History of urodynamics. Its origins, development and implication for urology as a specialty in Europe and the USA

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History of urodynamics. Its origins, development and implication for urology as a specialty in Europe and the USA

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ABSTRACT

The field of urodynamics playes a major role in the development of urology as a specialty. It was the corner stone in functional thinking and a major point in establishing a science of its own, because physiological aspects payed the major role in generating new theories. This was in contrast to surgery. Within this field of medicine it needs up to the 1970th and 1980th establishing a functional view on aspects of treating diseases at all. Up to this time here, knife had the first place.

A part of this topic regarding aspects of the German speaking countries had just been published Moll F. Halling T Geschichte der Urodynamik in: Schultz-Lampel, D., Goepel, M., Hampel, C. (eds) Urodynamik. Springer, Berlin, Heidelberg. 2022 pp 3-22 https://doi.org/10.1007/978-3-662-59066-9_1 p 2-22.

Moll, F. 2001 Historische Anmerkungen zur Entwicklung der Neuro-Urologie in: Nissen G., Badura F. (Hrsg) Schriftenreihe der Deutschen Gesellschaft für Geschichte der Nervenheilkunde, Band 7. Königshausen und Neumann Würzburg 2001.

1. Introduction

Besides cystoscopy and uroscopy (modern: the analysis of urine), urodynamics is one of the early examination techniques, which constitutes the medical specialty of urology. Significantly urodynamics helps to establish the way of functional thinking within this field. Saul Boyarsky stated, that urodynamics has made possible a physiological directed surgery, because this discipline has amalgamed the physical, engineering and biological sciences into clinical surgery [1]. While cystoscopy has been regarded as an essential diagnostic tool of the discipline within the culture of remembrance in urology [2], the examination technique of urodynamics and the associated functional theory of the processes of micturition or urine transport in general. Driving forces, energy supply and control in the physiological and pathological dimensions were and are usually associated with the transfer of science and knowledge from the USA after WW II. This may be related to the fact that the term "urodynamics" was first uses in a publication by David Malvin Davis (1866–1968) in 1954 and first appeared in the renowned "Journal of Urology" in 1962 in an article by Davis and Zimskind [3–5]. The term was coined as "Urodynamik" e g.in the German literature at the beginnings of the 1970th [6]. In the former GDR the process of introduction needs up to the 1980th to establish this field. In Spain urodynamic studies of functional disorders of the lower urinary tract (LUT) were initiated in the 1970s. Azagra Cortado (Seville), Resel Estévez (Madrid) and Solé Balcells (Barcelona) were the first to write a paper for the XXXIX National Meeting of Urology in Spain at Las Palmas at 1974 on -Urodynamics General Methodology-, -Urethral and pyelic Urodynamics-and Urodynamics of the Lower Urinary Tract-. In this country the first book on neurogenic bladder disturbances was published at the same time. (Solé Balcells, Conejero Sugrañes and Rovira Rosell: Neurogenic bladder. Practical Manual-1974) [7].

The 1st International Symposium on Urodynamics had already taken place in Aachen in July 1971 under the tutelage of Wolfgang Lutzeyer (1923–2006) and Hans-Joerg Melchior. An equally important meeting for Germany has had already been organized in 1969 [8]. Several postdoctoral thesis e g at German University departments as Aachen (Hannappel), Homburg/Saar (Haubensack) and Mainz (Stockamp, Jonas) underline the new university claim in this European country. This was an important cornerstone of research for founding a new academic group, the "International Continence" Society in

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1971, which today has about more than 3000 members and whose historicization process is just at its beginnings with collecting personal memories and the depending literature [9–14].

The mayor contributions and contributors from other European and non-European countries should not be forgotten here. (e.g. Frank Hinman 1915–2011, José Gil-Vernet 1922–2020, Pieter Doncker 1914–1999, Marco Caine [15] 1923 - ? and D. Edwards, Emil Tanagho 1929–2024 and Ahmed Elbadawi 1945–2010).

For many physicians at that time the publication of Richard Turner-Warwick (1925–2020) in 1979 in the famous series "The urologic clinic of North America" "Clinical Urodynamics" was regarded as the bible for many clinicians dedicated to this field at that time [16]. The other one was Saul Boyarsky's, St. Louis (1923–2019) "Neurogenic Bladder" in 1967 [17].

For a long time, urodynamics as a pure examination technique was even only referred to as an "experimental set up" [18], "bladder measurement", "measurement of micturition performance". Urinary transport disorders in the upper urinary tract received little attention or were still considered purely radiologically according to Alexander von Lichtenberg's (1880–1949 Mexico City) statement "Excretion urography is approximately a functional examination" [19].

For many decades up to the 1940–1950th, only a medical history and descriptions of the phenomenology had been used [20]. At best, "palpation" with a sound and later "cystoscopy" were the clinical standards, although functional disorders in the context of neuro-lues or injuries after wars, "bladder symptoms in neuroses and neurasthenia" were largely known and described in detail. However, the symptoms were often difficult to classify. For a long period of time, textbooks of urology tended only to refer to them [21–26].

Historical studies on this branch of urology had been relatively frequent in the historisization process of this subdiscipline and describe usually a history of technical progress [27–31].

