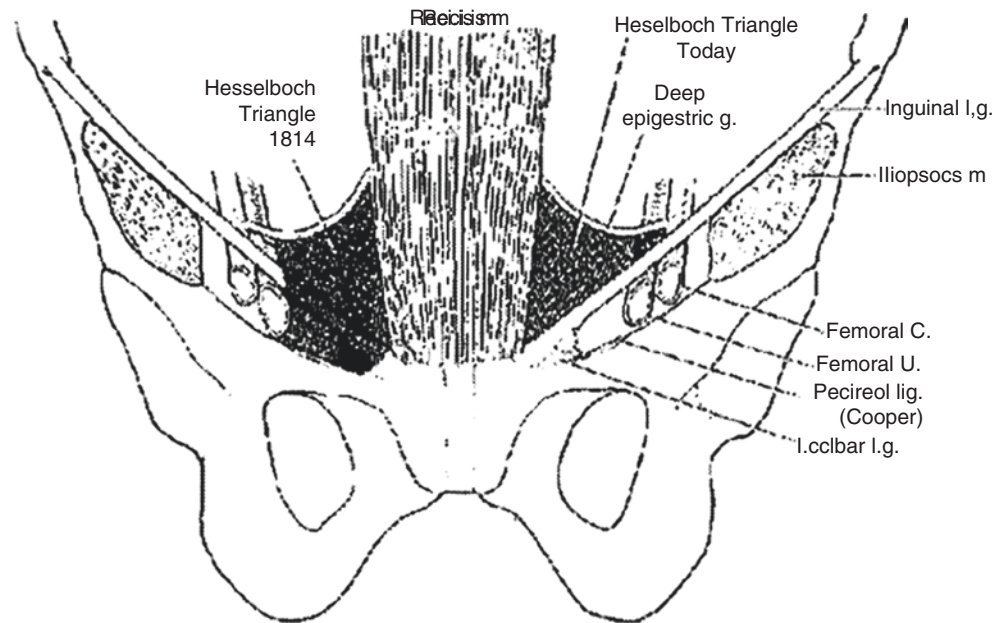
From his careful anatomical study in the inguinal region, he made a detailed description of the lacunar ligament, which John Hunter called Gimbernat's ligament in his honour. Gimbernat was also a radical surgical educator and health services innovator of the Enlightenment [111].

The Era of Antisepsis and Asepsis

Before bacteria were recognized and simultaneously the need for meticulous cleanliness in the environment of the operating theatre, postoperative sepsis was virtually routine and mortality rates extremely high. Oliver Wendell Holmes in 1842 and Semmelweiss in 1849 emphasized the importance of hand washing before operating. However, identifying and understanding the problem of infection and the causal bacteria, had to await the discoveries of Louis Pasteur which were later put into practice by Joseph Lister (1827–1912). The application of Lister's principles of providing clean linen and special coats, special receptacles for antiseptic dressings, cleansing sponges soaked in carbolic acid and thymol and the segregation of post-mortem examinations and operating theatres profoundly influenced British and European surgeons and decimated postoperative infection rates. Modern surgery commenced with Lister's discoveries [74].

Other important innovations were acquired before operative surgery presented a minimal danger to the patient. Ernst von Bergman invented the steam sterilizer in 1891 and introduced the word 'aseptic'. Halsted with the nurse Caroline Hampton introduced rubber gloves in 1896, and together with the introduction of a face mask by von Miculicz, the conversion from antiseptic to aseptic technique was finally set for the techniques of modern hernia surgery to develop [59].

The Dawn of Anaesthesia

The removal of pain during surgical operations not only eliminated the terror of the surgical operation from the patient but also enabled more careful anatomical dissection and reconstruction and the evolution of planned surgical procedures [94]. An American dentist Horace Wells pioneered the use of nitrous oxide as an anaesthetic, but his first public attempt at demonstrating a painless dental extraction was a failure. It was left to his associate William Thomas Green Morton to demonstrate the first successful anaesthetic using sulphuric ether in the theatre of the Massachusetts General Hospital in Boston. The operation on Edward Gilbert Abbott was for removal of a tumour angioma in the neck. Following this demonstration on 16 October 1846, the practice spread widely into Europe, and Listen in London used it for a thigh amputation on Frederick Churchill on 21 December 1846. With patients no longer fearing pain, the scene was set for the great technological advances of the second half of the nineteenth century.

The Technological Era

Initial surgical attempts at hernioplasty were based on static concepts of anatomic repair using natural or modified natural materials for reconstruction. Wood [103] described subcutaneous division and suture of the sac and fascial separation of the groin from the scrotum. Czerny (1876), in Prague, pulled the sac of an inguinal hernia through the external ring, ligated it, amputated the redundant sac and allowed the neck to spring back to the deep ring [57]. MacEwen [79], of Glasgow, bundled the sac up on itself and stuffed it back along the
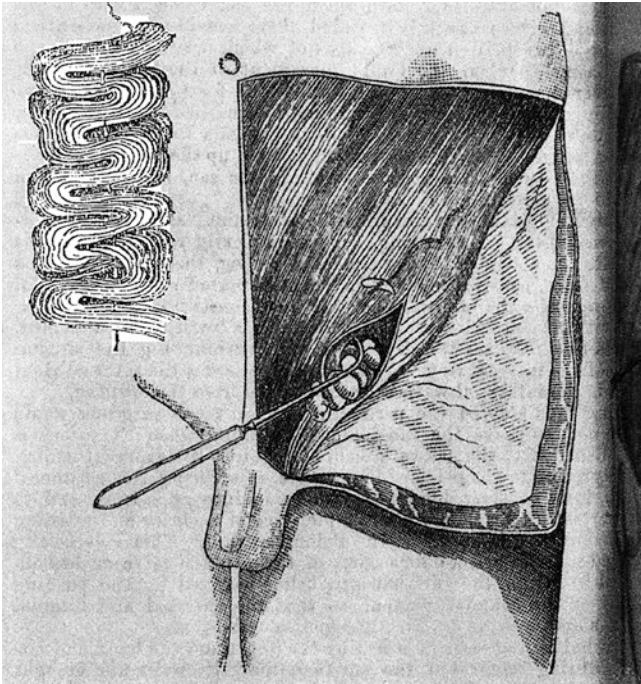
Fig. 1.16 The operation of McEwan 1886. The dissected indirect sac is bundled up and then used as an internal stopper or pad to prevent further herniation along the valved canal

canal so that it would act as a cork or tampon and stop up the internal ring (MacEwan 1886) (Fig. 1.16). Kocher [70], surgery's first Nobel Prize winner, invaginated the sac on itself and fixed it laterally through the external oblique [70] (Fig. 1.17). Suffice to say, none of these operations has stood the test of time.

As so often in surgery, a new concept was needed before further progress could be made in herniology. Two (Figs. 1.18 and 1.19) pioneers—the American Marcy [80] and the Italian Bassini (1884)—vie for priority for the critical breakthrough [46–48]. Both appreciated the physiology of the inguinal canal, and both correctly understood how each anatomic plane, the transversalis fascia, transverse and oblique muscles, and the external oblique aponeurosis, contributed to the canal's stability. Read, having carefully surveyed all the evidence, agrees with Halsted [65, 67] that Bassini got there first [89].

Although both contributed to herniology, Bassini made another seminal advance when he subjected his technique to the scrutiny of the prospective follow-up. The paper of Bassini [48] is truly a quantum leap in surgery; indeed, if it is read alongside the contribution of Haidenthaller, from Billroth's Clinic—reporting a 30%, early recurrence rate—which appears in the same volume of Langenbeck's Archiv fur Klinische Chirurgie, Bassini's stature is further enhanced [64].

Marcy directed his attention to the deep ring in the fascia transversalis; his operation for indirect inguinal hernia
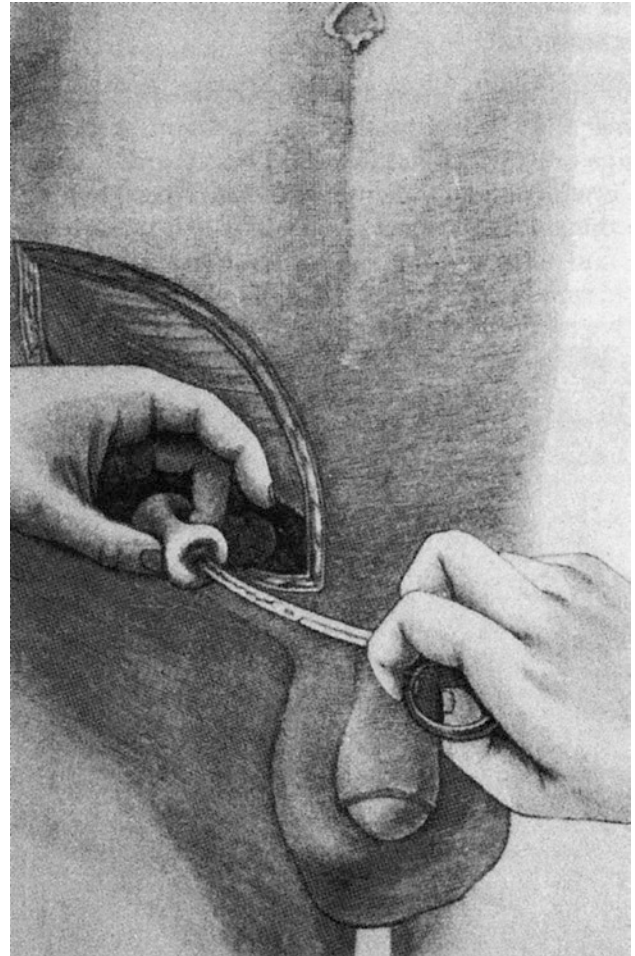
Fig. 1.17 Invagination of the sac which is fixed laterally by suturing its stump to the external oblique. No formal dissection or repair of the deep ring was made (operation by Kocher in 1907)

entailed closure of the deep ring with fascia transversalis only, the object being the recreation of a stable and competent deep ring. In 1871 he reported two patients operated on during the previous year 'in which I closed the (deep) ring with the interrupted sutures of carbolized catgut followed by permanent cure' [81].

