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Review Article

Milestones in the early history of arthroscopy

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ABSTRACT

Background: Before arthroscopy, an arthrotomy had to be made to make a definitive diagnosis and treat any intraarticular pathology. The purpose of this review paper was to investigate the transition from open to arthroscopic surgery.

Methods: The authors have been interested in the subject of the history of arthroscopy since the beginning of their professional careers. The three most senior authors started performing arthroscopy already in the late 1970s. During our careers, we have collected personal experiences, artifacts, scientific papers and other documents, as well as memories of conversations of fellow enthusiasts of arthroscopy. Further, for this historic review paper, we did search procedures at PubMed.gov with combinations of search terms, i.e., "((history or historic or milestones) and (endoscopy or endoscopic or arthroscopy or arthroscopic))". Important leads were followed-up with specific searches, e.g., on important persons and equipment/inventions.

Results: Physicians have always had a desire to examine body cavities of their patients. Some cavities are quite accessible for diagnostic purposes, using specula and light, while others are difficult to inspect. This is where the endoscope comes into play. The female bladder was the first organ to be examined using an endoscope, by Philipp Bozzini in 1806. Whereas the urologists immediately embraced the idea of endoscopy, the orthopaedic surgeons were reluctant. The first arthroscopy was performed by Severin Nordentoft in 1912. In this paper, we focus on some important milestones in the early history of endoscopy generally and later, arthroscopy specifically. Our story ends in the 1970s with the introduction of the modern arthroscope with rod lenses, a fibreoptic light cable connected to an external light source and a live video camera connected to a monitor.

Conclusion: Today, arthroscopic surgery is generally regarded as one of the most important innovations in orthopaedic surgery, together with joint replacement and internal fixation of fractures. The benefits of arthroscopy include minimally invasive surgery with low morbidity, early mobilization and the ability to perform surgery as an outpatient procedure. We document some important milestones and important figures on the thorny path from open surgery to the adoption of the arthroscope as a useful orthopaedic tool.

Level of evidence: Literature study, Level IV.

1. Introduction

Vision, the ability to see with our eyes, is the dominant sense of humans and the sense physicians generally rely on the most for making the correct diagnosis of disease and injuries. Physicians have probably always had a desire to be able, when relevant, to peek into the orifices of a patient's body cavity of concern to diagnose and cure diseases. This statement is based on 5000-year-old Mesopotamian (present-day Iraq) artifacts (specula and tubes), as well as similar artifacts from other more recent, but still ancient cultures, e.g., Greek, Roman. Further, scriptures of their use exist, some of them possibly written by Hippocrates.[1]

Some body cavities are quite accessible for diagnostic purposes, using specula and mirrors and a proper light source, initially, sunlight or candlelight. However, some cavities are difficult to inspect. This is where the endoscope comes into play. Not surprisingly, the female bladder was the first organ to be examined using an endoscope. Bozzini, Desormeaux and others made ground-breaking innovations in the early 1800s.[2–4] As the nineteenth century was ending, Nitze in collaboration with

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instrument makers in Berlin and Vienna, had developed a fully functioning cystoscope, with a miniature Edison incandescent lamp at the tip.[4] Our colleagues in urology embraced the cystoscope immediately and hailed Nitze as the father of their specialty. Within 10–20 years, many competitors in Europe and USA were advertising and selling cystoscopes of similar design.

Still, the stubborn orthopaedic surgeons kept asking: "Why bother to peek through the keyhole, when you can open the door?" This attitude was based on the innovations in the mid-1800s of anaesthesia (1846) and antiseptics (1867), which paved the way for large surgical incisions with good visibility and low mortality. This absurd notion (of opening doors) held ground well into the 1970–80s because many orthopaedic surgeons at the time did not master the arthroscope, and just as importantly, did not bother to ask their patients how they preferred to have their surgery performed. The truth is that endoscopy, including arthroscopy, generally offers a much better view of the body cavity of interest (including joints). This is due to the great manoeuvrability in tight spaces, the magnification offered by modern arthroscopes and the inclusion of video cameras and monitors, today in HD or 4K. Thus, the correct question to ask today is: "Why break through a door that isn't there, when you can peek through small keyholes, and do the surgery required, with lower morbidity and faster recovery?"

The first arthroscopy devotees were plagued with the many shortcomings of their endoscopes, which were initially based on the designs of the cystoscopes of the day (as mentioned, introduced by Max Nitze in the late 1880s).[5–10] The incandescent miniature lamp (based on Edison's patent of 1880) placed at the tip of the scope, 1.5 cm from the viewing optics introduced a physical obstruction when manoeuvring in a tight joint (it was not a problem inside the urinary bladder). The viewing angle was originally 90° (again, in a straight endoscope, due to the lamp). Further, the early designs consisted of thin lenses separated by long stretches of air (light travels faster in glass than in air), and the lenses lacked anti-reflective coating, both factors resulting in great loss of light and, thus, providing a dark field of vision.

The great breakthrough came with the introduction of endoscopes fitted with anti-reflective coated rod-lenses, and light provided by a strong external light source connected to the endoscope by a fibreoptic cable (so-called "cold light"). Instrumental to this development were inventions by the English physicist, Hopkins.[11,12] This new type of endoscope, a cystoscope, was first produced by K. Storz, based in Tuttlingen, Germany in 1965 in cooperation with H. Hopkins. In 1970, O. Wruhs in Vienna was probably the first to promote the clinical application of the cold-light arthroscope.[10] Later, in the early 1980s, the development of small, charged couple device (CCD) TV cameras attached to the eye piece of the endoscope, and connected to a monitor, further advanced endoscopy in general and arthroscopy specifically. The addition of a camera and a monitor was instrumental to performing therapeutic surgery, as well as teaching colleagues the necessary skills. Initially, the arthroscopies were merely diagnostic and were often followed by open surgery. However, even in the early days, in some cases open surgery could be avoided when the arthroscopy failed to document pathology amenable to surgery.[13,14]

2. Methods

The authors have been interested in the subject of the history of arthroscopy since the beginning of their professional career. The three most senior authors started performing arthroscopy already in the late 1970s. During our careers, we have collected personal experiences, artifacts, scientific papers and other documents, as well as memories of conversations of fellow enthusiasts of arthroscopy in a historic light. For this historic review paper, we did many search procedures at PubMed.gov and other scientific online libraries with combinations of the search terms, i.e., "(history or historic or milestones) and (endoscopy or endoscopic or arthroscopy or arthroscopic)". Further, we did specific search on important persons, e.g., "Philipp Bozzini" and equipment/inventions, e.g., "lichtleiter", "rod lens" and "fibreoptic". All material were discussed in plenum and selected for inclusion in this paper.

In this paper, we will focus on some important milestones in the early history of endoscopy generally (from 1806 onwards) and later, arthroscopy specifically (from 1912 onwards). Our history ends with the development of the modern arthroscope with rod lenses, cold light and a video camera, and its general international acceptance as a useful tool in the 1970–80s. After that, arthroscopy evolved anatomically from being used primarily for the knee joint to almost every joint in the human body, and arthroscopically-assisted procedures flourished widely beyond what is possible to cover in this paper.

We recognize that in focusing on the work of some important figures (so-called founding fathers), we may have left others out who may have been equally important to the progress of arthroscopy. We also want to recognize that the work of engineers, opticians, and technicians (including what we call 'the medical industry'), has been, and still is, instrumental to the development of arthroscopy and arthroscopic surgery.

3. Early development of endoscopy

3.1. Philipp Bozzini

The history of endoscopic devices starts with the construction of the Lichtleiter (light conductor) by the German physician Philipp Bozzini (1773–1809). He was also a painter and made a self-portrait in 1805 (Fig. 1). He was born in Mainz, Germany and was the son of an Italian nobleman. His father, Nicolaus Maria Bozzini de Bozza, came from a rich Italian family, but had to flee his home country around 1760 after killing a man in a duel. The father started a business in Mainz and married Anna

Fig. 1. Self portrait painted by Phillip Bozzini (1773–1809) in 1805. Public domain.

Fig. 2. Map of the strategic situation of Europe in 1801 when Phillip Bozzini (1773–1809) chose to move from Mainz (situated on the left bank of River Rhine, becoming a French city) to Frankfurt (situated 34 km north-east of Mainz). The Department of History, United States Military Academy. The locations of Mainz and Frankfurt have been added to the map by the authors. Public domain.