2. Material and methods

Writing the history of a physiological diagnostic tool and its implication on a new subspecialty in the emerging field of urology needs not only to present original sources of several authors from different fields in a changing environment in medicine. It must deal with persons, theories and the process of merging into the specialty. Often authors from the field of medicine tend to a positivistic view – the old Whiggish history – and write a story of progress. In a modern view History of Medicine must be changed towards a History of Science and Health in general. By stressing the ways in which scientific and medical ideas and practices are shaped in a given context, it enjoins medical historians to conceptualize, explain, and interpret the process through which this happens [32]. By stressing that knowledge is produced in and through social processes, social constructionism encouraged historians to conceptualize the constituent process and to come up with imaginative ways of creating them, including through the use of a wide range of primary sources.

3. Early historical reports on bladder dysfunction

Section 31 of the Edwin Smith Papyrus (1500–1300 BC) describes overflow incontinence after a spinal trauma and is still traditionally cited up to today. However, the problems of a retrospective diagnosis had to be taken into account when analyzing the text [33–35] (see Fig. 1).

Leonardo da Vinci (1452–1519) was one of the first to apply the rules of statics, mechanics, and hydrodynamics to the understanding of the physiology of the human body. His understanding of the anatomy and physiology of the upper and lower urinary tract was mainly based on a static concept and passive concept, which led him to describe, for example, the ureters only as simple water conduit and the internal sphincteric muscle as the only active part in this system. Drawings

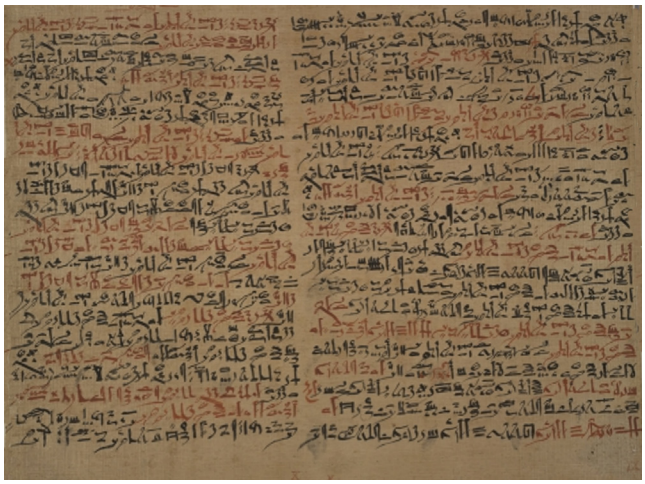


Fig. 1. Plate X and XI of the Edwin Smith papyrus including the five cervical spinal injury cases in hieratic script. The US National Library of Medicine Turning the Pages Information System (TTPI). Available at http://archive.nlm.nih.gov/proj/ttp/smith_home.html, since 1948 at the Rare Book Room, New York Academy of Medicin, with permission.

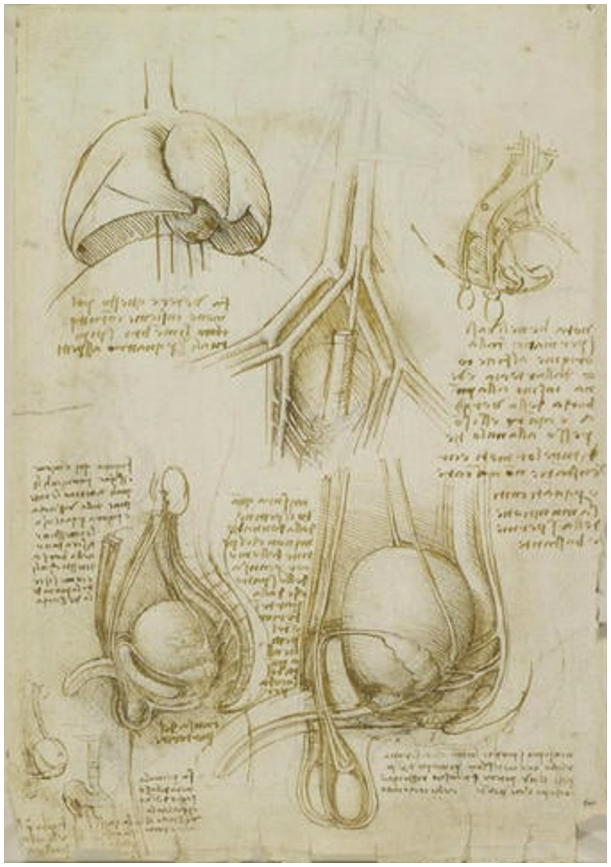


Fig. 2. Leonardo da Vinci (1452–1519) - RCIN 919098, The male genito-urinary system v, c.1508, pen ink over black chalk, 27.2 × 19.2 cm; Probably acquired by Charles II 1630–1685;The Royal Collection Trust, online Wikipedia commons.

by Leonardo Da Vinci (1452–1519) (sheet K/O 106v, RCIN 919098v) contain references to the bladder sphincter [36] (see Fig. 2).

Further on the Spanish physician and surgeon Francisco Díaz (1527–1590), was in his "Tratado nueuamente impresso de todas las enfermedades de los riñones, vexiga *y* carnosidades de la verga *y* vrina"

ACCOUNT

OF THE

MUSCLES OF THE URETERS;

AND

THEIR EFFECTS

IN THE IRRITABLE STATES OF THE BLADDER,

By CHARLES BELL, Esq. F. R. S. Ed.

TEACHER OF ANATOMY IN GREAT WINDMILL STREET.

COMMUNICATED BY

DR. CURRY.

Read June 31, 1812.

I AM about to describe a set of muscles which seem not to have been observed by former anatomists. They are attached to the orifices of the ureters, and are seated in the bladder. In health they are the instruments of a very peculiar organic action, and in disease the cause of most distressing complaints.