Bassini had become interested in the management of inguinal hernia in about 1883, and from 1883 to 1889, he operated on 274 hernias. After trying the operations of Czerny and Wood, he modified his approach and attempted a radical cure, so that the patient would not require a truss after surgery. He decided to open the inguinal canal and approach the posterior wall of the canal; gradually he was focusing onto the deep ring and fascia transversalis. Seven times he opened the canal, resected the sac and closed the peritoneum at the internal ring. He then constructed a tampon of the excess sac at the internal ring and sutured this sac stump, or tampon, to the deep surface of the external oblique. One of his seven patients died 3 months after the operation from an unrelated cause. Post-mortem examination showed the

Fig. 1.18 Henry Orville Marcy (1837–1924), Boston surgeon, anatomist, and philanthropist. The first American student of Lister (courtesy of the New York Academy of Medicine Library)

Fig. 1.19 Edoardo Bassini (1844–1924) invented the first successful inguinal hernioplasty

sutured portion of the neck, the 'stopper' or tampon, to be completely reabsorbed. Bassini deduced that although the risk of recurrent herniation was diminished by this technique, it did not afford adequate tissue repair; and some external support—a truss—would still be needed to prevent recurrence. He now proceeded to complete anatomical reconstruction of the inguinal canal.

> This might be achieved through reconstruction of the inguinal canal into the physiological condition, a canal with two openings one abdominal the other subcutaneous and with two walls, one anterior and one posterior through the middle of which the spermatic cord would pass. Through a study of the groin, and with the help of an anatomical knowledge of the inguinal canal and inguinal hernia, it was easy for me to find an operative method, which answered the above described requirements, and made possible a radical cure without subsequent wearing of a truss. Using the method exclusively I have, during the year 1884, operated on 262 hernias of which 251 were either reducible or irreducible and 11 strangulated.

His series included 206 men and 10 women; the non-strangulated cases were 115 right, 66 left and 35 bilateral inguinal hernias. The age range was 13 months to 69 years. The operations were performed under general narcosis and there were no operative deaths; however, three patients who each had strangulated hernias died postoperatively—one of sepsis, one of shock and one of a chest infection. Bassini's patients were carefully followed up,

some to 4¾ years, and seven recurrences were recorded. There were, in fact, eight recurrences; Bassini failed to tabulate case 65, a 54-year-old university professor in Padua with a strangulated right direct inguinal hernia, with a recurrence at 8 months. The wound infection rate was 11 in 206 operations, and the time to healing averaged 14 days [48]. These statistics compare favourably with reports made up to the 1950s.

Bassini dissected the indirect sac and closed it off flush with the parietal peritoneum. He then isolated and lifted up the spermatic cord and dissected the posterior wall of the canal, dividing the fascia transversalis down to the pubic tubercle. He then sutured the dissected conjoint tendon consisting of the internal oblique, the transversus muscle and the 'vertical fascia of Cooper', the fascia transversalis, to the posterior rim of Poupart's ligament, including the lower lateral divided margin of the fascia transversalis. Bassini stresses that this suture line must be approximated without difficulty; hence the early dissection separating the external oblique from the internal oblique must be adequate and allow good development and mobilization of the conjoint tendon (Fig. 1.20).

Fig. 1.20 Suturing the 'triple layer' (F) (fascia transversalis, transversus tendon and internal oblique) to the upturned edge of the inguinal ligament. An anatomical and physiological repair of the posterior wall of the inguinal canal preserving its obliquity and function (operation by Bassini in 1890 [20])
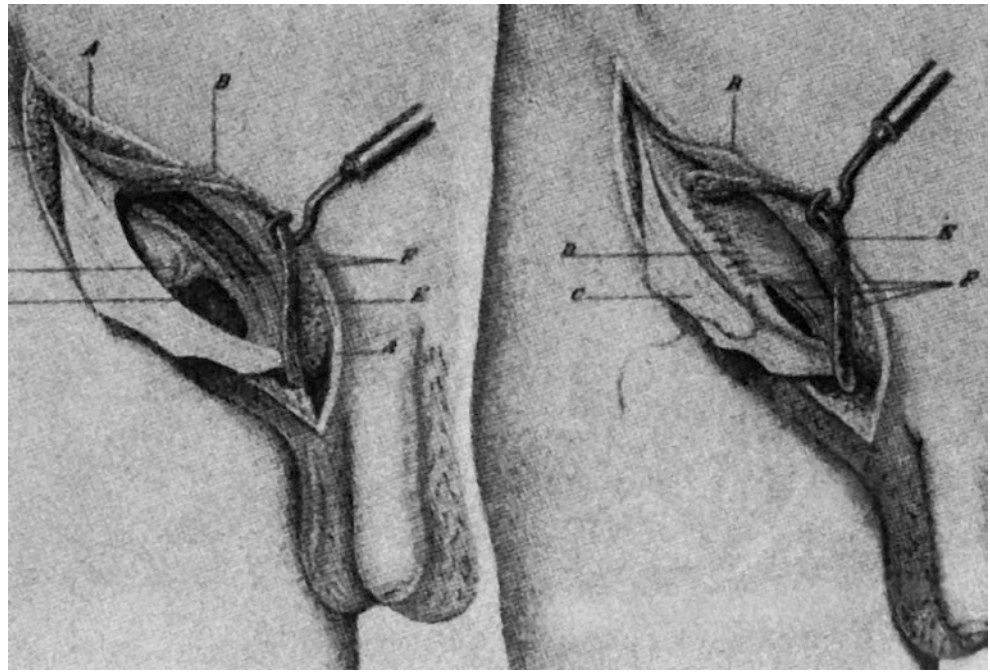
The Bassini legacy was popularized by Attilio Catterina, Bassini's assistant in Padua in 1887 who later became professor in Genoa in 1904. Catterina was entrusted by Bassini to teach the exact surgical technique. To do this he wrote an atlas of *The Operation of Bassini*! This adds 16 life-sized colour plates by the artist Orazio Gaicher of Cortina. This book was published in London, Berlin, Paris and Madrid in the 1930s and described in detail the uncorrupted Bassini technique, especially the division of the transversalis fascia, resection of the cremaster muscle and complete anatomical survey of all the relevant anatomy nowadays considered so essential [50, 51]. This represented a foretaste of the Shouldice operation [99, 100]. The illustrations show quite clearly that Bassini resected the cremaster muscle (Fig. 1.21) and completed division of the posterior wall of the inguinal canal (Fig. 1.22). The Shouldice and Bassini hernioplasties are therefore essentially the same.

By contrast, Haidenthaller, from Billroth's Clinic in Vienna, reported 195 operations for inguinal hernia, with 11 operative deaths and a short-term recurrence rate of 30.8% [64]. Although Halsted made important contributions to herniology, his general technical contributions of precise haemostasis, absolute asepsis and the crucial importance of avoiding tissue trauma are easily overlooked. Halsted was always concerned to achieve optimum wound healing, and he not only practiced surgery but he experimented and theorized. His observation on closing skin wounds is best repeated verbatim: 'The skin is united by interrupted stitches of very fine silk. These stitches do not penetrate the skin, and when tied they become buried. They are taken from the underside of the skin and made to include only its deeper layers—the layers which are not occupied by sebaceous follicles' [65–68]. In today's world haematoma, sepsis and damaged tissue leading to delayed healing mean not only a poor surgical outcome but weigh heavily on the debit side of any economic evaluation. These Halstedian principles should be rigidly applied by any surgeon who undertakes hernia surgery.

Halsted must also be given priority for recognizing the value of an anterior relaxing incision, first described by Wolfler in 1892 [102] and subsequently popularized in the USA by Rienhoff [90] and in England by Tanner [98]. Apart from Halsted, countless other authors have corrupted or simplified the original Marcy-Bassini concept of a review of the posterior wall of the canal and the correction of any deficits in it, the reconstruction of the patulous deep ring for indirect herniation and the repair of the stretched fascia transversalis in cases of direct herniation. Bull and Coley independently sutured the internal oblique and the aponeurosis over the cord [49, 55], whereas Ferguson [60] advised against any mobilization of the cord and, therefore, any review of the posterior wall of the canal: Ferguson [60].