Maria Florentin de Cravatte from Frankfurt. Bozzini studied medicine in Mainz and Jena and earned his title of Doctor of Medicine in Mainz in June 1796. This allowed him to establish himself as a general practitioner in Mainz. In 1798, he married Margarete Reck, and the couple had three children.[2]

The army led by Napoleon Bonaparte, in the War of the Second Coalition, conquered Mainz, and the (peace) Treaty of Lunéville was signed in 1801 between the French Republic and Emperor Francis II. Bozzini, not wanting to become a French citizen, chose to move to Frankfurt, although the new government offered him the privilege of continuing his medical practice in Mainz (Fig. 2). However, starting a new practice in Frankfurt turned out to be both difficult and costly due to local colleagues carefully protecting their own privileges (as a "physicians' guild"). Still, eventually, Bozzini managed to obtain the right to practice and earned a reputation for being a skilful obstetrician. Probably due to his being a newcomer, he was appointed as one of four "plague physicians" in Frankfurt, a most dangerous duty.[2]

The Lichtleiter (light conductor) endoscope constructed by Philipp Bozzini was first presented in 1806 at the Medical Academy in Vienna (Fig. 3). Further, he published a paper the same year on the subject[15] and described the Lichtleiter and its use in his book a year later.[16] The construction and use of the Lichtleiter is often considered the beginning of endoscopy.[4] The Lichtleiter still exists. It is about 35 cm high and shaped like a vase. It is made of sheet metal covered with an insulating layer of paper and leather. It contains a double-barrelled system (a tube divided vertically into two halves) for sending light into the organ and receiving the image to the viewer's eye, respectively. A lit candle in front of a concave mirror occupies one half, closed on the viewer's end. The other half is open in both ends allowing the viewer to receive the image at the eye piece without interference from the light-source. The Lichtleiter was used for examination of the urethra, urinary bladder in women, ear, nose, mouth/throat, rectum, cervix and wound cavities, using various inserts/specula. Unfortunately, its use was largely censured (due to pressure by the church) as it was considered to provoke unnatural curiosity against contemporary morals.

Bozzini died during a typhoid epidemic in Frankfurt in 1809, aged just 36, leaving his wife and three children in economic misery. He treated a large number of patients before he fell ill, and it is believed that he was infected by a patient during a house call. His wife died just 6 months later, and their children were left to the care of friends. The Bozzini Lichtleiter, which was kept at the Josephinum institutions in Vienna for more than 100 years, disappeared (probably looted) in 1945 during the occupation of Vienna by Allied forces. Twenty years later, the instrument was found in a cardboard box together with several other surgical tools in the basement of the old Headquarters of the American College of Surgeons (ACS) in Chicago. Infamously, it later spent several years as a decoration on top of a television set of an American surgeon. However, during the next few decades, the historical importance of the Lichtleiter was increasingly acknowledged and the piece was exhibited on several occasions. At the same time, American surgeons and urologists recognized that the artifact belonged to its hometown in Austria. Eventually, the Lichtleiter was returned to Vienna in 2002 and is kept by the Nitze-Leiter Research Society of Endoscopy.[2]

Fig. 3. The Lichtleiter (light conductor) constructed by the German physician, Phillip Bozzini (1773–1809) and presented in 1806 at the Medical Academy in Vienna. The Lichtleiter is about 35 cm high and shaped like a vase, made of sheet metal covered with an insulating layer of paper and leather. By attached specula and tubes, it could be used for peeking into human orifices and hollow organs. Public domain.

3.2. *Antonin Jean Desormeaux*

Antonin Jean Desormeaux (1815–1894) was born in Paris, studied in Paris and worked his whole career as a surgeon and urologist at a Parisian city hospital, Hôpital Necker (Fig. 4). He has been referred to by many as the father of endoscopy[34] because he developed Bozzini's Lichtleiter to become much more useful and was the first to perform surgical interventions with the help of endoscopy (including the treatment of strictures and papilloma in urethra). As the light source, he used the flames of a mixture of alcohol and turpentine, which burned with a clearer, whiter and brighter light than candlelight. Moreover, he was able to concentrate the light better (by a concave mirror) and, thus, further enlighten the subject of interest. He demonstrated his instrument for the Académie Impériale de Médecine in Paris in 1853 and is credited on the same occasion for being the first to use the term "endoscopy" (Figs. 5–6). The disadvantages of his endoscope included large size, heavy weight, production of significant amounts of smoke and ash, and the risk of burns to both the patient's thighs and the operator's face.[34] Still, his endoscope found some clinical use and others made some minor improvements to its construction. The New York physician, Robert Newman, described his experience with Desormeaux's endoscope for diagnostic use in seven cases involving the female bladder and urethra in 1872. Newman praised the endoscope stating: "Finding the true pathologic process absolutely relates to the physician's ability to treat it".[4]

Fig. 4. French physician Antonin Jean Desormeaux (1815–1894) based in Paris, improved on the Lichtleiter and is together with Nitze often mentioned as a father of endoscopy. Wikimedia Commons. Public domain.

3.3. *Julius Bruck*

German Julius Bruck (1840–1902) from Breslau studied medicine and odontology at universities in Breslau, Bonn, Berlin and Paris before settling as a dentist at his father's practice in his hometown (Fig. 7). In the effort of bringing light into body cavities, Bruck used the light emitted from electrically heated platinum wire, an invention of 1828 by German chemist C. H. Pfaff.[17] The downside was the considerable amount of heat generated, making even brief examinations painful, and longer ones harmful to the patient. This problem was solved with a bulb, developed by Bruck, containing 2 layers of glass with water circulating between them (Fig. 8). However, the new bulb increased the size of the instrument so much that its use was limited to only larger cavities. Bruck therefore attempted to illuminate the bladder by placing the light source in the vagina or rectum (transillumination), e.g., in an effort to locate bladder stones. In 1867, he published his work "Das Urethroscop und das Stomatoscop zur Durchleuchtung der Blase, der Zähne und ihrer Nachbartheile durch galvaisches Glülicht" (Fig. 9).[17] His instrument only offered illumination of body cavities and did not include a part for viewing, as is the case in endoscopes. In 1871, he was offered a docenture in odontology at the University of Breslau (located in what is now Wrocław, Poland), and he was later promoted to a professor in 1891.

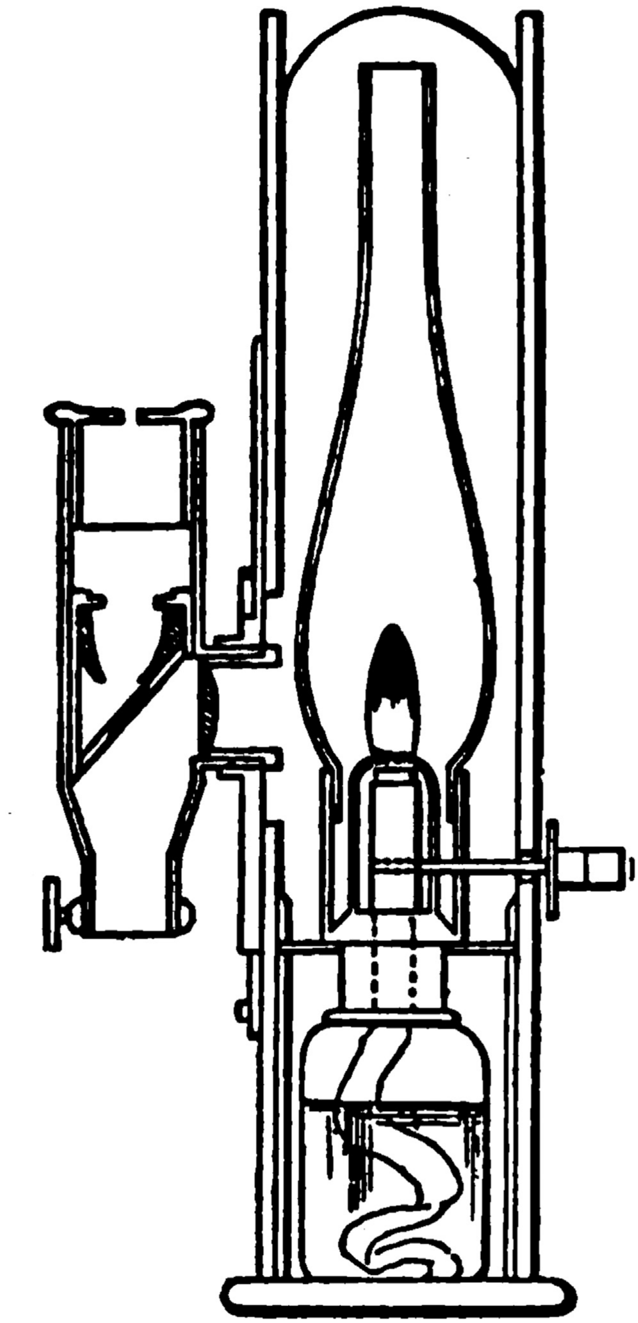


Fig. 5. A modification of the Desormeaux endoscope by a colleague of his at the time, Mr. Cruise, Dublin, 1865. From the book, The electric illumination of the bladder and urethra. By Edwin Hurry Fenwick 1889. Digitized by Google Books. Public domain.