Before I proceed to describe the anatomy of this part of the bladder, the subject seems to require, that I should give a short historical review of the opinions respecting it.

Fig. 3. a Charles Bell (1774–1812), b first page of his paper Muscles of the ureters of 1812, Repro Moll-Keyn, with permission.

(Newly printed treatise on all diseases of the kidney, bladder and carnosities of the penis), one of the first physicians to speak of the benign prostatic hypertrophy as a cause of bladder outlet obstruction [37]. Within this text he presents a very practical perspective on fleshiness and calluses in the exit of the penis.

Until the early 20th century, the classification of the Dutch anatomist Adriaan van der Spieghel (1578–1625), Brussels, who distinguished two fiber systems of the bladder musculature (longitudinal detrusor, circular sphincter), was generally accepted. The publication is just cited today as a basic work in the anatomical literature [38,39].

Albrecht von Haller (1708–1777), Goettingen, described the bladder closure musculature in many new details even more quantitatively in the sense of an "Anatomia animata" [40].

These anatomical studies on the musculature of the bladder and sphincter system had already been supplemented at the beginning of the 19th century by Charles Bell (1774–1842), Edinburgh, who also clarified the different functions of the anterior and posterior roots of the spinal cord. In 1812, he published his pioneering study of the musculature of the ureter and bladder. The term "Bells 's muscle" as an eponym for the musculature of the bladder trigonum (M trigonalis) can still be found in urology textbooks of today [41] (see Fig. 3).

In a paper which dealt with the "nervous affections of the bladder neck" in detail Jean Civale (1792–1867) of Paris opened this topic to the new French school of urology, being just in establishment [42]. This work seems to be an influential indicator for an early preoccupation of clinically active urologists with physiological questions (see Fig. 4).

In his textbook of 1847 on physiology, Gabriel Valentin (1810–1883) of Bern, pointed out that the bladder muscles themselves carry out the emptying process and that the abdominal muscles only serve to accelerate the process of voiding in some individual cases [43].

4. Development of bladder physiology and the field of urodynamics in a new scientific context

Karl Ludwig's (1816–1895) Kymnographion (1846) [44] made it possible for the first time to record continuously physiological processes, praised as the new "graphic method of physiology" and thus also the first visual record of intravesical pressure in the form of a graph. The observation of a bodily process, in our case micturition, was now replaced by the recording of a physiological function, from which pathologies such as an increase in micturition time or a weakening of the "projection force" could then be visualized. In his habilitation (post doctoral) thesis, Ludwig himself dealt scientifically with bladder physiology and fought against the concept of the "energy of live" (vitalism), which at the time was severely hampering the development of physiology [45,46] (see Fig. 5).

In 1858, Rudolf Heidenhain (1834–1897), Halle, later, Breslau, and his colleague August Colberg (1829–1869) succeeded for the first time in registering bladder pressure in living and dead rabbits and in formulating a theory "On sphincter tone" [47] (see Fig. 6).

The work was supplemented by the investigations of Ludwig Julius Budge (1811–1888), Greifswald, in 1865, in which he was able to localize sensitive and motor pathways, the exact course of which could only be described more precisely at the end of the 19th century. Budge established that the bladder contractions either by stimulation of the pelvic never o the hypogastric nerve, although in was not until the beginnings of the 20th century that the particular difference of the species were outlined, especially concerning the hypogastric nerve [48]. At that time, the selection of laboratory animals such as frogs, rabbits, dogs and cats played a decisive role in publications on physiology. Rosenthal and Wittlich carried out these study models on human cadavers in 1857 [49].

As early as 1863, Theodor Engelmann (1843–1910), Utrecht, from 1897 Physiological Institute of Berlin "Friedrich Wilhelms Universität", was one of the first to demonstrate ureteral peristalsis in animal experiments [50].

Around 1860, the clinical – symptomatic classification of the corresponding "bladder affections" was: "atonia, paresis et paralysis vesicae" (residual urine), especially in cases of neuro-lues, diabetes, urethral strictures, apoplexia, "enuresis et incontinentia" (incontinence) in "pregnant uterus" or prostatic hypertrophy and "cystospasm et neuralgia vesicae" (urgency) in "bladder catarrh, lithiasis or carcinoma vesicae, hysterical women, masturbation". The affections were generally recognized in the repertoire of knowledge [51].

THÉRAPEUTIQUE CHIRURGICALE.

DES AFFECTIONS DITES NERVEUSES DU COL DE LA VESSIE ET DE LEUR TRAITEMENT, PAR M. CIVIALE.

J'ai signalé divers états morbides, mal déterminés jusqu'à présent, qui ont leur siége à l'urètre ou au col vésical. J'ai dit que ces états méritaient au plus haut degré de fixer l'attention des praticiens, soit à cause des accidents spéciaux dont ils deviennent la cause provocatrice lorsqu'ils existent indépendamment de toute lésion organique appréciable, soit en raison des caractères particuliers qu'ils impriment aux symptômes, quand ils compliquent d'autres maladies. Je veux élucider ici plusieurs questions qui n'ont point encore été abordées, ou qui du moins n'ont pas reçu de solution satisfaisante.

La sensibilité et la contractilité du col vésical étant liées ensemble par d'étroites connexions, l'augmentation de l'une doit nécessairement modifier l'autre, et, par suite, porter le trouble dans les fonctions de la vessie. Il est indubitable, en effet, que les divers modes de constriction du col vésical jouent un grand rôle dans la plupart des affections dont la vessie peut être atteinte.