Imbrication, or overlapping, of layers was introduced by Wyllys Andrews in 1895 in Chicago [43]. Andrews confessed that his technique was an outgrowth of experience with MacEwan, Bassini, Halsted and similar operations. Andrews laid great stress on careful aseptic technique: 'Finally, I unite the skin itself with a buried suture which does not puncture any of its glands or ducts'. Andrews used cotyledon only as a dressing. Again the importance of careful surgical technique is emphasized. Andrews stressed the importance of the posterior wall of the canal: 'The posterior
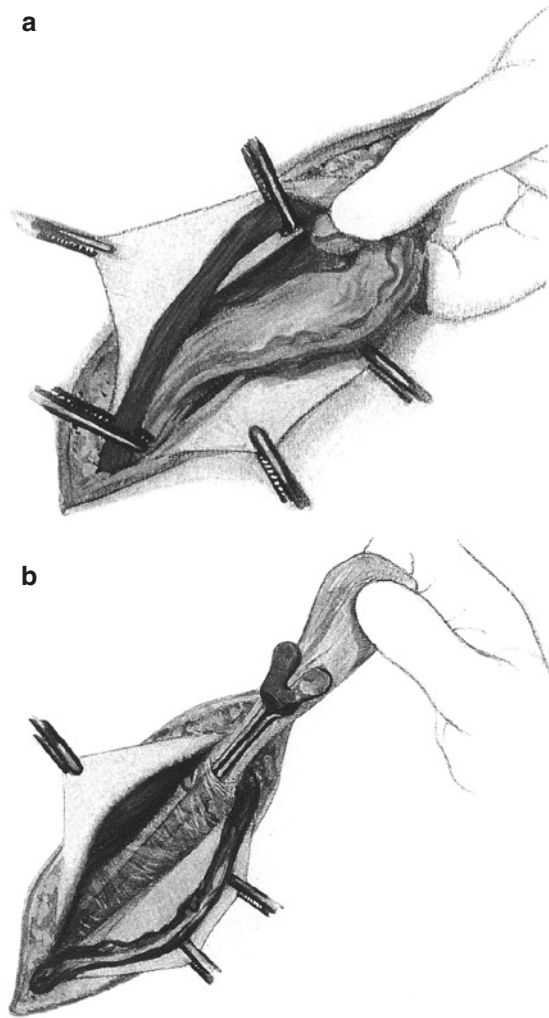
a

b

Fig. 1.21 (**a**) Bassini completely isolated and excised the cremaster muscle and its fascia from the cord. He thus ensured complete exposure of the deep ring and all the posterior wall of the inguinal canal, an essential prerequisite to evaluate all the potential hernial sites. (**b**) Bassini stressed the complete exposure and incision of the fascia transversalis of the posterior wall of the inguinal canal. To complete the repair, he sutured the divided fascia transversalis, together with the transversus muscle, and the internal oblique muscle, 'the threefold layer', to the upturned inner free margin of the inguinal ligament [24]

wall of the canal is narrowed by suturing the conjoined tendon and transversalis fascia firmly to Poupart's ligament'. Andrews recommended the kangaroo tendon introduced by Marcy. Andrews then reinforced the posterior wall with the upper (medial) margin of the external oblique aponeurosis, which he drew down behind the cord and sutured to Poupart's ligament. Andrews' intention was to interlock or imbricate the layers. The lower (lateral) flap of the external oblique aponeurosis was then brought up anterior to the cord. Andrews concluded his article: 'Any successful method of radical cure must be a true plastic operation upon the musculo-aponeurotic layers of the abdominal wall. Cicatricial tissue and peritoneal exudate are of no permanent
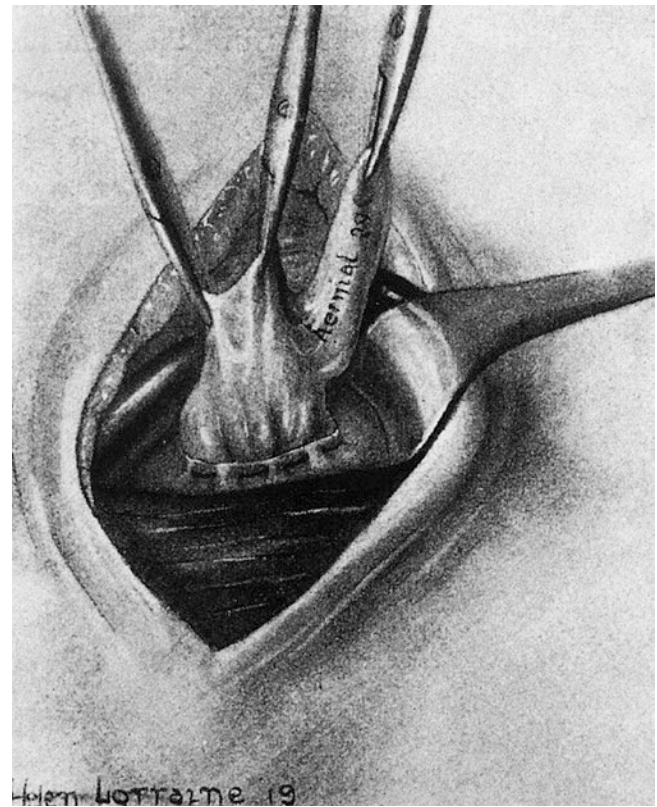
Fig. 1.22 Transabdominal approach to the groin through a muscle-splitting incision above the inguinal canal with subsequent closure of the peritoneal sac away from the canal

value'. Andrews had visited Bassini in Padua on several occasions to acquaint himself with the revolutionary operation. However, in his future descriptions of the operation, Andrews failed to mention that Bassini had divided the posterior wall of the inguinal canal, and these erroneous observations were passed on to a generation of European and American surgeons because Catterina's atlas was not published in Europe until the 1930s. Andrews description of Bassini's operation was therefore the only definitive description and the classical Bassini operation became corrupted until it was reintroduced as the Shouldice operation in the 1950s.

Perhaps we should pause at about 1905 and summarize what empiricism had achieved thus far. First, all authors agree that division of the neck of the sac and flush closure of the peritoneum is imperative to success. Second, dissection of the deep ring with exploration of the extraperitoneal space to allow adequate closure of the fascia transversalis anterior to the peritoneum emerges as a cardinal feature. Marcy and Bassini stress the fascia transversalis repair, Halsted emphasized it, and Andrews' diagram suggests it. Ferguson did not examine the entire posterior wall, but tightened the internal ring lateral to the emergent cord. All are agreed that the deep ring is patulous in indirect herniation, and consequently the

fascia transversalis must be repaired. In the English literature, Lockwood in 1893 clearly emphasized the fascia transversalis and Bassini's 'triple layer'. Lockwood obtained good results by repairing this important layer [75, 76]. Third, preservation of the obliquity of the canal is suggested by Marcy and Bassini, and by the later Halsted and Bloodgood papers.

Fourth, double breasting (imbrication) of aponeurosis gives improved results and is recommended by Andrews. Lastly, all the authors stress careful technique. Avoidance of tissue trauma, haematoma and infection leads to impressively better results. Sepsis is an important antecedent of recurrence.

After the nineteenth-century advances of Marcy and Bassini, and the important contribution to surgical technique by Halsted, little of major importance was contributed until the 1920s. Countless modifications of Marcy's and Bassini's operations were made and reported frequently. The Bassini operation re-emerged as the Shouldice repair in 1950s (Fig. 1.23). Earl Shouldice (1890–1965) also promulgated the benefits of early ambulation and opened the Shouldice Clinic, a hospital dedicated to the repair of hernias to the abdominal wall. A huge experience accumulated with an annual thro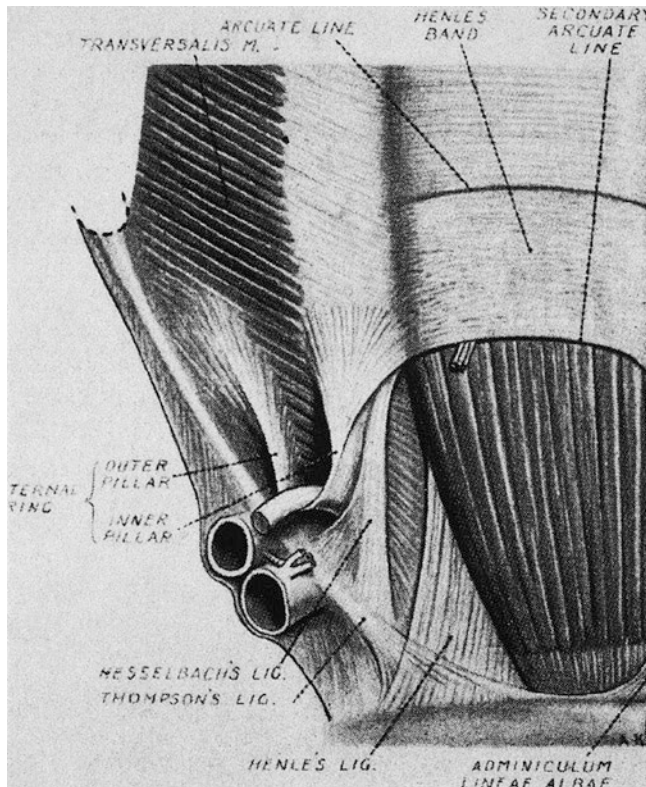ughput of 7000 herniorrhaphies per year enabled the surgeons at the Shouldice Clinic to study the pathology in primary and recurrent hernias and to emphasize adjuncts to successful outcomes. Continuous monofilament wire was used in preference to other suture materials, and the hernioplasty incorporated repair of the internal ring, the posterior wall of the inguinal canal and the femoral region. The cremaster muscle and fascia with vessels and genital branch of genitofemoral nerve were removed, and the posterior wall after division was repaired by a four-layer imbrication method using the iliopubic tract as its main anchor point. The landmark publication with long-term follow-up was produced by Shearburn and Myers in 1969, and from this time until the introduction of mesh, the Shouldice operation became the gold standard for inguinal hernia repair [92].