3.4. Maximilian Carl-Friedrich Nitze

Maximilian Carl-Friedrich Nitze (1848–1906) was born in Berlin and studied medicine at the Universities of Heidelberg, Würzburg and Leipzig (Fig. 10). He earned his doctorate in 1874 and started working as a medical assistant at a city hospital in Dresden. Soon, his prime interest became urology. Probably based on the experience of Bruck, Nitze understood that the light source had to be inside the hollow organ being examined ("In order to light up a room, you must bring the lamp in", he said) and also that the field of vision could be enlarged by the use of optical systems, as in a telescope.[9,17]

With the help of opticians at the University of Berlin, foremostly Wilhelm Deicke, Nitze made a slimmer 21-French/Charrière (7 mm in diameter) water-cooled platinum cystoscope and was able to present it to colleagues in 1877, when he was only 28 years old (Fig. 11). He later contacted instrument maker Joseph Leiter in Vienna and they presented their improved Nitze/Leiter cystoscope in 1879. However, they eventually started quarrelling about the degree of each other's contributions to the construction of the cystoscope, including patents and legal rights, ultimately ending their collaboration. According to biographer, Hauri: "Nitze had a difficult character. He was introverted, jealous, domineering, and quickly prone to quarrels. Nitze was a self-deprecating tinkerer …"[18]

After ending his association with Joseph Leiter, Nitze returned from Vienna to Berlin and established a urological hospital in Berlin. With Thomas Edison's invention of the incandescent lamp, the cooling system could be removed and provide a leaner cystoscope. Nitze presented his incandescent cystoscope in 1887. He continued to improve the cystoscope and was the first to take endoscopic photographs. From this time on, the devolvement of cystoscopes for clinical use flourished among European and American makers. Nitze became a professor at the University of Berlin in 1900.[17]

Among urologists, Nitze is widely regarded as the father of urology. The 4th president of the American Urological Association, Bransford Lewis, stated the following in his 1907 presidential address, The Dawn and Development of Urology: "… how shall I adequately express the esteem in which the father of cystoscopy, Max Nitze, is held? The one who did more than any other to pave the way to precision in urological diagnosis and therapy as they exist to-day." He also added: "Through this instrument, the world is ours, now, for the taking".[4] Still, it took orthopaedic surgeons and rheumatologists, in general, another 70 years to truly embrace the idea and develop suitable arthroscopes for routine inspection of the interior of the knee and other joints.

3.5. Hans Christian Jacobaeus

Hans Christian Jacobaeus (1879–1937) was an innovative Swedish specialist in internal medicine (Fig. 12). In 1906, he earned a Doctor Medicinae degree with a dissertation on Paget's disease. In 1916, he was appointed professor at the Karolinska Institute. He was a member of the Nobel Prize Committee from 1925 until his death.

Jacobaeus is credited, in 1910, for being the first to describe, in a scientific paper, the endoscopic examination of the abdominal (n = 17) and chest cavity (n = 2) with a Nitze cystoscope.[9,19,20] However, he was probably not the first to actually carry out the procedures. Later, he developed a more suitable endoscope together with Georg Wolf in Berlin. He is particularly known for thoracoscopic release (cauterization) of pleural adhesions in patients with pulmonary tuberculosis, to make the lung collapse.[21] The procedure was named Jacobaeus' operation and was widely used. However, after streptomycin was discovered in 1943 and became the primary treatment for tuberculosis, there was less need for the procedure.

4. Pioneers in arthroscopy

4.1. Severin Nordentoft

The merit of performing the first knee arthroscopy was initially credited to Professor Kenji Takagi at the University of Tokyo, in 1918, when he started studies examining the inside of the knees of deceased people with a cystoscope. However, in 1997, the medical historian, G. Seydl based in Vienna, rediscovered a long-forgotten work of 1912, and it became clear that the Danish physician, Severin Nordentoft at St. Joseph's Hospital in Aarhus carried out endoscopic examination of the knee before 1912.[22,23]

Thomas Severin Johannes Nordentoft (1866–1922) was the son of a parish priest (Fig. 13). He began studying medicine in 1883 and graduated in 1890 from the University of Copenhagen in Denmark. He worked

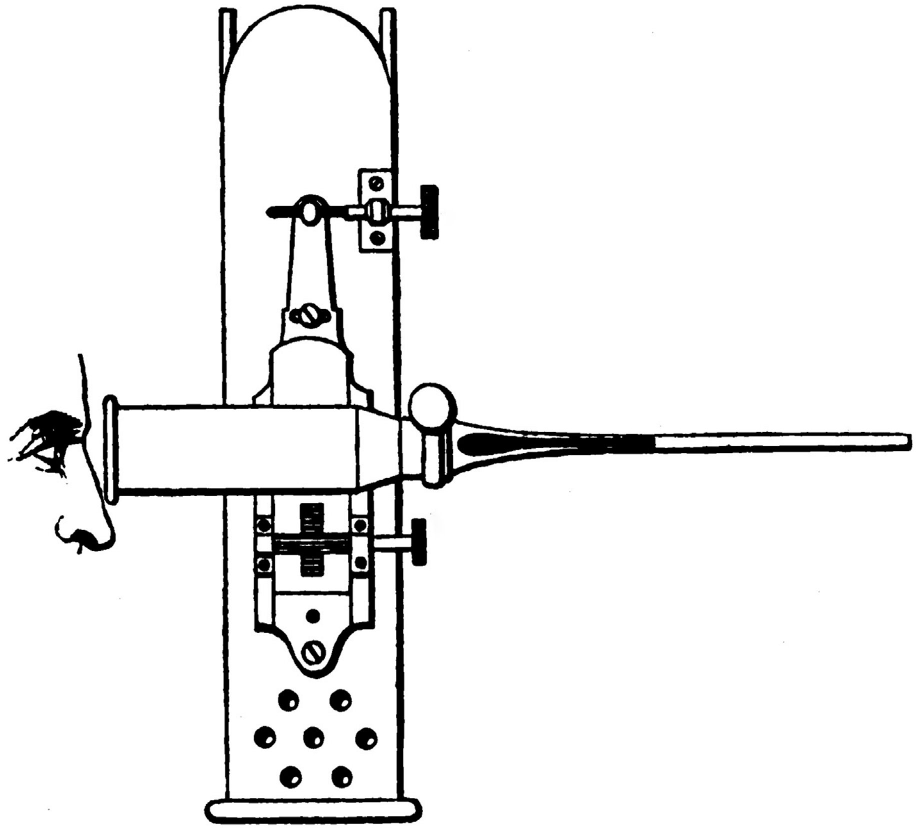


Fig. 6. A modification of the Desormeaux endoscope by a colleague of his at the time, Mr. Cruise, Dublin, 1865. From the book, The electric illumination of the bladder and urethra. By Edwin Hurry Fenwick 1889. Digitized by Google Books. Public domain.

as an intern ("candidate") at several hospitals in Copenhagen and spent a year as a "district doctor" (family physician) on the Faroe Islands. From 1894 to 1901, he was a district doctor in Jutland. Seeking further academic recognition and credentials into surgery, he travelled to Vienna in 1896 and collected material for his doctoral work with the renowned private practitioner, Dr. Wertheim. In 1899, he defended his work "About Uretero-Genital Fistulas in the Woman" for the Doctor Medicinae degree. He had a private practice in Aarhus, Denmark from 1903-20 and eventually also started working as a surgeon at St. Joseph's Hospital (established in 1907). In 1906, he competed for a docenture in surgery in Copenhagen, but lost to the academically (and possibly clinically) more experienced surgeon Vilhelm Schaldemose (1866–1933), who later advanced and received a professorship.

Some years later, Nordentoft had an endoscope made by the technician/engineer Loewenstein in Berlin after a design suggested by himself and his brother, Dr. Jacob Nordentoft. Most likely, the endoscope was more or less a copy of the Jacobaeus endoscope produced by Georg Wolf, who was also in Berlin. Thus, what the Nordentoft brothers actually contributed to the design (and the production) of the endoscope seems unclear. Severin Nordentoft presented the endoscope at the "41st Congress der Deutschen Chirurgengesellschaft" in Berlin in 1912 under the title "Ueber Endoscopie geschlossener Cavitäten mittelst meiner Trokart-Endoskops". Nordentoft described how it could be used for suprapubic cystoscopy (in cases of urethra stricture), laparoscopy and endoscopy of the knee. According to Nordentoft, the instrument's cannula had a diameter of Charriere 16 (5.3 mm), and the endoscope Charriere 13 (4.3 mm) and, he stated, that the instrument was available for purchase at Loewenstein Inc. for the sum of 95 Goldmarks.[5,22,23] Until 1914, the German Empire was on the gold standard and one mark corresponded to the value of 358 mg of pure gold. In 1912 the average price on a metric ton of rye in Berlin, Germany was 186 marks.[24]