Jusque dans ces derniers temps, on n'a eu, sur la sensibilité et la contractilité de la vessie, que des notions assez confuses, déduites de

Fig. 4. a Jean Civiale (1792–1867) lithography by Maurin, BIUM Paris b First page of the paper Des affections dites nerveuses du col de la vessie et de leur traitment. Bull gen. de therap. med chir 28 1841 214–227, Repro Moll-Keyn, with permission.

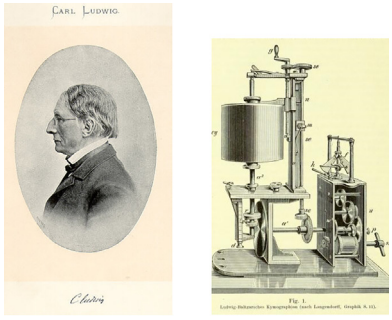


Fig. 5. a Carl Ludwig (1816–1895) "Galerie hervorragender Ärzte und Naturforscher"sides cut, Münchener Medizinische Wochenschrift, Lehmanns Verlag, after 1900, Repro Moll-Keyn, with permission b Frank, O. (1911). Kymographion, Schreibhebel, Registrierspiegel, Prinzipien der Registrierung. In: Robert Tigerstedt (ed.). Handbuch der physiologischen Methodik, Erster Band: Allgemeine Methodik. Protisten, wirbellose Tiere, physikalische Chemie. Stoff- und Energiewechsel, Vierte Abteilung: Allgemeine Methodik II. 1–50. Insb. S. 2, Hirzel, Leipzig.

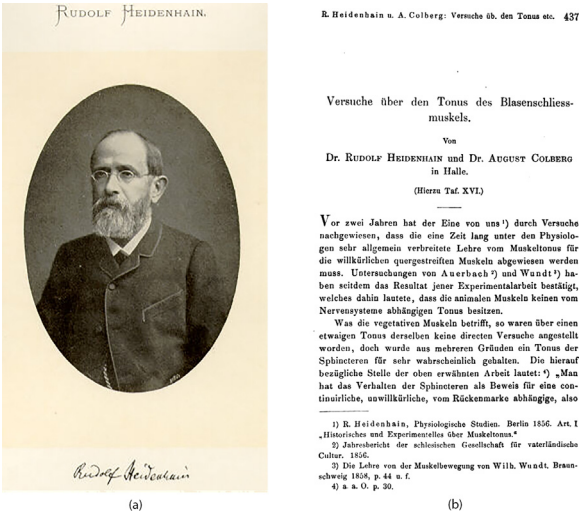


Fig. 6. Rudolf Heidenhain (1834–1897) a "Galerie hervorragender Ärzte und Naturforscher"sides cut, Münchener Medizinische Wochenschrift, Lehmanns Verlag, nach 1900, b first page publication of 1858 Repro Moll-Keyn, with permission.

In 1912, Ramon Guiteras (1858–1917), the founder and first president of the American Urological Association by example differentiated just in the same way as 50 years earlier mainly the disturbances of micturition into two major groups: "urinary retention" and "incontinence" [52].

During the same period of time, "measuring" methods began to establish themselves in clinical medicine. These were based on the principles of experimentation, observation and graphic recording, which were already established in physiology at that time. This promoted a precise methology at the patient's bedside and finally dispensed with speculation and metaphysics. Apparatus and endoscopes made it possible to measure body temperature and blood pressure. Chemistry helps to analyze excretions. The graphical representation, the "(fever) curve", became the central reference point of the "medical record" even for urological patients [53].

As a French scientific contribution, Gianuzzi registered contractions of the bladder muscle after stimulation of the spinal cord in a dead dog in 1863 following spinal cord transsections [54].

Friedrich Goltz (1834–1902), Halle, later professor at the Imperial University in Strasbourg from 1871 on, discovered the lumbosacral reflex of micturition in 1874, referring to Gianuzzi 's publication. He described that micturition could be triggered by the stimulation of sacral dermatomes or by increased pressure on the suprapubic region [55].

In 1872, gynaecologist Christian F. Schatz (1841–1920) publishes the results of the fist cysto manometric bladder pressure measurement in humans, whereby he actually records the pressure within the cavum uteri [56].

Based on the preliminary work of Schatz, Paul Charles Dubois (1848–1918), later a neuropathologist in Bern, Switzerland, carried out systematic studies on living persons under certain stress conditions and in different postures in this doctoral thesis (dissertation) in 1874. At the same time, he also carried out rectal pressure measurement for

VI.

Ueber den Druck in der Harnblase.

Von

Dr. P. Dubois,
chemal. Assistenzarzt der med. Klinik zu Bern.

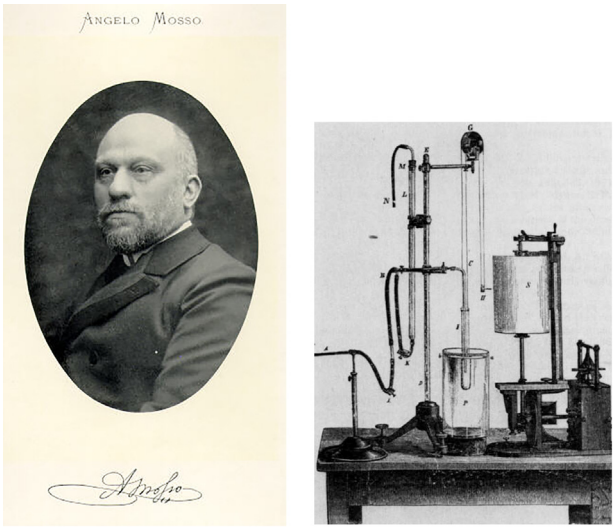
Meines Wissens sind über den Druck in der Blase speciell noch keine Untersuchungen gemacht worden. Nur von Schatz[1]) wurden einige Messungen des Blasendruckes vorgenommen, indessen in der Absicht, den Intraabdominaldruck auf diese Weise zu studiren.