The Extraperitoneal: Preperitoneal Approach to the Groin

Alternatives to the anterior (inguinal) approach to the internal ring include the transabdominal (laparotomy) [71, 97] and the extraperitoneal (preperitoneal) [52]. Marcy recognized the advantages of the transabdominal intraperitoneal approach to the ring in 1892:

> It may rarely happen to the operator who has opened the abdomen for some other purpose to find the complication of hernia. When the section has been made considerably large, as in the removal of a large tumour; the internal ring is within reach of the surgeon. Upon reflection, it would naturally occur to any operator that under these conditions it is better to close the internal ring, and reform the smooth internal parietal surface from within by means of suturing. My friend, Dr. N. Bozeman of New York, easily did this at my suggestion in a case of ovariotomy more than 10 years ago.

Marcy attributed the transabdominal technique to the French in 1749 [82]. Lawson Tait recommended midline abdominal section for umbilical and groin hernia in 1891 [97]. LaRoque, in 1919, recommended transabdominal repair of inguinal hernias through a muscle-splitting incision about 1 in. (2.5 cm) above the ring. The peritoneum was opened, the sac dissected and then inverted into the peritoneal cavity by grasping its fundus and pulling it back into the peritoneal cavity. The sac was excised and a repair of the deep ring effected [71] (Fig. 1.24). LaRoque believed that the transabdominal approach provided absolute assurance of high ligation of the hernia sac and wrote three papers with accumulative experience of almost 2000 inguinal hernia repairs [91].

Battle, a surgeon at St Thomas' Hospital, London and the Royal Free Hospital, described his approach to repair of a femoral hernia in 1900. Battle pointed out the difficulties of diagnosing femoral hernia and the difficulties, principally the age, sex and comorbidity, of managing patients with femoral hernia. He approached the hernia sac from above through

Fig. 1.23 The 'shutter mechanism' of canal and the internal anatomy of the deep ring, demonstrating the sling of fascia transversalis which pulls the deep ring up and laterally when the patient strains [50]

Fig. 1.24 (**a**) Fruchaud's concept of the myopectineal orifice ("l'orifice crural classique") incorporating the inguinal and the femoral canals. An external view showing the two canals separated by the inguinal ligament and internal dissection (**b**) demonstrating how the muscles of the groin form a tunnel down to the myopectineal orifice [51]
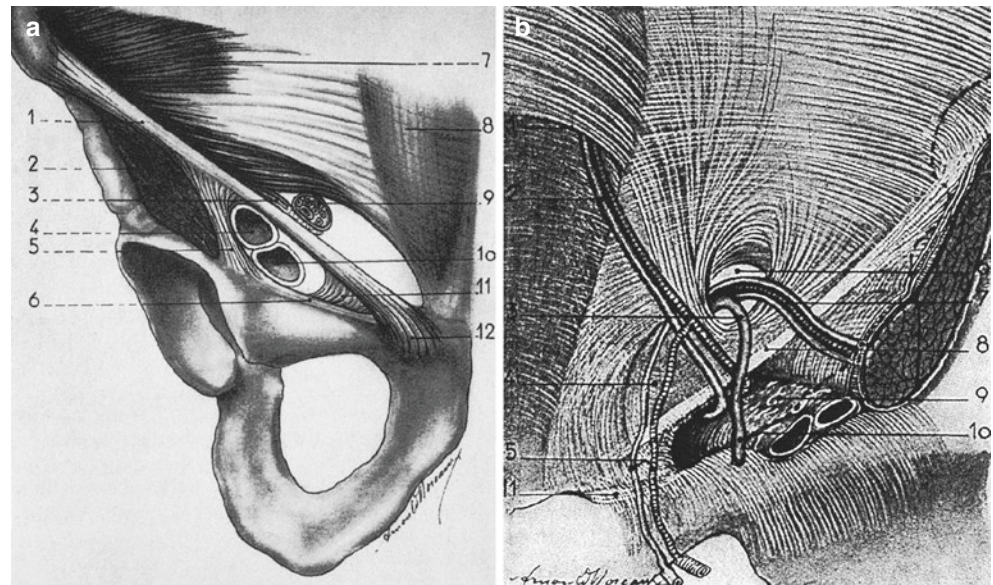
an incision splitting the external oblique above the inguinal ligament. After dealing with the peritoneal sac, Battle repaired the femoral canal, constructing a 'shutter' of the aponeurosis of external oblique which he sutured to the pectineus fascia and the pectineal ligament across the abdominal opening of the femoral canal [45, 91]. The Battle operation like many operations for groin hernia has now passed into oblivion.

The extraperitoneal-preperitoneal approach owes its origin to Cheatle [52] who initially used a midline incision but subsequently (1921) changed to a Pfannenstiel incision [52, 53]. Cheatle explored both sides, and inguinal and femoral protrusions were reduced and amputated. If needed, for strangulation or adhesions, the peritoneum could easily be opened. The fascia transversalis was visible and easily repaired. Cheatle advised against this approach for direct hernia because the direct region was usually obscured and distorted by the retraction of the rectus muscles. However, Cheatle's landmark contribution had a minimal impact at the time and remained little used for many years [91].

A.K. Henry, a master anatomist, rediscovered and popularized the extraperitoneal approach in 1936 [69]. At this time he was the Director of the Surgical Unit, Kasr-el-Aini Hospital and Professor of Clinical Surgery in the University of Cairo although he later returned to the Hammersmith Hospital and subsequently became Professor of Anatomy at the Royal College of Surgeons in Ireland. The full impact of the Cheatle/Henry operation was not recognized until after the Second World War, when McEvedy [83], adopted a unilateral oblique incision retracting the rectus muscle medially to approach a femoral hernia. In the USA, Musgrove and McCready [85] adopted the Henry approach to femoral hernia [85]. Mikkelsen and Berne [84] reported inguinal and femoral hernias repaired by this technique and commended

the excellent access obtained even in the obese. Furthermore, femoral, inguinal and obturator hernias were all repairable through this 'extended suprapubic approach' [84].

Two Europeans: Lytle and Fruchaud

In the immediate aftermath of the Second World War, two European surgeon anatomists, Lytle and Fruchaud, are important contributors. Lytle was principally concerned with the anatomy and shutter mechanism of the deep inguinal ring. He dissected the deep ring and in a remarkable film demonstrated its prophylactic mechanism in indirect herniation. He was concerned to preserve the mechanism of the ring and at the same time to reinforce its patulous medial margin in indirect herniation. He emphasized that manoeuvres which damaged the lateral 'pillars of the ring' inevitably compromised the physiological shutter mechanism. In a subsequent study, he clearly described the embryological anatomy of the ring and how it could be repaired, in the fascia transversalis layer, without losing its function [78] (Fig. 1.25).

A remarkable Frenchman, Henri Fruchaud, published two books in Paris in 1956: *L'Anatomie Chirurgicale de la Region de l'Aine* (Surgical Anatomy of the Groin Region) [62, 63] and *Le Traitement Chirurgical des Hernies de l'Aine* (Surgical Treatment of Groin Hernias) [62, 63]. Fruchaud combined traditional anatomical studies of the groin, the work of Cooper, Bogros and Madden, with his own extensive anatomical and surgical experience. He invented an entirely new concept—'the myopectineal orifice'—which combined the traditionally separate inguinal and femoral canals to form a unified highway from the abdomen to the thigh. The abdominocrural tunnel of fascia
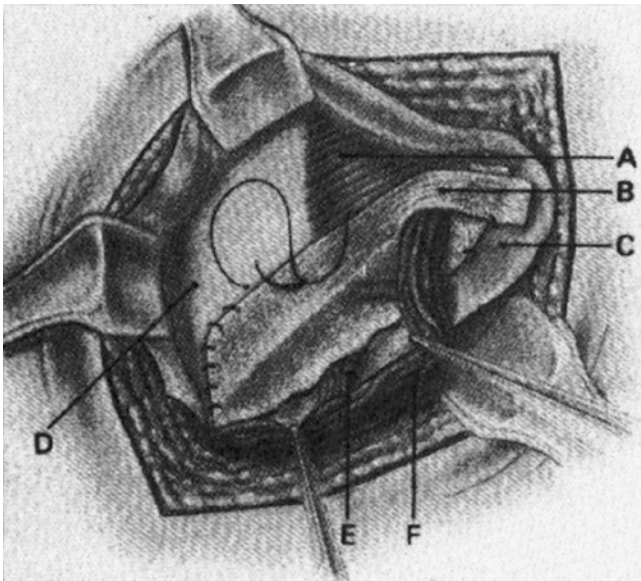
Fig. 1.25 The Lichtenstein's tension-free hernioplasty [150]

transversalis extended through this myopectineal orifice, through which all inguinal and femoral hernias pass, as do the iliofemoral vessels. Based on this anatomical concept, Fruchaud recommended complete reconstruction of the endo-fascial wall (fascia transversalis) of the myopectineal orifice. This unifying concept forms the basis for all extra-peritoneal mesh repairs, open or laparoscopic, of groin hernias (Fig. 1.26). Fruchaud's two books were never published in English (until recently by Bendavid), and therefore his findings remained relatively obscure and did not have the full impact and recognition until the laparoscopic era of hernia repair [94]. The concept of Fruchaud has been expanded by Stoppa in France and Wantz in the USA into the 'giant reinforcement of the peritoneal sac' repairs of inguinal hernias [95, 99–101].