Dr. Severin Nordentoft is now credited both for performing the first knee arthroscopy in history (before 1912) and for introducing the term "arthroscopy" (he used the Latin term arthroscopia genu). Nordentoft most vividly described the various structures inside the knee and the portals he used for viewing them. Further, he suggests using arthroscopy for diagnosing meniscal lesions: "A rupture or fibrillation of this structure (the meniscus) would very easily and clearly be seen." Most likely, the knee arthroscopies he performed were anatomical studies in deceased humans and not examination of joints in live patients. Unfortunately, Nordentoft did not indicate one or the other. Nordentoft's arthroscopic efforts received little or no attention at the time and were barely mentioned in later publications on the subject, until the last 25 years after his work was rediscovered in 1997.[22,23]

Disappointed with the lack of recognition in the surgical communities, Nordentoft gradually concentrated his energy more and more around radiography. From 1910, he ran an X-ray clinic with his brother Jacob Nordentoft. In 1920, he was appointed head of Aarhus Municipality Hospital's departments of X-ray (diagnostics) and radium treatment. However, being a stern man, he came into conflict with management and colleagues from early on. He therefore moved to Copenhagen in 1922 to continue his work, but died soon after of aplastic anaemia, related to the harmful effects of radiation.[25]

4.2. *Eugen Bircher*

Eugen Bircher (1882–1956), a Swizz physician, military officer and politician, published his experiences of 18 clinical knee arthroscopies as early as 1921 (Fig. 14). Bircher was chief of the surgical department at Kantonsspital Aarau (KSA) in Switzerland. He used the endoscope developed by Hans Christian Jacobaeus.[26] As mentioned earlier, the endoscope was produced by Georg Wolf in Berlin for use in the

Fig. 7. Julius Bruck (1840–1902), German dentist, inventor and professor of odontology in Breslau. He used a water-cooled electric lamp of glowing platinum to light up hollow organs and paved the way for modern endoscopes. Wikimedia Commons. Public domain.

examination of the thoracic cavity (thoracoscopy) and abdominal cavity (laparoscopy). Unfortunately, this endoscope was far from ideal for examining the inside of the knee and other joints. The endoscope's viewing angle was 90° and the lens for visibility was located 1.5 cm above the tip of the scope where the tungsten lamp sat. The construction of the endoscope consisting of thin lenses without surface treatment and long stretches of air, resulted in a large loss of light. The loss of light could be more than 90% resulting in a very dim image in the eyepiece. All these conditions contributed to the fact that the Jacobaeus endoscope was not very suitable for examination of the knee joint.

Bircher did about 60 knee arthroscopies from 1921 to 1930. Most of them were performed during the first two years, gradually becoming rarer. While he initially recommended knee arthroscopy as a diagnostic aid in almost all knee surgeries, in later years, he only did so when he was very much in doubt about the diagnosis. This shift was likely related to frustration with the mentioned shortcomings of the Jacobaeus' endoscope, but also an increasing interest in radiography. In 1930, he started performing double contrast radiographic examinations with air and Uroselectane. The following year he published his experiences from the first 250 double contrast examinations of the knee and other joints. Among non-orthopaedic surgeons, Bircher is probably most remembered for being an officer (colonel) and a politician. He was instrumental in the establishment of the politically far-right Schweizerischer Vaterländischer Verband (SVV) in 1919.[27]

4.3. Kenji Takagi

Professor of orthopaedic surgery Kenji Takagi (1888–1963) at the

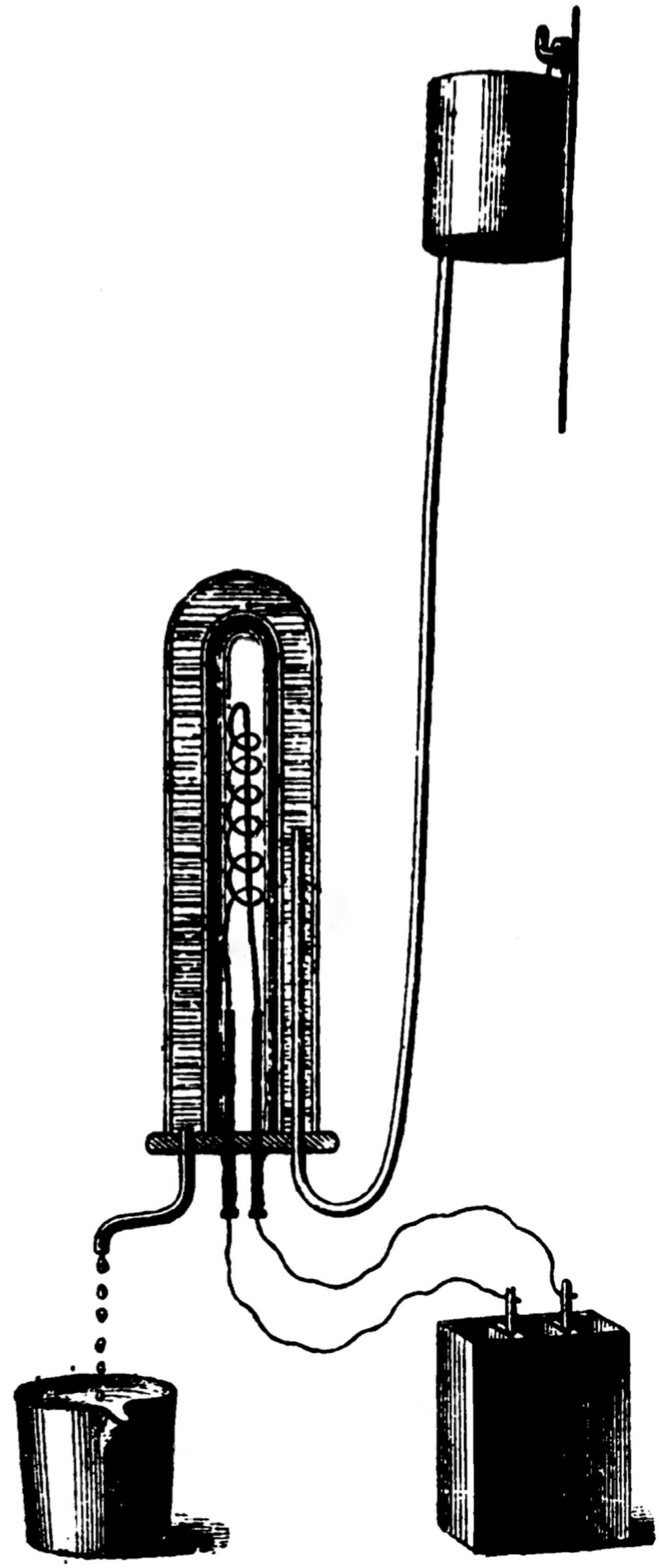
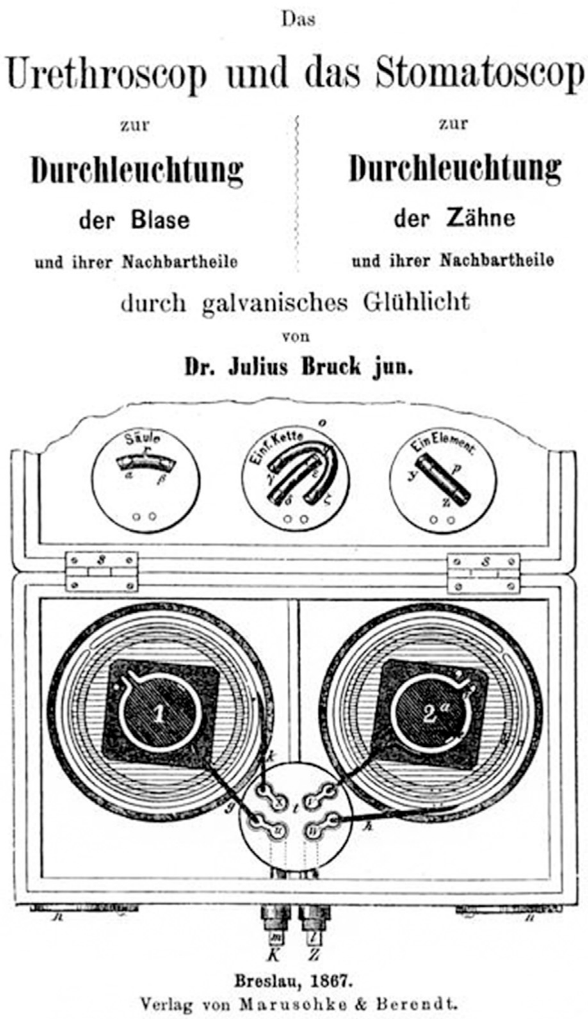


Fig. 8. The construction of the device, Das Urethroscop und das Stomatoscop by Julius Bruck. Digitized by Google Books. Public domain.

Tokyo University, Japan described in a 1939 paper[8] how in 1918 he started experiments with arthroscopy of knees of deceased humans with a 7.3 mm cystoscope (Fig. 15). However, his initial experiences were disappointing and led him to develop his own endoscope intended specifically for arthroscopy. By 1920, he had a prototype of his arthroscope.