Folgende Experimente, welche ich auf Veranlassung meines hochverehrten Lehrers, Herrn Prof. Dr. Quincke, anstellte, haben zum Zweck, den Blasendruck bei verschiedenen Menschen im normalen und pathologischen Zustand zu messen.

Die von mir angewandte Methode ist die von Schatz in genannter Arbeit angegebene.

Ein metallener oder elastischer Katheter wurde in die Blase eingeführt und mittelst eines Kautschukschlauches mit einer geraden, etwa 150 Cm. langen Glasröhre in Verbindung gebracht. Ein gra-

Fig. 7. a Paul Charles Dubois (1848–1918) State archives of Bern, b paper "Über den Druck in der Blase" (About the pressure within the bladder) Dubois P Über den Druck in der Harnblase. Dt Arch Klin Med 17 1876 148–163, Repro Moll-Keyn, with permission.



(a) (b)

Fig. 8. Angelo Mosso (1846–1910) a "Galerie hervorragender Ärzte und Naturforscher", sides cut, Münchener Medizinische Wochenschrift, Lehmanns, b situation of the experiment of Angelo Mosso 1882. Repro Moll-Keyn, with permission.

the first time. Later on he described involuntary detrusor contractions with consecutive urine leakage in some patients, which he was unable to detect in himself. He also found that the internal bladder pressure during filling the bladder with physiological volumes of water was constant over a certain period of time during filling up the bladder [57] (see Fig. 7).

The breakthrough in the study of bladder function was the paper of the experimental physiologist Angelo Mosso (1846–1910), who was particularly interested in muscle physiology. In 1881, together with his colleague and later forensic physicist at Pavia Paolo Pellacani (1859–1931), he was able to record bladder pressure continuously by means of a smoked glass cylinder plethysmograph for the first time [58]. They discovered that the tone of the muscles could adapt to different filling volumes without an intravesical increase in pressure (see Fig. 8).

Around 1886, Fritz Born, Bern, summarized the physiological knowledge of the time with the existing different views of renowned anatomists and physiologists on bladder function, in particular detrusor function and the pelvic floor (spincter vesicae). He discussed this in connection with his own investigations, some of which he had also carried out as micturition pressure measurements in patients with prostatic hypertrophy and urethral strictures. This may certainly have been on reason why this paper was received and cited for a long period of time [59].

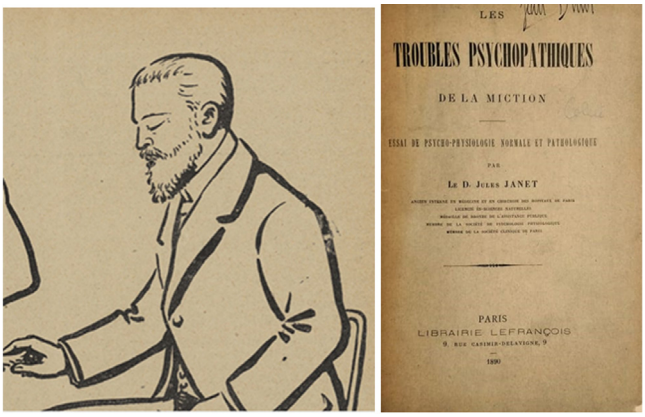


Fig. 9. a Jules Janet (1861–1945), caricature 1913, BIUM Paris, Frontispiz of Jules Janet s publication of 1890, which seems to be forgotten today. Repro Moll-Keyn, with permission.

At the end of the 19th century, the French school around Jean Casimir Felix Guyon (1831–1920), Hopital Necker, Paris, in particular his colleagues Louis Duchatelet and Felix L Genouville, had taken theory and technique into clinical practice to such an extent that the filling cystometry was used in the daily routine for determining individual bladder capacity [60–62].

A further important French contribution of the time was the paper of Jules Janet (1861–1945) who focussed on psychogenic disturbances of micturition as a famous example of the connections of urology and psychiatry during the belle époque in France and who is much more known of his bladder syringe [63,64] (see Fig. 9).

The method also appears in clinical settings in Vienna (Maximilian von Zeissl 1853–1925) [65,66] (see Fig. 10).

Urology, which was itself establishing at the European university centres of Berlin, Vienna, Paris and London, was thus one of the early representatives of a medicine, which was developing scientifically, in that it was precisely the measurement methods originating from physiology. Urodynamics was integrated in the developing specialty alongside "cystoscopy". While the "urological endoscopists" emphasized their own contributions to the establishment of the new specialty of urology it took the "urodynamicists" until the 1990th to present their own contributions as a constitution factor of urology [67]. Until the 1930s, it was quite common in contemporary major reviews to present and derive the traditional body of knowledge chronologically from its beginnings [68].

It was Eugen Rehfisch (1862–1937), Berlin, a partly assistant to famous Leopold Casper (1859–1959), who was the first in graphically recording intravesical pressure and urinary flow as a pressure – flow curve [69] (see Fig. 11).

5. Development of cystometry during the 20th century

In 1921, Walker was able to present an inexpensive and easy to use cystometer to the public in the USA, which used a blood pressure manometer (measuring the change in pressure via an airtight bottle) as a manometer [70].