Inguinal Hernias in Soldiers in Georgian England

Hernias in England during the Georgian period of the early eighteenth century were prevalent amongst servicemen typically recruited from amongst the malnourished. Civilian medical practice had deemed the rupture incurable consequently taking a palliative approach. For the military this was unacceptable; wastage rates due to ruptures were high and servicemen were valuable commodities. Treatment (experimentation) was a contentious activity relying on the whim of patronage and wartime budgets. Two clinical trials with the War Office funding were carried out between 1721 (Grenton) and 1770 (Lee) and were eventually exposed as ineffectual and 'polemic doggerel and quackery'.
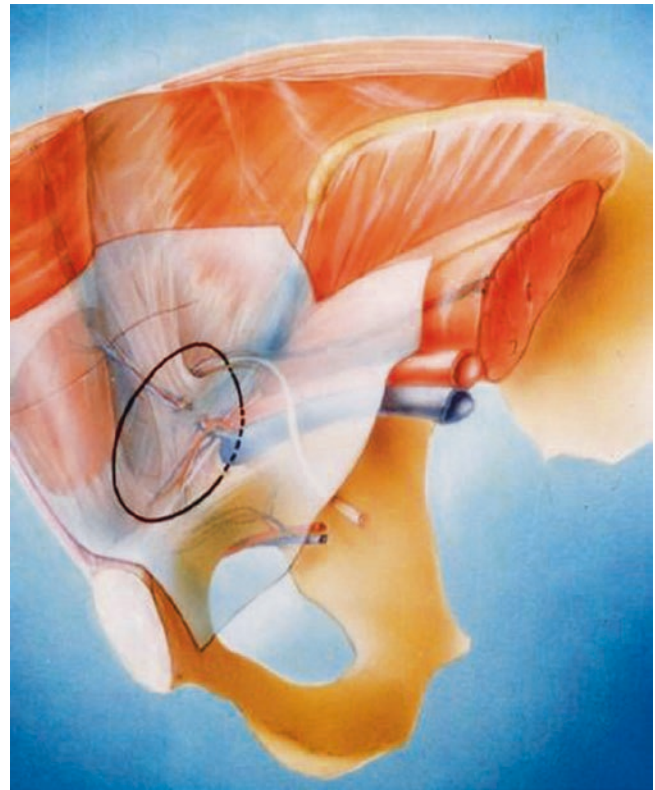
Fig. 1.26 Myopectineal orifice of Fruchaud

The four major characteristics of eighteenth-century hernia treatment in Britain were as follows:

1. It was considered an unmanly ailment that questioned the virility and general health of the afflicted.
2. Hernia was a chronic disorder only to be managed by palliative nonoperative procedures.
3. Most hernias were inguinal.
4. Afflicted males were poor and usually labourers.

In 1776, Dr. George Carlisle reported biographical and autopsy details of an ex-serviceman, John Hollowday, who died of natural causes aged approximately 80 years with a massive inguinoscrotal hernia stretching down to his knees (Figure). Such a hernia was apparently not an uncommon finding in ex-military men, and Hollowday had initially concealed the hernia 'to avoid the scoffs of his companions'. The hernia increased in size until Hollowday was adjudged unfit to serve, and he was admitted as an out-pensioner to the Royal Hospital Chelsea in 1725 whilst still in his mid-30s. Neglected hernias such as these can now only be found in third-world countries such as Africa.

Radical cures for hernia in the eighteenth century included escharotics (a caustic seal of the inguinal rings with scar tissue), castration (the skin was used to close the opening) and

trusses (after reduction of the hernia) which were of multiple types and military trusses were mass produced. To treat this massive problem of hernia, a rupture hospital (voluntary) was opened in Greenwich in 1756 but which only stayed open until 1765.

The exact number and rate of hernia occurrences in the Georgian British Army is unknown. However, the periodically malnourished, diseased and constipated, occasionally physically overworked and perpetually unfit British troops manning camps and barracks ringing with hacking smokers' coughs and a distinctive short consumptive bark may be a gross characterisation, but we should not detract from the fact that the underlying causes of hernia were endemic characteristics of eighteenth-century soldiers and soldiering. To counter this debilitating disorder, the Army required an efficacious cure that conventional therapeutics could not deliver. But even though patronage was directly responsible for the establishment of a preferred treatment in a military hospital, the management of rupture slipped back into the margins of military and medical consciousness. The cure for inguinal hernia had to wait for at least another 100 years.

A Royal Rupture

Caroline of Ansbach had married Prince George Augustus of Hanover in 1705, becoming Princess of Wales in 1714 when the British throne passed from the Stuart Queen Anne to Caroline's father-in-law, George I. It would be another 13 years before Caroline and her husband came to the throne themselves, but already their lives acquired greater political significance. They helped to define the character and the promise of Britain's new Hanoverian dynasty and guaranteed the future of the Hanoverian line. The physical health of Caroline and her husband could be seen as underwriting the nation's new succession.

Caroline was a model of good motherhood. Seven of her children (two boys and five girls) survived into adulthood. She was celebrated for breastfeeding her children. Even her adventurous decision to inoculate the princes and princesses for smallpox—a highly controversial parenting choice in the 1720s—ultimately contributed to an image of Caroline as a caring forward-thinking mother. She also became a queen with an important political role, even acting a Regent during her husband's long visits to Hanover. This in turn had an impact on the way that her general health was perceived, and the potential threat to political stability should she die prematurely.

There was intense, daily media speculation about Caroline's health. The details of the days leading up to the eventual strangulation of the hernia and the ensuing events were recorded by her husband's vice-chamberlain, Lord Hervey. Since the birth of her youngest daughter Louisa, 12 years previously Caroline had an umbilical hernia, which she had kept secret from all but a few close confidantes. Even her husband, though was aware of the hernia, was encouraged to disregard it as a minor nuisance. Her first recorded symptoms, some months previously, had arisen as she inspected one of her favourite projects, a library testifying to her intellectual aspirations. Yet the manner in which she would soon resort to quack cordials and conceal the true nature of her infirmity. On Wednesday, 9 November 1737, Caroline experienced severe abdominal pain, the first clear sign that the hernia had become strangulated. However, the increasingly numerous doctors were not allowed a thorough examination for fear of letting out her secret. When they did attend, they suggested the standard remedies of bleeding, blisters, elixirs, enemas and laxatives.

The true cause of Caroline's mounting intestinal obstruction was only discovered on Saturday, 12 November, when the king finally broke his silence and ordered his House Surgeon, John Ranby, to examine the queen's abdomen. After consultation between Ranby and the other doctors, the decision was taken to lance the incarcerated hernia. During the night of 12 November, the wound was again inspected, the doctors observing the 'signs of a mortification' and determining that there could be hardly any hope of recovery. In spite of this, the queen survived for another week. Her strangulated bowel ruptured on Thursday, 17 November, covering the bed and floor with what Hervey described as 'immense quantities of excrement'. On Sunday, 20 November, with most of her family near her, the queen died.

The public account of the duration and nature of Caroline's sufferings were downplayed, since they were not in keeping with the wholesome and robust image of Hanoverian royalty that had been propagated as part of Britain's new constitutional settlement. The image needed to be qualified. Alured Clarke, the Dean of Exeter and later founder of the Royal Devon and Exeter Hospital, epitomised a new emphasis on fortitude as Caroline's most admirable characteristic. Other English and Latin eulogies printed after her death repeatedly return to her prolonged ordeal as confirming her nobility rather than detracting from it.

Caroline's strangulated hernia was no more a private condition than the notorious madness of her grandson, George III would be. It was a subject for debate and discussion, but more than that, it was also an encouragement to consider anxieties and contradictions in the prospect of public discussion itself. In Hervey's opinion, the medical establishment had failed his friend, the queen [112].

Winston Churchill's Hernia Repair

Schein and Rodgers reported an interesting vignette of Winston Churchill's hernia repair in 1947. On an early summer morning, June 11, in a small private nursing home on Berwick Street, London, within walking distance of Harley Street, the 73-year-old Winston Churchill had his inguinal hernia repaired by Thomas Dunhill who was only 2 years younger than his patient. Both elderly gentleman, the patient and his surgeon, were rather short in stature, grey haired and balding, but the patient was corpulent and stocky and his surgeon was lean and agile.

Dunhill was described by his colleagues, as 'modest, courteous, professionally correct and of complete intellectual integrity'. He was a master surgeon being appointed to the Royal household in 1928 and in 1930 as honorary surgeon to King George V and later to King Edward VIII and King George VI. In 1935, on his 60th birthday, Dunhill retired from the staff of St Bartholomew's Hospital and engaged in a flourishing private practice at No 54 Harley Street. He was born and educated in Australia and after qualifying in medicine came to London as first assistant to Professor George Gask at the new Professorial Unit at the University of London at St Bartholomew's Hospital. In 1939, he was awarded an honorary FRCS England, the first time this title had been bestowed on a surgeon who was in active practice.

Winston Churchill first became aware of his hernia on 5 September 1945, writing to his wife Clementine that he had recently ruptured himself and developed a painless swelling and would have to be fitted with a truss. He was consulted by Lord Moran, long-time president of the Royal College of Physicians who in turn consulted Brigadier Edwards the consulting surgeon for the army in Italy who advised that Churchill should buy a truss in Milan.

For almost 2 years, nothing was heard about Churchill's hernia until in June 1947 in Moran's diaries, it is reported that the hernia was now much larger, it had been increasingly difficult to control with a truss and it was hardly ever out of his mind. Thomas Dunhill has been selected as the prospective surgeon.

Churchill's habits of smoking cigars and alcohol consumption were well known, and he undoubtedly suffered from chronic obstructive airway disease and obesity. The operation would therefore have been challenging.

On the morning of the operation Churchill was found in bed reading loudly from Thomas Babbington McCauley's essays. The operation was performed under general anaesthesia, presumably ether, and lasted for more than 2 h. The type of hernia and the method of repair were unknown but were probably a type of Bassini procedure. Postoperative recovery was uneventful with the patient experiencing little discomfort.

Dunhill's herniorrhaphy proved successful and durable for Churchill's groin remained asymptomatic for the next 17.5 years until his death. Dunhill stopped operating in 1949 when he had only three patients left, 'The King (George VI), Queen Mary and Winston Churchill'.