Das

Urethroscop und das Stomatoscop

zur Durchleuchtung der Blase und ihrer Nachbartheile | zur Durchleuchtung der Zähne und ihrer Nachbartheile

durch galvanisches Glühlicht

von

Dr. Julius Bruck jun.

Breslau, 1867.

Verlag von Maruschke & Berendt.

Fig. 9. Front page of the book, Das Urethroscop und das Stomatoscop zur Durchleuchtung der Blase, der Zähne und ihrer Nachbartheile durch galvaisches Glülicht by Julius Bruck, 1876. Wikimedia Commons. Public domain.

However, this first prototype was not very suitable for regular clinical use, probably primarily due to its size. Thus, Takagi writes retrospectively (in 1939): “Only in one exception, in an elderly woman who had fistula due to tuberculous arthritis of the knee, was this primitive arthroscope successfully inserted from the external orifice of the fistula”. The 1939 article was translated from Japanese and reproduced in 1982.[8] Takagi's ambition was to develop an arthroscope that could be used routinely in patient care. The prime motivation was to be able to detect, at an early stage, tuberculosis of the joint, which often resulted in ankylosis, and initiate early treatment.

It was not until 1931 that he had managed to create a 3.5 mm arthroscope, Takagi #1, that was suitable for clinical use. The following year, 1932, he presented his experience at the Japanese Orthopaedic Association's meeting in Tokyo, illustrated with black-and-white arthroscopic photographs. In 1933, at the next year's meeting of the association, he presented colour images and film footage from arthroscopies.[8] In 1937, the first arthroscope with adjustable focus, “Takagi #4″, became available and was presented at the World's Fair in Paris, France that same year. In the article from 1939, Takagi describes his recommended portals for arthroscopy of the knee, shoulder, ankle and hip.[8] These are about the same portals that are still being used today. After the second world war, his student, Watanabe, headed the development of arthroscopy in Tokyo.

Fig. 10. Maximilian Carl-Friedrich Nitze (1848–1906), German urologist and inventor. His cystoscope, developed in cooperation with instrument makers in Berlin and Vienna, was quickly embraced by the urologist community all around the world. Wikimedia Commons. Public domain.

4.4. Phillip Heinrich Kreuscher

Phillip Heinrich Kreuscher (1883–1943), a son of German immigrants, started his surgical education as an intern at the Murphy Institute in Chicago in 1909. In 1912, he travelled to Heidelberg and worked there as part of his surgical education. It was most likely in Heidelberg that he became familiar with the use of Jacobaeus' endoscope for examination of the abdominal and chest cavities. Further, it is not unlikely that he attended the surgical congress in Berlin (Congress der Deutschen Chirurgengesellschaft) in 1912 and heard Nordentoft describe his arthroscope.[5,28]

Back in Chicago, he performed thoracic endoscopies with a Jacobaeus' endoscope and eventually also did knee arthroscopies, presumably with the same endoscope.[28] He was the team physician for the Chicago White Sox baseball team (Fig. 16) and used the endoscope to make the correct diagnosis of meniscal tear. In 1925, he published the paper “Semilunar cartilage disease, a plea for early recognition by means of the arthroscope and early treatment of this condition".[29] He is therefore credited with the first publication on arthroscopy in North America. However, just like most other contemporary arthroscopy devotees, he soon realized that most orthopaedic colleagues had little interest in the procedure. Further, the endoscope he used was not very suitable for arthroscopy (see section above on Eugen Bircher, who used the same endoscope) and he hardly did more than 25–30 arthroscopies before he lost his drive.[28]

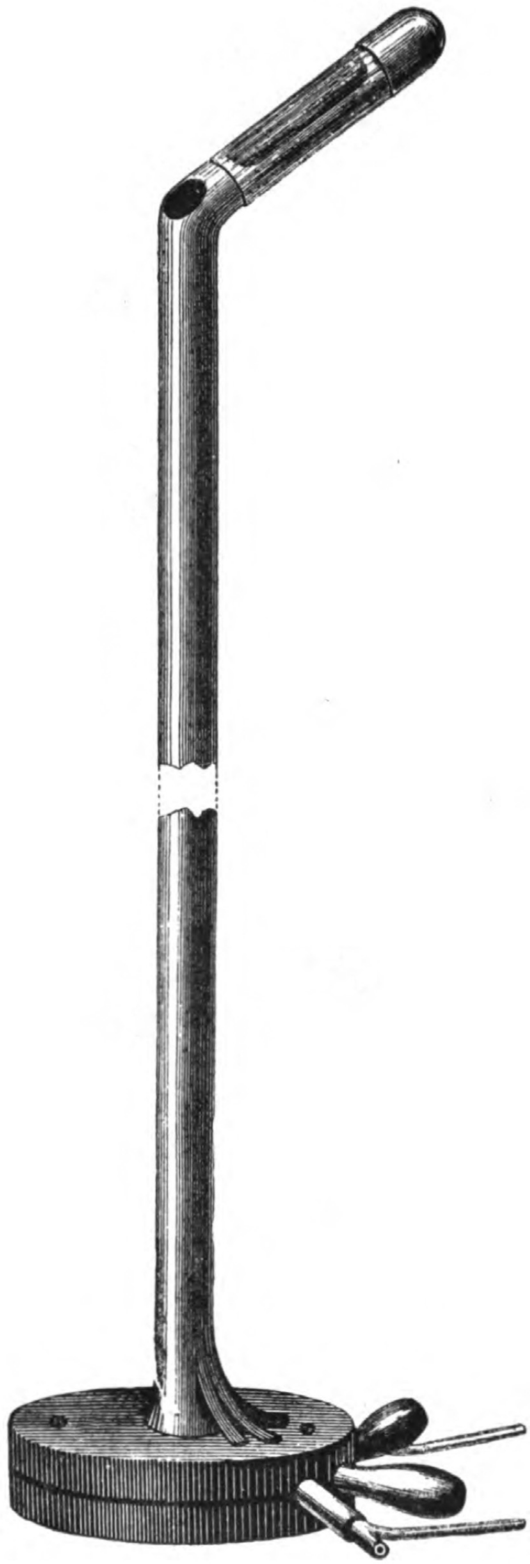


Fig. 11. Nitze's cystoscope of 1877 (with water-cooled platinum lamp, later to be replaced by the incandescent lamp invented by Edison, resulting in a slimmer endoscope). From the book, The electric illumination of the bladder and urethra. Edwin Hurry Fenwick 1889. Digitized by Google Books. Public domain.

Fig. 12. Professor Hans Christian Jacobaeus (1879–1937), was an innovative Swedish specialist in internal medicine He is credited, in 1910, for being the first to describe the endoscopic examination of the abdominal and chest cavity with a Nitze cystoscope. He later developed a method for treating pulmonary tuberculosis thoracopically. Wikimedia Commons. Public domain.

4.5. Michael S. Burman

American surgeon Michael S. Burman (1896–1974) got the idea for an arthroscope in 1929. He contacted instrument maker Reinhold Wappler in New York City in February 1930 and had him make a specially designed 4 mm endoscope. At the time, Wappler, as a founding partner of the American Cystoscope Makers Inc., was a large producer of cystoscopes based on the invention of Nitze, in competition with German and Austrian producers in the American market. In March 1930, attempts began to examine cadaver joints at the anatomical/pathological department of New York University Medical School. However, his anatomical arthroscopy studies in New York were interrupted the same summer due to a lack of body parts for the purpose. That same fall, Burman travelled to Europe financed by a travel scholarship. The experiments were resumed in February 1931 when he arrived at the pathological institute at the Krankenhaus der Friedrichstadt-Dresden.[30]

At the time when he was about to publish a paper about his own experience, he became aware that Bircher had already completed a great number of clinical knee arthroscopies, and Burman gallantly credited Bircher for predating him with the idea and implementation of arthroscopy.[6] He also became aware that colleagues in New York had started similar studies while he was working in Dresden. Neither Bircher nor Burman seemed to be aware of the publication of Nordentoft in 1912. Further, Takagi's work in Tokyo was probably not known of either in North America or Europe, and even in Japan, few surgeons paid any notice to his work. The work of Burman included arthroscopy of the shoulder, wrist, hip, knee and ankle. At first, he considered the elbow to