In 1927, Dalton Keats Rose (1886–1976), Washington University at St. Louis, presented a relatively inexpensive mercury manometer in collaboration with the Sanborn Company, with which a standardized measurement of the bladder pressure during continuous bladder filling with water was technically easier. With this instrument, Rose was able to record curves that were very similar to those of today. He was the one who coined the term "cystometer" and described its development and clinical usefulness [71–73] (see Fig. 12).

Within the 1930th the equipment was developed in an easier to use way [74]. All these publications show the large scientific and clinical

(Aus dem Laboratorium für experimentelle Pathologie des Herrn Professor Dr. S. v. Basch in Wien.)

Ueber die Innervation der Blase.

Von

Dr. **Maximilian von Zeissl,**
Privatdocent in Wien.

Mit 8 Holzschnitten.

Die Frage, wie der Verschluss der Harnblase zu Stande komme, beschäftigte die Aerzte schon seit langer Zeit. Dieselbe hat aber bisher trotz vieler darauf abzielender Versuche noch keine endgiltige Entscheidung gefunden. Hieran sind sowohl die complicirten anatomischen Verhältnisse als auch die Methoden, nach welchen bisher experimentirt wurde schuld. Da Born[1])

1) Zur Kritik über den gegenwärtigen Stand von der Frage von den Blasenfunctionen. Deutsche Zeitschrift für Chirurgie, redigirt von Lücke und Rose. Band 25, 1887, Seite 118—192.

Fig. 10. a Maximilian von Zeissl (1853–1925) from Pagel, L 1901 Biographisches Lexikon hervorragender Ärzte des 19. Jahrhunderts, Sp 1894–1895, Repro Moll-Keyn, with permission b title of the publication Zeissl M Über die Innervation der Blase. Pflug Arch f. d ges Physiol 53 8 1893 560–575.

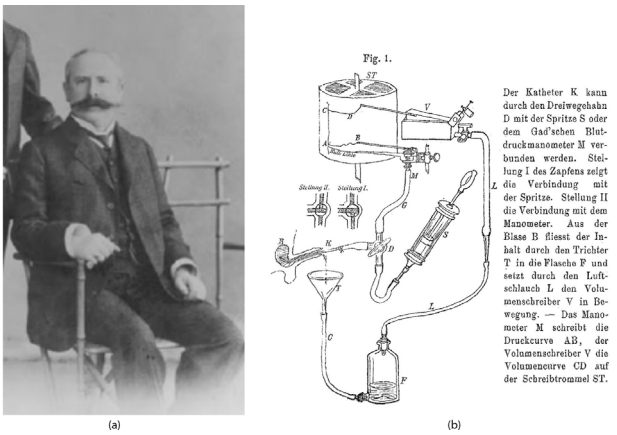


Fig. 11. Simultaneous recording of flow and pressure by Eugen Rehfisch (1862–1937) in 1897, Virch Arch Pathol Anat Physiol Klin Med 150 p 136 Repro Moll-Keyn, with permission.

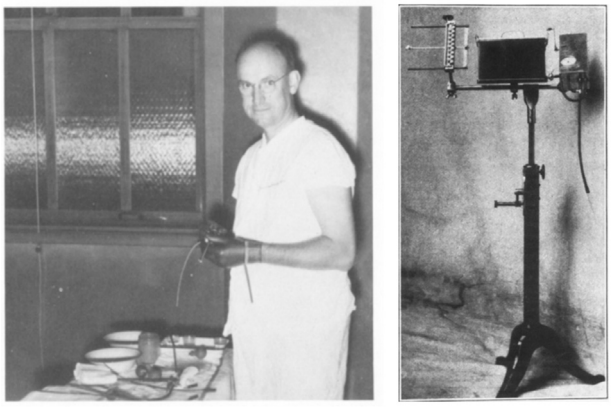


Fig. 12. a Dalton K Rose (1886–1976), b cystometer from Cystometric bladder Pressure Determinations: their clinical importance. J Urol 17 1927 487–501 Repro Moll-Keyn, with permission.

interest in the USA during the 1920s and 1930s. This was a result of the scientific isolation of German speaking physiology, urology and medicine after WWI, when scientific language changed from German into English. But there was no further input in the common textbooks of urology of the time. Within ‘‘the Keyes’’ (Edward Loughborough Keyes jun 1873–1949), which was leading in the US since 1874 (van Buren, Keyes sen. The surgical diseases of the Genito- urinary tract) with the word ‘‘incontinence’’ was referred to ‘‘enuresis’’ in the index [75].

Further development were closely associated with the names of Reed Nesbit (1898–1979) [76] normally connected with pediatric urology and TUR P, Maurice Muschat and Donald Munro (1889–1973) [77, 78] (see Fig. 13).

At the end of the 1930s Loyd G Lewis, Johns Hopkins, Baltimore, later Walter Reed Washington, developed a cystometer that was to become very popular. This model had the advantage of interchangeable and sterilizable peripheral parts and was inexpensive and very compact, too.

In the 1960s, an ‘‘air cystometer’’ was introduced, which made it possible to fill the bladder with air in just a few minutes. It could also be used in children. Gas cystometry was promoted by D M Gleason and colleagues, among others, and was used regularly until the 1970th [79]. After a series of air embolisations, carbon dioxide was utilized instead of air. More sensitive and compact electronic devices were developed as part of the CO2 gas cystometry.