Fig. 1.27 Drs. Shulman, Lichtenstein and Amid, pioneers at the Lichtenstein Clinic

Tension-Free Hernia Repair

Irving Lichtenstein is the seminal thinker who introduced tension-free prosthetic repair of groin hernias into everyday, commonplace, outpatient practices. As well as being an office procedure under local anaesthetic, Lichtenstein pioneered the idea that hernia surgery is special, that it must be performed by an experienced surgeon and cannot be relegated to the unsupervised trainee doing 'minor' surgery. The key feature of Lichtenstein's technique is the 'tensionless' operation. With his co-workers Shulman and Amid, he has developed a simple prosthetic operation, which can be performed on outpatients [44, 73] (Fig. 1.27). As a pioneer, Lichtenstein worked hard to promulgate his ideas but even so the first edition of his book *Hernia Repair Without Disability* written in 1970 sold rather poorly and never went beyond the first printing [91]. Subsequent additions, however, required numerous reprints to meet demand paralleling the increase in popularity and worldwide success of the mesh-patch repair devised by Lichtenstein.

Mesh Technology (See Chap. 20)

Mesh hernioplasty would not have been possible without the pioneering engineering work of Karl Ziegler and the clinical research and development of Francis Usher [113].

Laparoscopic Repair

Laparoscopic repair continues to develop its place in the surgical armamentarium of inguinal hernia. The use of the laparoscope has been extended to repair incisional, ventral, lumbar, and paracolostomy hernias. This latter technique is rapidly gaining in popularity.

The first attempt to treat an inguinal hernia with the laparoscope was made by P. Fletcher of the University of the West Indies in 1979 [19]. He closed the neck of the hernia sac. The first report of the use of a clip (Michel) placed laparoscopically to close the neck of the sac was made by Ger in 1982, who reported a series of 13 patients: all the patients in this series were repaired through an open incision except the 13th patient who was repaired under laparoscopic guidance with a special stapling device. The 3-year follow-up of that patient revealed him to be free of an identifiable recurrence. Ger continued his efforts to repair these hernias laparoscopically. He reported the closure of the neck of the hernia sac using a prototypical instrument called the 'Herniostat' in beagle dogs [20]. The results in these models appeared to be promising. In that same article, he reported the potential benefits of the laparoscopic approach to groin hernia repair as: (1) creation of puncture wounds rather than formal incisions,

(2) need for minimal dissection, (3) less danger of spermatic cord injury and less risk of ischaemic orchitis, (4) minimal risk of bladder injury, (5) decreased incidence of neuralgias, (6) possibility of an outpatient procedure, (7) ability to achieve the highest possible ligation of the hernial sac, (8) minimal postoperative discomfort and a faster recovery time, (9) ability to perform simultaneous diagnostic laparoscopy, and (10) ability to diagnose and treat bilateral inguinal hernias. These potential advantages and advances in the laparoscopic repair of hernias continue to be the recognized goals that each method is attempting to achieve.

Bogojavalensky, a gynecologist, presented the first known use of a prosthetic biomaterial in the laparoscopic repair of inguinal and femoral hernias in 1989 [4]. He placed a roll of polypropylene mesh into indirect hernias of female patients. The neck of the internal inguinal ring was then closed with sutures. Popp repaired a coincidental direct hernia that was found at the time of a uterine myomectomy [35]. He recognized the need to provide coverage of a wider area than that of the defect itself. To accomplish this, he placed a 4 × 5-cm oval dehydrated dura mater patch over the defect. This was secured to the peritoneum with catgut sutures that were tied extracorporeally. Popp expressed concerns that the intra-abdominal repair of inguinal hernia could lead to adhesive complications and suggested that a preperitoneal approach might be preferable.

Schultz published the first patient series of laparoscopic herniorraphy in 1990 [39]. Rolls of polypropylene were stuffed into the hernial orifice, which was then covered by two or three flat sheets of polypropylene mesh (2.5 × 5 cm) over the defect. These rolls of mesh were not secured to either the fascia or peritoneum. To achieve access to the hernia defect, he incised the peritoneum. Following the placement of the rolls, he closed the peritoneum with clips. This probably represents the earliest attempt at a type of transabdominal preperitoneal (TAPP) repair that is commonly used today. Corbitt modified this technique by inverting the hernia sac and performing a high ligation with sutures or with an endoscopic stapling device [8]. Despite the initial success of these early reports, because of recurrence rates approaching 15–20%, these techniques were abandoned [9]. The lack of extensive dissection with the above methods, however, remained appealing. A similar concept was applied in the intraperitoneal onlay patch (IPOM) technique. Salerno, Fitzgibbons and Filipi investigated this type of repair in the porcine model [38]. They placed rectangular pieces of flat polypropylene mesh to cover the myopectineal orifice and secured it with a stapling device. The success of these repairs led them to apply this method in clinical trials.

At about the same time, Toy and Smoot reported upon their first ten patients that were repaired with the IPOM technique [41]. They secured an expanded polytetrafluoroethylene (ePTFE) patch to the inguinal floor with staples that

were introduced by a prototypical stapling device of their own design, the 'Nanticoke Hernia Stapler'. They successfully used this fixation device in 20–30 patients without adverse results. A subsequent report of their first 75 patients was published in 1992 [42]. In this later series, the same prosthetic biomaterial (7.5 cm × 10 cm) was attached with the Endopath EMS® stapler. After a follow-up of up to 20 months, the recurrence rate was 2.4%. They noted a significant decrease in postoperative pain and an earlier return to normal activity as compared to the open repair of the hernia defect. Others reported similar results [24–28, 40, 159].

Fitzgibbons later abandoned the IPOM repair except for simple indirect inguinal hernias [16]. One patient developed a postoperative scrotal abscess that may or may not have been related to the placement of the mesh in that position. This patient was noted to have firm attachment of the appendix to the site of the polypropylene mesh. He also noted that, in follow-up of these patients, the patch material could be pulled into the hernial defect because it was affixed to the peritoneum alone rather than fascia. Because of these adverse events, he believed that the transabdominal preperitoneal (TAPP) approach, which had been reported by Arregui [1] for inguinal hernia repair, was more appropriate. In this repair, the peritoneum is incised and dissected away from the transversalis fascia to expose the inguinal floor. The mesh material is then secured to that fascia which was believed to ensure superior fixation and tissue ingrowth. Both the TAPP and IPOM techniques require the entry into the abdominal cavity.

In a continuing effort to prevent bowel contact to the prosthesis, Popp described a method to dissect the peritoneum away from the abdominal wall prior to the incision of the peritoneum in the TAPP repair in 1991 [36]. Saline was inserted into the preperitoneal space with a percutaneous syringe. This 'aquadissection' was found to be helpful in the dissection of this area to create a space in which to operate within the preperitoneal space. This early concept probably led to the idea that the entire dissection could be accomplished from within the preperitoneal space, thereby eliminating the need to enter the abdominal cavity.

Additional variations that did not gain acceptance were the 'ring-plasty' and a preperitoneal iliopubic tract repair. The former method was simply a sutured repair that approximated the deep structures of the lateral iliopubic tract to the proximal arching musculotendinous fibres of the transversus abdominis muscle [11, 23]. The latter technique was also a 'tissue' repair but secured the iliopubic tract to the transversus abdominis muscle [17, 18]. This repair incorporated the use of an inlay of a prosthetic material but still had the disadvantage of being a repair under tension. These methods may have limited usage in rare circumstances.

In these earlier years, the predominant laparoscopic method of inguinal herniorraphy was the TAPP approach using either a polypropylene mesh or an expanded polytetrafluoroethylene material [5, 23, 36]. In 1992, Dulucq [12, 13] was the first surgeon to perform 'retroperitoneoscopy' to effect a repair of an inguinal hernia without any direct entry into the abdominal cavity. In 1993, Phillips and Arregui separately described a technique that did not utilize a peritoneal incision in the repair of the inguinal floor [2, 34]. The dissection of the preperitoneal space was accomplished under direct visualization of the area via a laparoscope placed into the abdominal cavity. The laparoscope was then moved into the newly dissected preperitoneal space to complete the repair. Ferzli and McKernan later popularized the technique of Dulucq preferring the term 'totally extraperitoneal' [15, 31]. Using the 'open' entry into the preperitoneal space, the dissection of the space was carried out under direct visualization. This totally extraperitoneal (TEP) repair was identical to that of the TAPP but appeared to incur less risk of injury to the intra-abdominal organs.

Currently, the majority of laparoscopic inguinal hernia repairs are approached by either the TAPP or TEP method and utilize a polypropylene mesh biomaterial. The majority of the surgeons that perform the TEP repair utilize the commercially available dissection balloons to create the space within the preperitoneal area to perform the repair.

In an earlier multicentre report, the recurrence rate of these repairs was 0.4% in 10,053 repairs with a median follow-up of 36 months [14]. The surgeons that continue to perform the laparoscopic herniorraphy believe that the goals that were anticipated by Ger have been realized.

The improvement in recovery in laparoscopic cholecystectomy patients and results that were seen in herniorraphy patients encouraged attempts to repair ventral and incisional hernias in 1991. The initial report by LeBlanc involved only five patients using an ePTFE patch biomaterial [24, 26, 159]. Although the overlap of the hernia defect by the prosthesis was only 1.5–2 cm, these patients were free of recurrence after 7 years of follow-up. The fixation used was that of the 'box-type' of hernia stapler without the use of sutures. Sutures were used only to aid in the positioning of the patch. These sutures were removed from the prosthesis at the completion of the stapling of the patch. With further patients and follow-up, no recurrences were noted [25, 27, 28]. Barie proposed the use of a polyester material covered on the visceral side with a mesh of absorbable polyglactin [3].

