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NAPOLEON CYBULSKI - POLISH PIONEER IN DEVELOPING OF THE DEVICE FOR MEASURING BLOOD FLOW VELOCITY

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Napoleon Cybulski (1854-1919) was the most prominent Polish physiologist who chaired the Department of Physiology at the Faculty of Medicine of Jagiellonian University between 1885 and 1919. One of his greatest achievements was the construction of a device for precise measurements of blood movement in the vessels - the **photohemotachometer**, which provided a better insight into the physiology and pathophysiology of the circulatory system. In the field of endocrinology Cybulski together with **Szymonowicz**, found out that adrenal extracts contain biologically active substances that elevate blood pressure.

He was also a constructor of an extremely clever microcalorimeter to measure the quantity of heat produced during isolated muscle contraction. He applied, for the first time, condensator discharges to stimulate nerves and analyzed changes in the excitability of the muscles. Cybulski proved that the cause of the electrical excitability of tissue depends on the electrical energy and the time of its duration.

Together with **Beck**, he performed the experiments on the sensory centers in the central nervous system by means of the observations of the electrical evoked potentials. They discovered the continuous electrical oscillations in the brain - the brain waves and recorded the negative electrical potentials in certain brain areas induced by sensory impulses coming from the periphery. Using this technique Beck and Cybulski localized various centers in the brain of dogs and Macaccus rhesus monkeys. The names of Beck and Cybulski were quoted in many publications on neurophysiology and electroencephalography.

The present paper describes Napoleon Cybulski as a constructer of an original instrument for studying the movement of blood under various experimental conditions an emphasizes the contribution of this invention to the development of physiology.

Key words: *photohemotachometer, linear blood flow, adrenaline, histamine, Pitot's cannulas*

HISTORICAL BACKGROUND

When **Gustaw Piotrowski**, for many years a professor of physiology at the Jagiellonian University Faculty of Medicine died on the last day of 1884, the Faculty Council initiated the search for the most suitable candidate for the vacant position in the Chair of Physiology (1). The decision was made very soon and turned out to be extremely fruitful. When other prominent scholars of that time such as **Marceli Nencki**, a biochemist, **Henryk Hoyer**, a histologist, **Jan Dogiel**, a pharmacologist or **Feliks Nawrocki**, a physiologist proposed the conditions that were unacceptable to the University, the Faculty offered the position to a young 31- year-old researcher Napoleon Cybulski (2, 3), a most promising student of Professor **Ivan Tarchanov**, a prominent physiologist at the Military Surgico-Medical Academy in St Petersburg. Professor Tarchanov father was a descendant of a noble family in Georgia, and a mother of Ormian origin (4). His contribution to the growth of science in the world was recognized by the International Union of Physiological Sciences and the American Physiological Society in 1956 in a book by Ch.D. Leake "Some Founders of Physiology" where Ivan Romanovich Tarchanov was mentioned among 100 other researchers one who first described psycho - galvanic reflex (5, 6), the concept applied to create lie detectors now widely used in criminology. Under Tarchanov's supervision Cybulski gained experience in physiology and experimental studies. An excellent professor - student relationship (2, 3, 7, 8) turned into lifelong friendship, when Professor Tarchanov moved to Krzeszowice near Krakow and continued his research work