BLADDER TONUS IN SPINAL SHOCK[1]

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When the spinal cord is injured, there is an immediate loss of sensation and complete flaccidity of the skeletal muscles below the level of trauma; and also urinary retention with subsequent overflow incontinence. These alterations of function are due to the abolition of all motor and sensory impulses, both visceral and somatic, below the lesion and the condition has been termed spinal shock. Spinal shock is said to persist until the paralyzed skeletal muscles exhibit a return of reflex activity.

The urinary retention which occurs during spinal shock has heretofore been ascribed to primary atony of the bladder[2,3,4,5], an assumption no doubt prompted by the belief that bladder muscle and skeletal muscle behave in an identical manner. But the two structures are made up of different types of tissue; the bladder is plain muscle and the skeletal muscles are striated. Furthermore they are innervated by different nervous systems. Neuroanatomists believe that the motor impulses to the bladder are mediated entirely over the autonomic nervous system and investigations[2] which we have recently conducted at the University of Michigan Hospital have substantiated this theory. It is well known that plain muscle retains its tonicity and even rhythmic contractility when completely deprived of all of its external innervation. Striated muscle, however, becomes flaccid and elongated when its motor nerves are interrupted. It would be indeed unusual therefore for the bladder, composed of non-striated muscle, to become flaccid when its motor nerve supply has been interrupted, either following spinal cord injury or by chemical blockade; and the observations which we have made both in the clinic and laboratory bear out this view.

The investigations which constitute the basis for the present report demonstrate conclusively that the bladder does not become flaccid when its motor nerves are paralyzed either by chemical interruption or by trauma, but that it retains its normal tonicity under these conditions. To be sure investigators have regularly found distended bladders in paralyzed patients to exhibit decreased tonicity and have doubtless ascribed the flaccidity to spinal shock; but one might reasonably inquire whether the bladders found in this condition are merely decompensated from prolonged distension. We believe that is the case.

[1] Presented at annual meeting, Southeastern Section, American Urological Association, Palm Beach, Fla., March 27, 1947.
[2] Holmes, G.: Brain, 56: 383, 1933.

Fig. 13. a Reed Nesbit (1898–1879), about 1954, Nat Lib Med, USA, B020077, b first page of a paper by Nesbit from 1948 in the famous Journal of Urology. Repro Moll-Keyn, with permission.

After the value of continuous recording of pressure and flow during patient examinations was recognized throughout the early 1960s [80] and its routine establishment, it took until the end of the 1960s for the

Fig. 14. Frank Hinman jun (1915–2011), about 1955 Natl Library of Med. USA B014590, Repro Moll-Keyn, with permission.

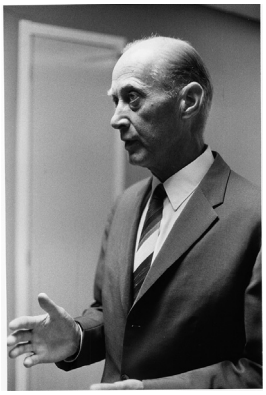

Fig. 15. Bodo von Garrelts (1914–1992), Assistant head Physician, Urological Clinic, Karolinska Hospital, Stockholm. He did major research in uroflowmetrie.

triad of simultaneous pressure- flow studies, recording the pelvic floor EMG and simultaneous radiological monitoring to become an integral part of a increasingly standardized examination technique Earl Miller (1907–1995), Frank Hinman (1915–2011), Goran Enhorning (1924–2013), Emil A Tanagho (1929–2024). This process of standardization is still ongoing today [81] and continues into current processes for ‘‘Guidelines for Good Medical Practice [82–84] (see Fig. 14).

The advent of all these instrument and elaborated techniques led to the most important aspect of interpretation of these data. It is in this matter that we must remember the physicists and engineers who made a fundamental contribution to interpret these data during the last decades.

In the early 1970s, Derek Griffiths [85], an English physics, who introduced the concept of fluid mechanics of collapsible tubes, in relation to the conduit function of the lower urinary tract. We owe this author some of the urodynamic parameters which measure urethral resistance such as the bladder outlet obstruction index (BOOI) which is the parameter recommended by the International Continence society based on the Abrams & Griffiths number, or the Urethral resistance factor (URA). These parameters allow us to diagnose a bladder outlet obstruction and consequently decide whether to operate on for instance a hypertrophic prostate.

Another author of great importance is the German aeronautical engineering Werner Schafer who introduced the concept of passive urethral resistance, reinforcing the concepts of Derek Griffiths. It is very curious how the laws that explain why airplanes fly (such as Bernoulli’s law) also explain why urine flows.

6. Development of the uroflow examination

Investigations into the measurement of the projection force of the urinary stream only became a field of interest for researchers at the beginning of the 20th century. It was Eugen Rehfisch, see above, who had realized an exact urinary stream measurement. There are studies from the 1920s by Oswald Schwarz (1883–1949 London) and Alexander Brenner (1889–1944) from Vienna [86]. H Grönvall from Sweden published a volumetric measuring principle in 1925.

The awareness of voiding control und analyze evolved during the 1920th and 1930th due to the more developed diagnosis techniques and the better options in desobstruction (TUR P) at that time. So we can find in an article of the well known text book author Edgar Garrison Ballenger (1877–1845) [87,88]. The author advised men over 45 years of age to measure their distance of voiding as a good routine screening test for prostatism and suggested that this should be done “*when alone in the country or out by the barn.*” As recommended, when the voiding distance was one-third to one-half the original, the patient was advised to visit his urologist [89].