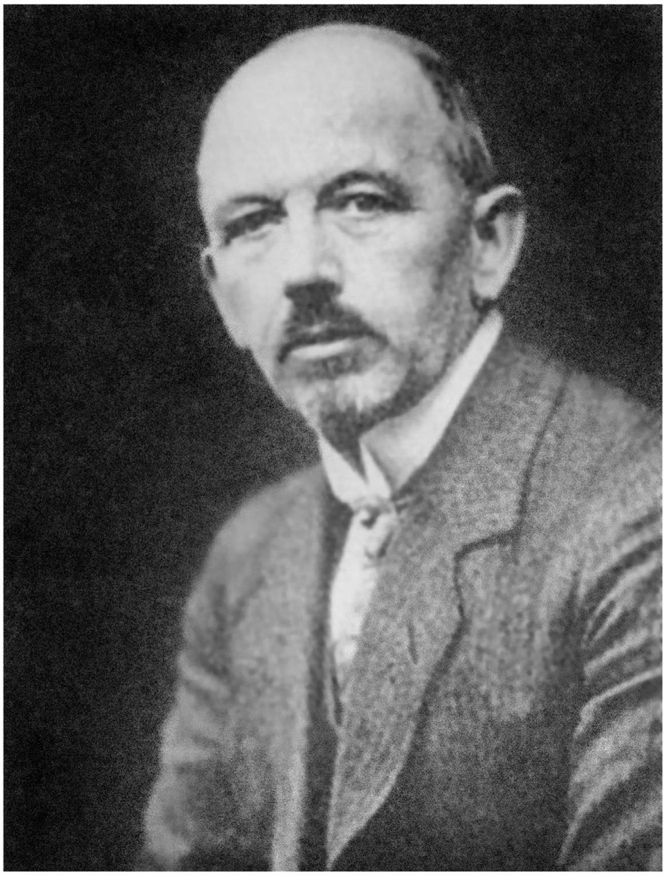


Fig. 13. Dr. med. Thomas Severin Johannes Nordentoft (1866–1922), Danish surgeon and radiologist, is credited for being first to report an arthroscopic examination in 1912. Public domain.

be inaccessible for arthroscopy, but he later changed his mind using other portals.[31] Burman, with the help of a skilled medical illustrator from Dresden, printed beautiful watercolour illustrations of the arthroscopic procedures of various joints. He is credited for publishing the first arthroscopic images in colour.[6,28] Back in New York City at the Hospital for Joint Diseases, he started clinical use of arthroscopy. He worked there for the rest of his life as an orthopaedic surgeon. Together with colleagues Finkelstein, Sutro, and Mayer, the group published several works on their clinical experiences with knee arthroscopy.[32,33] In the 1950s, he collected material for an arthroscopic atlas, but unfortunately never found any publishing house willing to print and publish it.[28]

4.6. Ernest Vaubel

Ernest Vaubel (1902–1989) was a German rheumatologist practising in Wiesbaden, Leipzig and Frankfurt.[10] He worked together with Georg Wolf in Berlin to produce a special endoscope with 45-degree optics making it more suitable for arthroscopy. Starting in 1936 in Leipzig, he performed his arthroscopies with local anaesthesia and with the knee distended by gas. He used arthroscopy purely for diagnostics and is said to be an eminent operator of the arthroscope. Vaubel's main interest in arthroscopy related to changes in the synovium. In 1938, he published the first textbook of arthroscopy in history. The book, a monograph of 64 pages, contained beautiful watercolour illustrations that were based on photographs captured with a rangefinder camera connected to the eyepiece of the arthroscope. In 1940, he established a private practice where he continued performing arthroscopy. In 1941, he entered the armed forces (WW II), and after the war, he stopped performing arthroscopy.[10]

Fig. 14. Eugen Bircher, Swiss physician, military officer and politician (1882–1956) published his experiences of 18 clinical knee arthroscopies as early as in 1921. Here seen together with fellow travellers in front of a Douglas DC-2 airplane operated by Swiss Air in 1935. Wikimedia Commons. Public domain.

4.7. Masaki Watanabe

Masaki Watanabe (1921–1994) was born in Nagano in Japan. He graduated from Tokyo Imperial University in 1937. He became interested in orthopaedic surgery, especially arthroscopy, and was mentored by Professor Takagi. Their work was interrupted by the Second World War. In 1949, Watanabe started working at the Tokyo Teishin Hospital, a hospital for postal employees and their families, and he became the director of the orthopaedic department. From this hospital and position, he continued the development of arthroscopic surgery started by his mentor more than 30 years previously.

In 1951, the 13th model of the arthroscope, based on Takagi's work, was for the first time named after Watanabe.[34] In 1958, Watanabe published the first edition of his Atlas of Arthroscopy with colleagues Hiroshi Ikeuchi and Sakaee Takeda as co-authors (the second edition illustrated with colour photographs was published in 1969). In 1960, the Watanabe #21 arthroscope was presented after 1–2 years of development. This device is today considered to be the first arthroscope suitable for routine use and it was made commercially available.[35] Still, the light source (electric lamp) sat at the end of the arthroscope and had an unfortunate tendency to get caught within soft-tissue and could, in the worst cases, be torn off inside the joint, or even be broken by an unfortunate move by a grasper, leaving pieces of glass inside the joint.[36,37] The arthroscope had a field of vision of 100° in air and 88° in water. The depth of focus was

Fig. 15. Professor Kenji Takagi (1888–1963) in Tokyo started experiments with arthroscopy of knees of deceased humans with a 7.3 mm cystoscope in 1918. However, the initial experiences were disappointing and led him to start work developing his own endoscope intended for arthroscopy. Wikimedia Commons. Public domain.

from 1 mm to infinity. The magnification was 10 times at a distance of 1 mm, growing smaller at greater distances.[35]

The first arthroscopic meniscectomy was done on May 4, 1962, by Masaki Watanabe. A young man had during a basketball game suffered a flap rupture of the medial meniscus. The flap was cut loose with a pair of scissors, which were brought into the knee via a separate incision. Then the flap was moved up into the suprapatellar recess and extracted with Kocher forceps. The man was back on the basketball court after 6 weeks. In 1969, the young colleague at Tokyo Teishin Hospital, Dr. Hiroshi Ikeuchi (previously also the translator between Watanabe and Jackson when the latter visited Tokyo in 1964), performed the first arthroscopic meniscus repair in history. The fact that arthroscopy was now used therapeutically and not only diagnostically, forced the development of special surgical instruments for this use.[36] In 1975, Watanabe #21 CL came with "cold light", an external light source that illuminated the joint via a flexible fibre optic light wire associated with the arthroscope.[35] Nippon Sheet Glass Co. supplied fibre optics to Tsunekichi Fukuyo who produced the arthroscopes.

4.8. Robert W. Jackson

In 1964, Dr. Robert W. Jackson (1932–2010) from Toronto received a travel scholarship. Jackson chose, quite untraditionally, to travel to Tokyo. His main purpose was to work with cell cultures at the University of Tokyo. However, the Summer Olympics were going to take place in Tokyo that year, and he was also going to be a physician for Canada's squad. Further, Jackson had heard from a colleague that a Japanese orthopaedic surgeon had made a presentation about knee arthroscopy at a congress in Europe a few years earlier. The colleague did not remember the name, but believed the surgeon was based in Tokyo. In Tokyo, Jackson eventually found the name of the orthopaedic surgeon (Masaki Watanabe) and where he worked (Tokyo Teishin Hospital). At the time, Watanabe was not well known either inside or outside Japan. Jackson

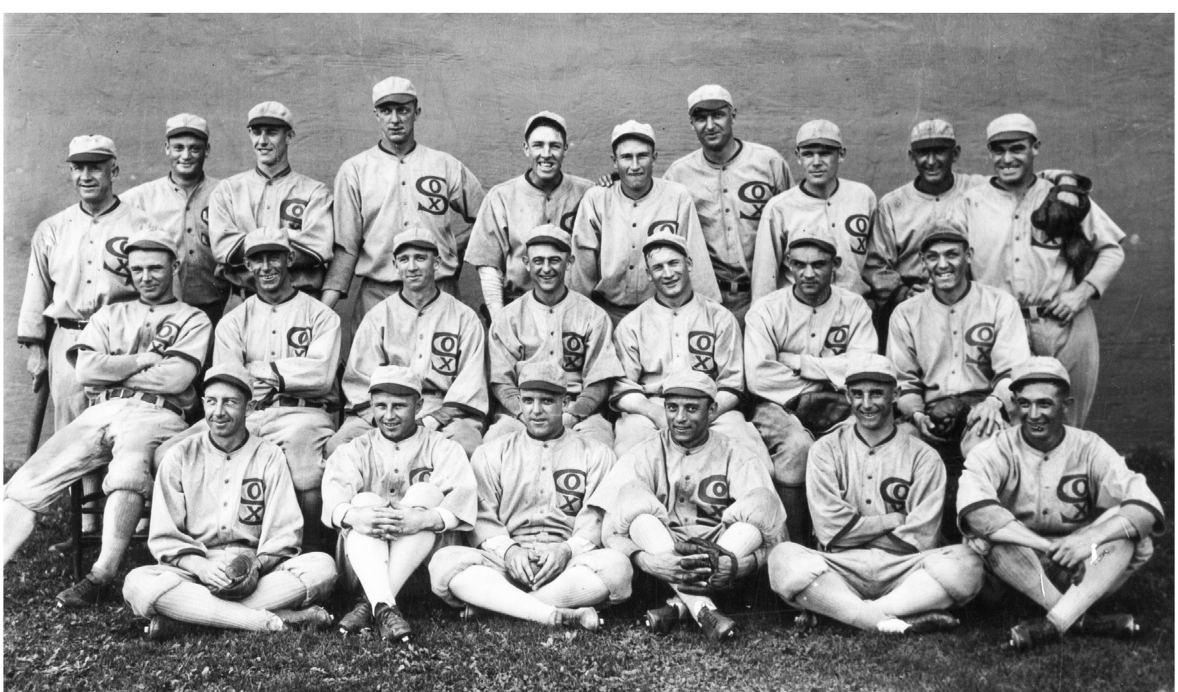


Fig. 16. The Chicago White Sox baseball team of 1919. After the 1919 season, the team was accused of match fixing bribery in the Major League Baseball League (MLB). The accusation was that the team had lost on purpose in important matches at the end of the season, bribed by a gambling syndicate (the Black Sox Scandal). Public domain.