Park modified the technique for the repair of large ventral hernias by utilizing the transfascial fixation of the ePTFE or Prolene® mesh with transabdominally placed Prolene® sutures passed through a Keith needle [32]. In their series of 30 cases, only 1 recurrence was noted. This repair used a fascial overlap of 2 cm. Holzman placed a Marlex® prosthesis with a 4 cm overlap onto normal fascial edges and secured them with an endoscopic stapler [22]. He found this technique to be safe and effective. In separate investigations,

Holzman, Park and others compared the open versus laparoscopic methods and found that the laparoscopic repair was associated with fewer postoperative complications, a shorter hospital stay and lower recurrence rates than open prosthetic repair [6, 10, 22, 33, 37]. The largest study published at that time confirmed that the laparoscopic repair of incisional and ventral hernias can be accomplished with reproducibility and with excellent results [21]. Additionally, the long-term follow-up of LeBlanc's patients has proven that this is a durable procedure when the tenets that are noted below are applied:

1. A minimum prosthetic overlap of 3 cm
2. Helical tacks placed at 1–1.5 cm intervals
3. Transfascial sutures placed at 5 cm intervals [29, 30]

Others, however, do not share this view. Some surgeons, notably in Spain, preferred the use of the 'double-crown' technique [7] (Morales-Conde 2001, Personal Communication). In this technique no sutures are used. Instead, two concentric rows of helical tacks are placed, the first at the periphery of the biomaterial as in the sutured technique and the second, inside of this one, near the hernia defect itself. The initial reports seem to have similar results as that of the authors using the transfascial sutures.

Incisional Hernia Repair

It was not until the second half of the nineteenth century at the start of the era of modern abdominal surgery that postoperative eventrations, what we now call incisional hernia, increased in number and were documented [114–119]. At the same time, surgical techniques aimed at their correction, developed and multiplied. Despite this, an awareness of the importance of the integrity of the abdominal wall in preventing herniation originated in the early years of written history and thereafter each historical time period has played a role in developing our understanding of incisional hernias.

Before the introduction of anaesthesia in 1846 by William Morton and antisepsis by Joseph Lister in 1865, restraining methods were the treatments of choice for the rare cases of incisional hernia [118, 120]. As survivable abdominal surgery became more common, so too did the incidence of incisional hernias. In the *Annals of Surgery* in 1901, Brindley Eads wrote, "The occurrence of ventral hernia as a sequence of abdominal section is so common that it should command our thoughtful consideration" [114].

These sentiments were reinforced in several other publications at the time [115, 116]. Since then, many thousand peer-reviewed articles on the topic of incisional hernia have been published. Many of these introduced a new technique or suggested a modification of an established technique for the repair of incisional hernia. Whilst several have played an

important role in shaping incisional hernia surgery, this historical review only mentions the most significant of these. Surgical repair developed along three lines:

1. Simple laparoplasty: suturing
2. Organic auto or heteroplasty: grafting
3. Alloplasty: the use of prosthetics

Simple Laparoplasty: Suturing

Simple suturing and more complex darns were the most commonly utilized repairs in this period. In 1886, Maydl performed an incisional hernia repair by dissecting out the various musculo-fascial layers and repairing them separately [121]. Quenu also advocated layered closure of postoperative eventration using simple sutures [122]. Others, such as Jonnesco, proposed the use of 'U'-shaped stitches through the rectus sheath, and Frappier described the mass closure of the hernia defect with 'figure-of-eight' sutures [123, 124]. In 1899, Mayo described his famous transverse overlapping technique for umbilical hernia (pants over vest), and this was adopted by many surgeons for the repair of incisional hernia [125]. Others, such as Witzel [126], Goepel [127] and Bartlett [128], described the repair of incisional hernia from continuous fascial sutures from the external oblique [126–128].

In 1954, a British surgeon, Rodney Maingot, described his extraperitoneal 'keel' technique for the repair of large incisional hernia [129]. The technique involved widely excising the stretched overlying skin and scar tissue and dissecting the fascial flaps well back to expose healthy margins. The peritoneal hernia sac was then inverted 'like a boat's keel' and the fascial edges approximated with interrupted sutures of floss silk. The approximated edge was then inverted with a continuous suture. Maingot described good results from 81 patients in which he had performed this operation. Despite these good results, suture repair, in all but the smallest of hernias, resulted in unsatisfactorily high recurrence rates [130]. This spurred surgeons to explore alternative techniques to reinforce the abdominal wall.

Organic Auto- or Heteroplasty: Grafting

In 1910, Kirschner (of the whom the *k-wire,* used in orthopaedic surgery, is named) used heterologous, homologous and autologous fascia, of which the latter was reported to have good results [131]. In 1912 Judd described an overlapping flap of peritoneum, muscle, fascia and scar tissue, and in 1913 Loewe described cutis grafts [132, 133]. Relieving or relaxing incisions were first described by Gibson in 1920 [134]. Nuttall described rectus muscle transplantation in 1926 [135]. This involved releasing the muscles at their ori-

gins, crossing them and suturing them to the opposite pubic bone. In the following years, free flaps were constructed from freeze-dried human fascia lata, dura mater and skin [117, 136–138]. Reconstruction with autologous material on the whole produced unsatisfactory results. Transplant harvesting was time consuming and was frequently followed by functional deficits at the donor sites. Moreover, the reconstructions often left bulges through denervated muscles and reherniation rates were high [139]. However, these attempts at grafting represented an important step in incisional hernia surgery and arguably were the precursors to biological collagen xenografts that are used today.

Alloplasty: The Use of Prosthetics

The first hernia prosthetics were made of metal. As early as 1900, Goepel and Witzel used silver wire braided meshes [126, 127, 140]. These early meshes were far from ideal. They were stiff, fragile and toxic sulphur silver formed on their surface. They were modified to contain braided stainless steel and were used as a bridging material between the two edges of the rectus muscles, sometimes as a double layer [141–143]. In 1948 Douglas and Throckmorton and several years later Koontz used tantalum gauze [144–146]. These meshes still fragmented and had extremely high rates of infection. Prefabricated perlon and nylon meshes were used by Cumberland; however, the nylon fell apart and the perlon caused an intense inflammatory response [147–149]. The plastics industry came of age during the Second World War. Steel and tantalum became precious metals allocated for military use. Desperate fabricators, who had never thought of plastic as a manufacturing material, began to reconsider. These 'new plastics' caught the attention of hernia surgeons and several new meshes with much more promising characteristics became available. These were polypropylene, polyester and expanded polytetrafluorethylene (ePTFE) [149–151].

Since the plastics era started, meshes have been manipulated to include changes in pore sizes, textures and additives. Additives include impregnated antimicrobials and elements of absorbable mesh or non-adhesion-forming substances in hybrid meshes. More recently biological materials have been introduced and provide a cross over between meshes and grafting. Most recently synthetic absorbable products have become available. The search for the 'ideal' mesh still continues today.

Whilst major developments in prosthesis aimed at repairing incisional hernias were being made, advances in surgical technique to prevent incisional hernia formation were also occurring. Perhaps the most significant of these was the work of Jenkins [152]. He used a mechanical and geometric approach to calculate the ideal suture length to wound ratio to prevent incisional hernia formation. Experimentally, Jenkins showed that the length of a midline laparotomy incision could increase up to 30% in the postoperative period. If the bites taken in suturing (and hence the length of the suture material used) were not large enough, the suture may cut through the fascia, resulting in wound dehiscence. His well-adopted rule states that the suture-length-to-wound-length ratio should be 4:1, and sutures should be placed 2 cm from the fascial edge and 2 cm from one another.

Some of the most important developments in incisional hernia repair during this time period have been in the technique for placing the mesh. For open incisional hernia repair, three methods for implantation of prosthetic mesh have dominated. The first involves placing the mesh inside the peritoneal cavity in contact with the viscera (intraperitoneal inlay or intraperitoneal onlay). Bare polypropylene mesh adheres to all adjacent tissues and therefore has the propensity for inducing extensive adhesions to viscera if placed in a position where it becomes adjacent to bowel. Erosion of the mesh then may occur into the intestines, which is a well-recognized drawback of this technique [153]. However, newer coated meshes, which reduce adhesion formation on the exposed visceral surface of the mesh, have reduced this risk [154]. The second is the premuscular onlay technique, in which the mesh is placed over the abdominal wall closure in the subcutaneous prefascial space. This technique was refined and popularized by Chevrel [155]. The third is the retromuscular sublay technique, in which the mesh is placed over the closed posterior rectus sheath and peritoneum. This technique was popularized by Rives and Stoppa [156, 157]. Stoppa, in fact, described retrofascial placement and Rives described retromuscular placement. The combined Rives-Stoppa technique has subsequently been adopted as the gold standard for traditional open incisional hernia repair. However, there is currently insufficient data in the literature to promote the Rives-Stoppa technique ahead of the Chevrel onlay repair [130].

Large incisional hernias with loss of abdominal domain from lateral retraction of the abdominal muscle present a difficult problem because of lack of healthy tissue for mesh placement or primary closure. In 1990, Oscar Ramirez, developed his 'component separation of the abdominal wall' technique to address this group of complex incisional hernias [158]. The advantage of the component separation technique is that the abdominal wall can be recreated in a one-stage procedure without the need of an additional musculofascial transfer (distant flaps) or the use of a bridging material.