The first direct flow device was carried out by Willard M Drake in 1948 using a gravimetric measuring principle [90]. He collected and weighted the voided urine in a measuring vessel [91] It was Drake who coined the terminus “uroflowmeter”. Further technical modifications followed, such as those by Bodo von Garrelts (1914–1992) in 1956, Karolinska Hospital, Stockholm [92] or Joseph J Kaufman (1921–1999), Los Angeles [93]. He later on was attributed “mentor of modern uroflowmetry” [94] (see Fig. 15).

7. Sphinterometry

While Genouville, Paris had already described a measurement of spincter pressure in the 19th century, it was not until Ernest Bors (1900–1990) after WW II, that this method was standardized in terms of measurement technology [95]. This ultimately formed the basis for further work by Malcom C Brown and John Wickham (1927–2017), St. Bartholomew ‘S Hospital [96] (see Fig. 16).

Further on we can talk about the pioneers in standardizing this discipline such as Jerry Blaivas [97], Mount Sinai, New York, who in 1978 formed the first committee for standardization of terminology and procedures. The terminology project merged with that of the International Continence Society and gave rise to the standard definitions of all the terms and concepts currently used in urodynamics [98].

We must also recall the contribution of the first urologists who studied the deleterious effect of neurogenic dysfunction of the lower urinary tract on the kidneys such as Jack Lapides (1914–1995) [99,100]. He studied the components of the urethral sphincter and was the introductory of clean intermittent catheterization in patients with spinal cord injury, and Ed McGuire (1940–2021), Ann Arbor, Michigan [101], who in 1981 described the concept of detrusor leak point pressure in myelodysplastic children. They were the founders of the subspecialty of neurourology within the field of urodynamics [102].

Complex calculation based on the above parameters would not be possible without the help of computers. The development of hardware improvements such as new micro-chips and specific software applications made possible new advances such as computer analysis, microtransducer instrumentation, and ambulatory testing.

Finaly, it is also interesting to remember the appearance of video urodynamics as an essential tool for the diagnosis of complicated urinary dysfunction like secondary vesicoureteral reflux due, whose pioneers were doctors who introduced the X-rays in the field of urology such as Einer Thomsen a gynecologist from Copenhagen, who reported the first series of voiding cystourethrograms in female patients, and Earl R. Miller who popularized the use of cinefluoroscopy in conjunction with the other urodynamic studies of the lower urinary tract [103–106].

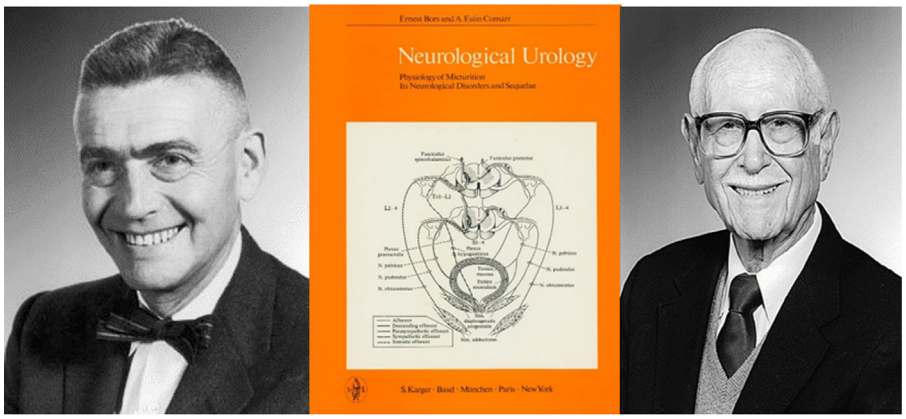

Fig. 16. a Ernest Bors (1900–1990) b frontispiz of one of the most influential textbooks in neurourology, which laid the base for this subspecialization in urology, c Estin Comarr (1915–1996) Repro Moll-Keyn, with permission.

8. Conclusion

Urodynamics as a teaching and diagnostic aid in the analysis of functional disorders of the lower and upper urinary tract symptoms was, alongside cystoscopy, an essential part of development in the medical specialty of urology.

This area resulted in the second level of differentiation within urology (e.g. the field of neuro- urology, particularly in the treatment of paraplegics or the treatment of patient with neurological diseases such as Parkinson's disease or multiple sclerosis or Diabetes from the 1950th onwards) which is now represented in textbooks, which were evident markers of this differentiation [107,108].

The preoccupation with aspects of bladder and ureter physiology illustrates the functional aspect which was firmly anchored in the field at an early stage. This change of the perspective contributed significantly to the essential demarcation at the end of the 19th century from the purely morphological- anatomical view of general surgery.

After WW II, urodynamics received a significant boost in innovation, particularly from the Anglo-American world, due to the enormous increase in war casualties with bladder voiding disorders, the improved surgical options for treating female and later also male urinary incontinence (especially after radical prostatectomy) together with the development of sufficient vesico - topic drugs for "urge incontinence". New modalities in the conservative treatment of prostatic obstruction by alpha-blockers became during the 19th also in focus of research.

Furthermore, the research field of urodynamics received an innovative boost from the end of the 1960th through the implementation of fluid mechanical- physical models (hydrodynamics). Research groups from the USA (Zinner, Sterling, Gleason, Bottacini) and the UK had already brought engineers and physicists (D J Griffiths) into their scientific working groups. In this cooperation the diagnosis of prostatic outflow obstruction as indication for prostate surgery (desobstruction) was significantly developed through this cooperation [109–111].

Declaration of competing interest

No conflict of interest.

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