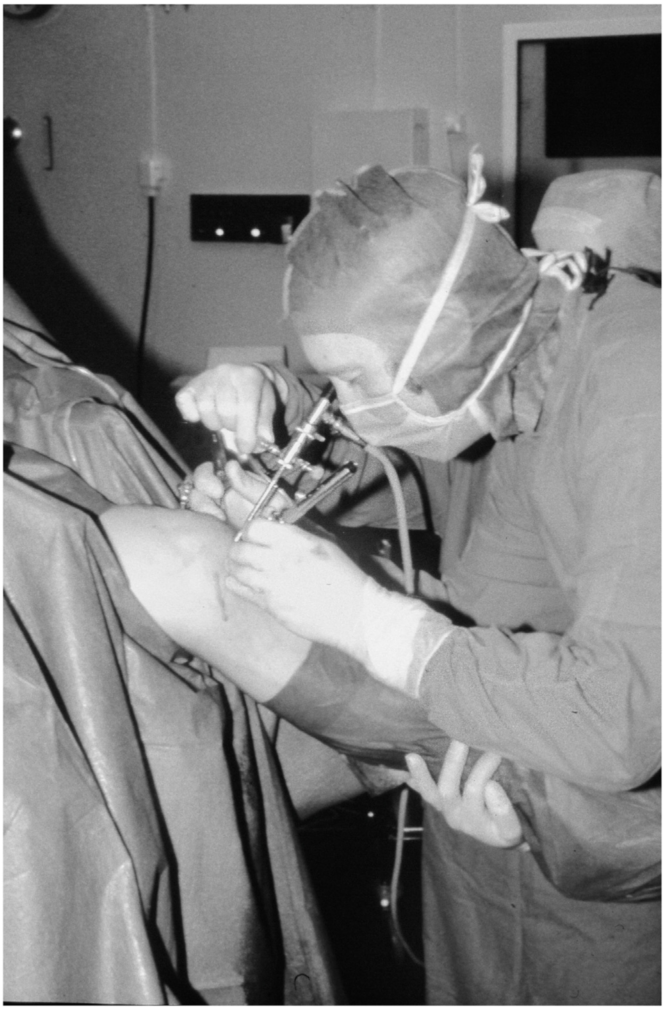


Fig. 17. One of the authors (G. U.) is performing a knee arthroscopy in 1978 with an arthroscope designed based on the inventions by Hopkins and Stortz. Private photography. Copyright by the authors.

sought out Watanabe and the two became good friends. Watanabe taught Jackson arthroscopy (Dr. Ikeuchi, mentioned previously as an innovative orthopaedic surgeon, spoke English after having spent three years as a resident in New York, and acted as a translator), and Jackson taught Watanabe English.

In 1965, Jackson was back at Toronto General Hospital. He had brought with him a Watanabe #21 arthroscope, paid for by the hospital, and he immediately started practicing arthroscopy. Jackson was enthusiastic, but the work was hampered by little enthusiasm, and even some distrust, among colleagues. Further, the arthroscope was at times damaged, including by erroneous autoclaving (it had to be sterilized in gas), and had to be sent back to Tokyo for repair. Luckily, things got better as time went on. Jackson was increasingly often asked to give lectures on arthroscopy and more and more colleagues contacted him in Toronto to learn the technique.[28] Thus, Jackson helped spread arthroscopic surgery in North America and Europe. It is also largely Jackson who made the group in Tokyo widely known.

In 1972, Jackson and Dr. Isao Abe published their experiences during their first 200 knee arthroscopies with the Watanabe #21 arthroscope.[14] Most arthroscopies were diagnostic and were followed by open surgery when indicated. However, open surgery could often be prevented when the arthroscopic examination concluded with normal findings. Further, in some cases the problem could be solved arthroscopically, especially when loose bodies were found and when simpler meniscus surgery could be performed. In 1976, Jackson together with British Dr. David Dandy,

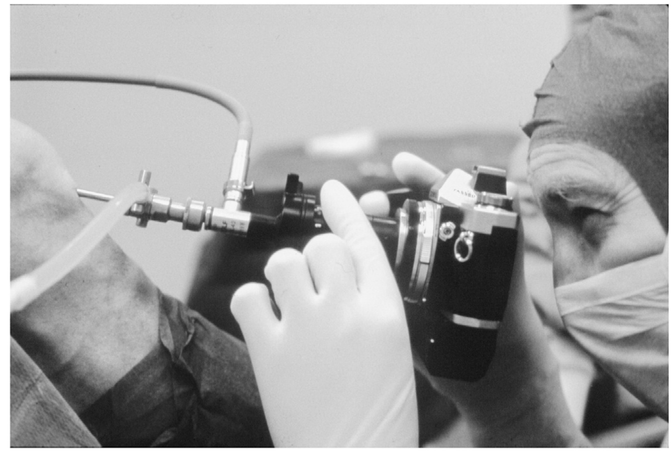


Fig. 18. One of the authors (G. U.) is performing a knee arthroscopy in 1978. An analogue (SLR) still film camera loaded with 36 frames of 35 mm film (popularised by Nikon, Japan in 1960) could be connected to the arthroscope providing photographic documentation of intraoperative findings. Private photography. Copyright by the authors.

who pioneered arthroscopy in UK, published the first textbook on arthroscopy in the English language.

In 1994, Jackson was mentioned as number 37 of the 40 most influential figures in the sports world over the past 40 years in Sports Illustrated, alongside Muhammad Ali, Michael Jordan, Pele, and Arnold Palmer. Jackson was honoured for being an inventive sports orthopaedic surgeon and especially for leading the introduction of arthroscopic diagnostics and treatment, which had allowed many injured athletes to return to their sport more quickly.[38] Thus, it was largely satisfied athletes, with shortened rehabilitation, who popularised arthroscopic procedures.

4.9. Harold Horace Hopkins

Harold Horace Hopkins (1918–1994) was the sixth child in a poor family living in the slums of Leicester, England. Still, his mother urged him to study, and at 11 years of age, he received one of only two scholarships in the county of Leicestershire, allowing him to enter a local grammar school. At the age of 18, he won a scholarship to University College of Leicester, later graduating in physics and mathematics. During the second world war, he worked for an optics company in Leicester producing a variety of war equipment. At the same time, he continued research on optical design and defended his PhD thesis on the subject in 1945. In 1947, he was employed as a researcher at Imperial College London. He received many prestigious rewards during his lifetime and was twice nominated for a Nobel Prize. Within optics, he is remembered for inventions instrumental to the development of zoom lenses for photographic cameras, flexible fibreoptic endoscopes, flexible fibreoptic light cables and rod-lens endoscopes.[39]

In the early 1950s, Hopkins and Kapany proposed the use of properly aligned bundles of very thin fibres of glass for flexible endoscopes and suggested the term "fibrescope".[11] Kapany (1926–2020), an Indian-American physicists played a very important role in the invention, and is by many regarded as the unsung hero (of the invention) (https://en.wikipedia.org/wiki/Narinder_Singh_Kapany). Further, they described a method for producing bundles of glass fibres correctly aligned, meaning that the arrangement of fibres is the same in both ends, as misaligned fibres would result in a distorted image.[11] Unfortunately, lack of financial support prohibited Hopkins and his co-workers from developing his innovation further and turning it into a commercial product. However, the South African gastroenterologist, Basil Hirschowitz, realized the innovation's great potential. He teamed up with two physicists at the University of Michigan, Ann Arbor, USA. They presented