In 1991, LeBlanc reported the first laparoscopic incisional hernia repair [159]. Although not considered to be a pathology that could benefit from this approach, laparoscopic repair of incisional hernias has attained wide acceptance in recent years because of the significant improvements in prosthetic materials and surgical technique.

Most recently the advent of robotic technology has resulted in a further evolution of hernia repair, especially incisional hernia repair. The short-term outcomes appear favourable, and it appears that the use of the surgical robot in hernia repair has established a firm foothold in the future of hernia repair.

Chronology of Hernia Surgery

Ancient	
1500 BC	Inguinal hernia described in an Egyptian papyrus. An inguinal hernia is depicted on a Greek statuette from this period
900 BC	Tightly fitting bandages are used to treat an inguinal hernia by physicians in Alexandria. A Phoenician statue depicts this
400 BC	Hippocrates distinguished hernia and hydrocele by transillumination
AD 40	Celsus described the older Greek operations for hernia
AD 200	Galen introduced the concept of 'rupture' of the peritoneum allowed by failure of the belly wall tissues
AD 700	Paul of Aegina distinguished complete and incomplete hernia. He recommended amputation of the testicle in repair
Medieval	
1363	Guy de Chauliac distinguished inguinal and femoral hernia
1556	Franco recommended dividing the constriction at the neck of a strangulated hernial sac
1559	Stromayr published Practica Copiosa, differentiating direct and indirect hernia and advocating excision of the sac in indirect hernia
Renaissance	
1700	Littre reported a Meckel's diverticulum in a hernial sac
1731	De Carengeot described the appendix in a hernial sac
1724	Heister distinguished direct and indirect hernia
1757	Pott described the anatomy of hernia and of strangulation
1756	Cheselden described successful operation for an inguinal hernia
1785	Richter described a partial enterocele
1790	John Hunter speculated about the congenital nature of complete indirect inguinal hernia
1793	De Gimbernat described his ligament and advocated medial rather than upward division of the constriction in strangulated femoral hernia. This avoided damage to the inguinal ligament and the serious bleeding, which sometimes followed
1804	Cooper published his three-part book on hernia—the plates are a tour de force; they are almost life sized and depict anatomy as never before. Cooper defined the fascia transversalis; he distinguished this layer from the peritoneum and demonstrated that it was the main barrier to herniation. He carefully delineated the extension of the fascia transversalis behind the inguinal ligament into the thigh as the femoral sheath and the pectineal part of the inguinal ligament—Cooper's ligament

1811	Colles, who had worked as a dissector for Cooper, described the reflected inguinal ligament
1816	Hesselbach described the anatomy of his triangle
1816	Cloquet described the processus vaginalis and observed it was rarely closed at birth. He also described his 'gland', so important in the differential diagnosis of lumps in the groin
1846	Anaesthesia discovered
1870	Lister introduced antiseptic surgery and carbolized catgut
1871	Marcy, who had been a pupil of Lister, described his operation
1874	Steele described a radical operation for hernia
1875	Annandale successfully used an extraperitoneal groin approach to treat a direct and an indirect inguinal and a femoral hernia on the same side in a 46-year-old man. Annandale plugged the femoral canal with the redundant inguinal hernial sacs
1876	Czerny pulled the sac down through the external ring, ligated it at its neck, excised it and allowed it to retract back into the canal
1881	Lucas-Championniere opened the canal and reconstructed it by imbrication of its anterior wall
1886	MacEwan operated through the external ring; he rolled up the sac and used it to plug the canal
1887	Bassini published the first description of his operation
1889	Halsted I operation described
1890	Coley's operation—placing the internal oblique anterior to the cord which emerged at the pubic end of the repair. This was the most pernicious and least effective corruption of Bassini's operation
1891	Tait advocated median abdominal section for hernia
1892	Wolfler designed the anterior relaxing incision in the rectus sheath to relieve tension on the pubic end repair and prevent recurrence at that site
1893	Lockwood emphasized the importance of adequate repair of the fascia transversalis
1895	W.J. Mayo—a radical cure for umbilical hernia
1895	Andrews introduced imbrication or 'double-breasting' of the layers
1898	Lotheissen used Cooper's ligament in repair of femoral hernia
1898	Brenner described 'reinforcing' the repair by suturing the cremaster between the internal oblique arch and the inguinal ligament. The fascia transversalis is not inspected. A serious corruption of the Marcy-Bassini strategy
1899	Ferguson advised leaving the cord undisturbed—a more serious corruption of Bassini
1901	McArthur darned his inguinal repair with a pedicled strip of external oblique aponeurosis
1902	Berger turned down a rectus flap to repair inguinal hernia
Modern aseptic	
1903	Halsted II operation. Halsted abandoned cord skeletonization to avoid hydrocele and testicular atrophy, and adopted Andrews' imbrication and the Wolfler-Berger technique of a relaxation incision and a rectus sheath flap
1906	Russell—the 'saccular theory' of hernias, postulating that all indirect inguinal hernias are congenital

1907	Kocher—revised operation for indirect hernia without opening the canal. The sac was dissected, invaginated and transposed laterally
1909	McGavin used silver filigree to repair inguinal hernias
1909	Nicol reported paediatric day-case inguinal herniotomy in Glasgow
1910	Kirschner used a free transplant of fascia lata from the thigh to reinforce the external oblique
1918	Handley reconstructed the canal using a darn/lattice technique
1919	LaRoque—transperitoneal repair of inguinal hernia through grid iron (muscle splitting) incision
1920	Cheatle—extraperitoneal approach to the groin through a midline incision
1921	Gallie used strips of autologous fascia lata to repair inguinal hernia
1923	Keith—classic review of the causation of inguinal hernia. He remarked that aponeurosis and fascia are living structures and speculated that a tissue defect could be responsible for the onset of hernias in middle age
1927	Keynes—surgeon to the London truss society—advocated elective operation using fascial graft techniques
1936	Henry—extraperitoneal approach to groin hernia
1940	Wakeley—a personal series of 2020 hernias
1942	Tanner popularized rectus sheath 'slide'
1945	Lytle reinterpreted the importance of the internal ring
1945	Mair introduced the technique of using buried skin to repair an inguinal hernia
1952	Douglas—first experimental studies of the dynamics of healing (aponeurosis) showed that aponeurotic strength was slow to recover and only reached an optimum at 120 days
1953	Shouldice—a series of 8317 hernia repairs with overall recurrence rate to 10 years of 0.8%. Emphasis on anatomic repair and early ambulation
1954	Roger Maingot describes the 'keel' technique for open incisional hernia repair
1955	Farquharson—an experience of 485 adults who had their hernias repaired as day cases
1956	Fruchaud—the concept of the myopectineal orifice and fascia transversalis tunnel for all groin hernias
1958	Marsden—a 3-year follow-up of inguinal hernioplasties. An important contribution to the evaluation of results
1958	Usher—the use of knitted polypropylene mesh in hernia repair
1960	Anson and McVay—classic dissections and evaluation of musculoaponeurotic layers based on a study of 500 body halves
1962	Doran described the pitfalls of hernia follow-up and set out criteria for adequate evaluation
1962	Chevrel describes the onlay repair for incisional hernia
1970	Lichtenstein showed the interdependence of suture strength and absorption characteristics with wound healing. Demonstrated experimentally the critical role of non-absorbable or very slowly absorbable sutures in aponeurotic healing
1972	Doran—critical review of short-stay surgery for inguinal hernia in Birmingham
1973	Glassow reported 18,400 repairs of indirect hernia with a recurrence rate less than 1%
1979	Laparoscopic hernia repair first attempted
1981	Read demonstrated a tissue defect, metastatic emphysema, in smokers with direct herniation
1981	Chan described patients developing hernia whilst undergoing continuous ambulatory peritoneal dialysis
1982	Rives describes retromuscular placement of mesh in ventral hernia repair
1983	Schurgers demonstrated an open processus vaginalis in a man 5 months after commencement on peritoneal dialysis
1984	Gilbert described the umbrella plug for inguinal hernia repair
1985	Read postulated an aetiological relationship between smoking, inguinal herniation and aortic aneurysm
1986	Lichtenstein described the tension-free repair of inguinal hernias
1989	Stoppa describes retrofascial placement of mesh in ventral hernia repair
1989	Gullmo demonstrates the value of herniorrhaphy in patients with obscure symptoms in the groin or pelvis and to exclude primary or recurrent hernia
1990	Robbins and Rutkow introduced the concept of a preformed mesh plug introduced into the hernia defect covered by a loose lying mesh patch Schultz first used a synthetic prosthetic biomaterial in the laparoscopic repair of an inguinal hernia
1990	Oscar Ramirez publishes his paper on anterior component separation
1991	LeBlanc performs laparoscopic incisional hernia repair
1992	Dulucq repairs an inguinal hernia laparoscopically without direct entry into the abdominal cavity
1993	First "Guidelines for the Management of Adult Inguinal Hernia" produced by the Royal College of Surgeons of England (Chairman of the Working Party—Kingsnorth
1993	Environmental factors in hernia causation redefined
1994	O Jeremy A Gilmore describes the surgical treatment of 1400 sportsmen with groin disruption detailing the pathophysiology and treatment
2000	Lowe publishes a case series of combined open and laparoscopic anterior component separation
2006	First open TAR (Transversus Abdominus release) performed by Yuri Novitsky
2007	Rosen publishes animal studies on laparoscopic anterior component separation
2008	Carbonell publishes the first series on posterior component separation
2013	Carbonell performs the first robotic posterior component separation (rTAR)
2014	Use of the surgical robot for hernia repair achieves approval by the USFDA

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