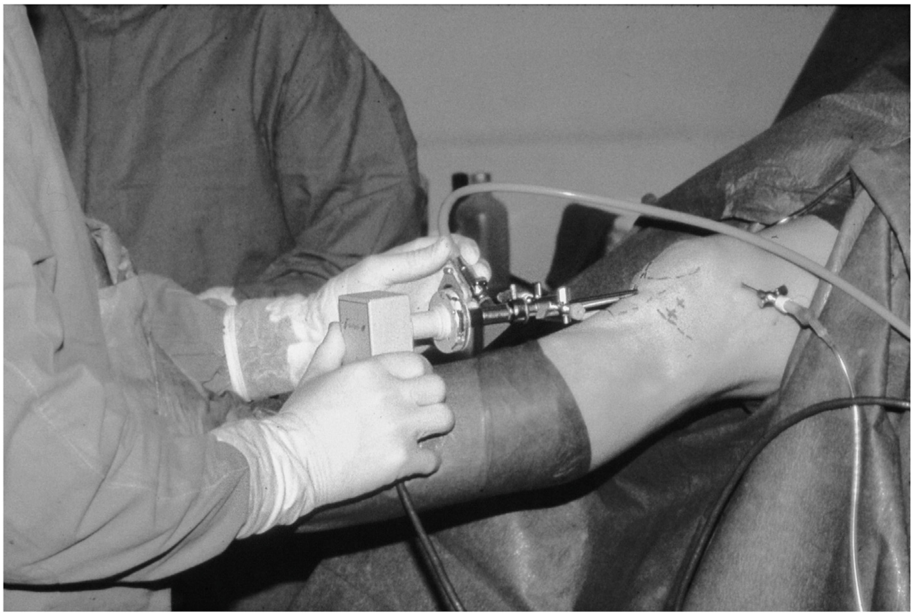


Fig. 19. One of the authors (G. U.) is performing a knee arthroscopy in 1983 with the same arthroscope as in Figs. 17 and 18, but now it is connected to a CCD camera and a monitor. Being able to see what was going on inside the joint, by a camera connected to the arthroscope and a monitor, in real time, was instrumental to performing therapeutic surgery, and teaching colleagues the necessary skills. Private photography. Copyright by the authors.

the first clinically useful flexible gastroscope at a scientific meeting in 1957.[40] The early fibreoptics tended to lose a large amount of light. This was prevented by coating each glass fibre before assembling the bundles, by melting together high-refractive-index (RI) optical core glass and low-RI coating. Later, in the mid-1960s, fibreoptics (as a flexible cable) was used for transmitting “cold light” from an external light source (halogen or, later xenon lamp) to the endoscope.[39]

The next important innovation by Hopkins and his co-workers was the use of rod lenses in inflexible endoscopes. The traditional endoscopes based on Nitze's design were plagued by massive loss of light, often 90% or more. Thus, a urologist from Liverpool, James Gordon Gow, was unhappy with the quality of the photographs (of bladder tumours) captured with his traditional cystoscope connected to a still camera, and he contacted Hopkins at Imperial College for help in improving upon the endoscope. Hopkins reluctantly agreed to investigate the matter after Gow managed to obtain funding for the project. The story has it that Hopkins stumbled onto the solution as he used thicker lenses when experimenting, as they were easier to mount within the endoscope, and discovered that they improved light transmission and, thus, the brightness and sharpness of the image brought to the examiner's eye. Thus, most of the inside of the endoscope was filled with rod lenses separated with only very short stretches of air, quite the opposite of the traditional design. To further increase light transmission and minimize optical aberration, the lenses were coated with a multilayer anti-reflective material.[12,39]

Once again, Hopkins was out of luck finding British or American investors and/or producers for his new ground-breaking endoscope. However, in 1965 he gave a presentation of his work on the new cystoscope at a meeting for urologists in Köln, Germany, illustrated by cystoscopy photographs captured by Gow. The audience was thrilled and asked where they could buy the endoscope. Hopkins had to respond that it was not yet in production. Back in London, he soon received a phone call from instrument maker Karl Stortz in Tuttlingen, Germany. Stortz offered to produce the endoscope, and a few days later a business deal was signed in London between the two. Karl Stortz suggested that the cystoscope be provided with light from an external lamp transmitted to and through the endoscope by fibreoptics (cold light). The new Hopkins-Stortz cystoscope was presented at an international meeting for urologists in München in 1967.[39]

4.10. The modern arthroscope – The end of this story

In 1970, O. Wruhs in Vienna was probably the first to promote the clinical application of a cold-light arthroscope fitted with rod lenses.[10] Eliminating the incandescent lamp on the tip of the arthroscope removed heat away from the joint (possibly causing pain and harm to the patient) and eliminated the danger of dislodged and broken lamps. Further, removal of the dead space caused by the lamp, allowed the arthroscope to get closer to the structures being examined. Lastly, it allowed the endoscope to have a broader spectre of viewing angles. Today, the most common arthroscopic optics have a viewing angle of 30° (followed by 70°).

At about the same time (late 1960s and early 1970s), in Tokyo, Watanabe was also working with prototypes implementing cold light into his popular #21 arthroscope, which was based on an older optics design, without rod lenses. Some have suggested that he was the first to design an arthroscope with an external light source that illuminated the joint via a flexible fibre optic light wire connected to the arthroscope.[28,41] However, Watanabe himself does not make such a claim and stated in 1978 that his first cold light arthroscope, the Watanabe #21 CL, was made available in 1975.[35] Reportedly, Nippon Sheet Glass Co. supplied the fibre optics to Tsunekichi Fukuyo, who produced the arthroscopes.[28,41] Still, for some years to come, Watanabe and his North-American colleagues preferred the old #21 with the incandescent lamp at the tip, using the lamp as a retractor to push and pull soft tissue away from the optics.[28,41] Gradually, however, the Watanabe arthroscopes lost market shares to European (and eventually American) makers of modern rod lens arthroscopes with cold light, to the point when the Watanabe arthroscopes were no longer produced. The reasons were probably the old-fashioned optical design (with greater loss of light), as well as the further distance to the market and, thus, less ability to provide optimum service to customers. Still, to this day, Takagi and Watanabe are remembered as two of the most important historical figures in the design and use of the arthroscope.

Until the appearance of a live TV camera connected to the arthroscope (and a monitor), the staff in the operating theatre, except for the operating surgeon, had little possibility of knowing what was going on inside the joint being examined. This fact made arthroscopic surgery quite boring for everybody but the surgeons holding their eye to the arthroscope's eyepiece. Further, hands-on teaching, as well as performing surgery that required assistance, were very difficult and cumbersome. Still, photographic documentation could easily be provided by attaching a 35 mm SLR analogue camera to the eyepiece (Figs. 17–18).

Since the invention of television in the late 1920s, the technology was for decades still based on the cathode-ray tube (CRT). The result was very large and very heavy cameras that were usually stationary on the floor and completely unsuitable for being connected to the optics of an endoscope held by a surgeon. However, this was about to change in the early 1980s with the development of small, charged couple device (CCD) TV cameras. The technology was based on the research of scientists Willard Boyle (Canadian) and George E. Smith (American) at Bell Labs, New Jersey, USA in the late 1960s and earned them both the Nobel Prize in physics in 2009 for "the invention of an imaging semiconductor circuit – the CCD sensor, which has become an electronic eye in almost all areas of photography". The resulting small and light-weight camera units could rather easily be manufactured to fit to the eyepiece of an arthroscope and allow for live images on a connected monitor. The surgeon and staff being able to view the inside of the joint in real time was instrumental to performing therapeutic surgery and teaching colleagues the necessary skills (Fig. 19).

Today, arthroscopic surgery is generally regarded as one of the most important innovations in orthopaedic surgery, together with joint replacement and internal fixation of fractures. Before arthroscopy (and MRI), the knee, and any other joint, had to be cut open, by an arthrotomy to make a definitive diagnosis and treat any pathology. The benefits of arthroscopy include minimally invasive surgery with low morbidity, early mobilization and the ability to perform the surgery as an outpatient procedure. Some of the first to recognize the benefits of arthroscopy were injured athletes, and their coaches, due to the significantly shortened rehabilitation. The development of MRI for diagnostic purposes and innovative arthroscopic techniques, equipment and implants, have changed arthroscopy into mostly therapeutic rather than merely diagnostic.

In the following years, after the introduction of the modern arthroscope with cold light and a CCD video camera, arthroscopy has evolved anatomically from being used primarily for the knee joint to application in almost every joint in the human body, first including the shoulder, then the ankle, hip, elbow and wrist. Further, arthroscopically-assisted procedures have flourished widely beyond what is possible to cover in this paper. Ending the story, we recognize that in focusing on the work of some important figures (so-called founding fathers), we may have left others out that may have been equally important to the progress of arthroscopy. We also want to recognize that the work of engineers, opticians, and technicians (including what we call 'the medical industry'), has been, and still is, instrumental to the development of arthroscopy and arthroscopic surgery.

5. Conclusion

Today, arthroscopic surgery is generally regarded as one of the most important innovations in orthopaedic surgery, together with joint replacement and internal fixation of fractures. The benefits of arthroscopy include minimally invasive surgery with low morbidity, early mobilization and the ability to perform surgery as an outpatient procedure. In this paper, we document some important milestones and important figures on the thorny path from open surgery to the adoption of the arthroscope as a useful orthopaedic tool.

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Authors contribution

All authors contributed to the conception and design of the study, the data collection and the analysis of the data. ES and CG drafted the manuscript. SD performed critical revision of the manuscript. All the authors read and approved the submitted version of the manuscript.

Declaration of competing interest

None.

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