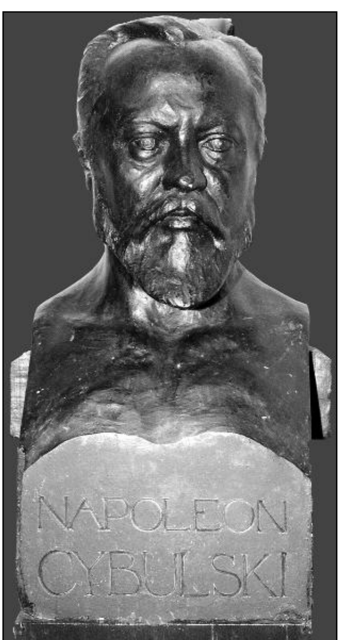


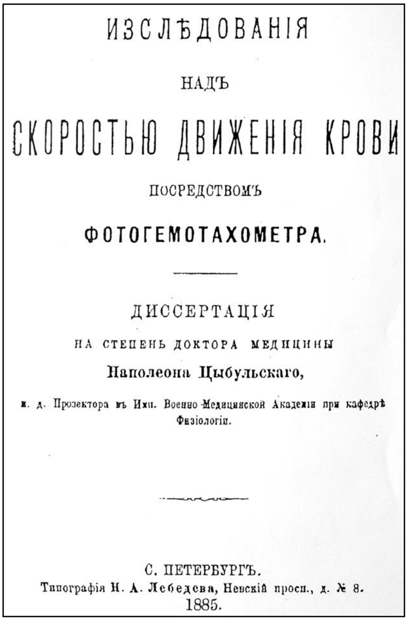
Fig. 1. Napoleon Nikodem Cybulski (1854 -1919)

with Cybulski. It was also the place where he passed away on 21 st August 1908, far from his home Caucasus and St Petersburg.

Napoleon Nikodem Cybulski (*Fig. 1*) was born into a moderately wealthy family descended from the gentry in Krzywonosy, Svencionys district in the Vilnius region on 13 September 1854. His father was Jozef Napoleon Prawdzic-Cybulski, his mother Marcjanna Hutorowicz, his wife Julia Rogozinska (9, 10). Cybulski graduated from the Minsk secondary school with a silver medal and in 1875 enrolled in the first course at the Military Medical Academy in St Petersburg. The same year **Ivan Pavlov**, who had just completed his course in natural sciences, took the third course at the Academy. The scientific contact between Cybulski and Pavlov was strengthened by the fact that they both worked on blood circulation at that time. Considered to be an outstanding student, Cybulski became an assistant in 1877. Also as a student he was awarded a first-class gold medal for presentation the paper entitled "The effect of body posture on lateral pressure, pulse and respiration in animals" (the paper was also published in Polish when he was a professor in Krakow) (11).

After his *cum eximia laude* graduation in 1880 with a medical diploma, Cybulski remained to work for Prof. Tarchanov as a prosector until leaving for Krakow in 1885. While staying in St Petersburg he performed several studies but he was recognized within relatively in a short time as an inventor of an original device to measure blood flow through the vessels in experimental animals. The device was called a photohemotachometer: "tachometer" - an appliance to measure flow velocity, "hemo" - blood, "photo" - because photographic record of the velocity of the blood stream on the tape of light sensitive paper was included. It was an important breakthrough in research of blood vessel flow - the formerly used methods were generally based on calculation of blood flow velocity. Cybulski's scientific success and very good opinion issued by Tarchanov and **Sechenov** (later called the father of Russian physiology) were the factors that prompted the Jagiellonian University to offer this young physiologist the position of a professor. The opinion was well founded as Cybulski was regarded as an exceptionally talented, hard working, ambitious and truth seeking investigator who had a great future. His appointment to the Chair of physiology, histology and embryology in Krakow following the unanimous decision of the Medical Faculty Council (8) preceded by the defense of his doctoral thesis "Studies of blood flow velocity based on photohemotachometer", which took place in St Petersburg on 13th April 1885 (2, 3). The first report on the device was published in 1883 (12), and the PhD thesis as the book (13) in Russian in 1885 (*Fig. 2*). Soon after receiving the PhD degree, Cybulski left for Krakow where he was appointed head of the Chair at the Jagiellonian University supervising it until his death on 26 th April 1919.

The year he arrived in Krakow (1885), apart from published in St. Petersburg doctoral dissertation, he published a paper describing the structure and function of the photohemotachometer in *Przegląd Lekarski* in Polish (*Fig. 3*) (14, 15) and



ИЗСЛѢДОВАНІЯ

НАДЪ

СКОРОСТЬЮ ДВИЖЕНІЯ КРОВИ

ПОСРЕДСТВОМЪ

ФОТОГЕМОТАХОМЕТРА.

ДИССЕРТАЦІЯ

НА СТЕПЕНЬ ДОКТОРА МЕДИЦИНЫ

Наполеона Цыбульскаго,

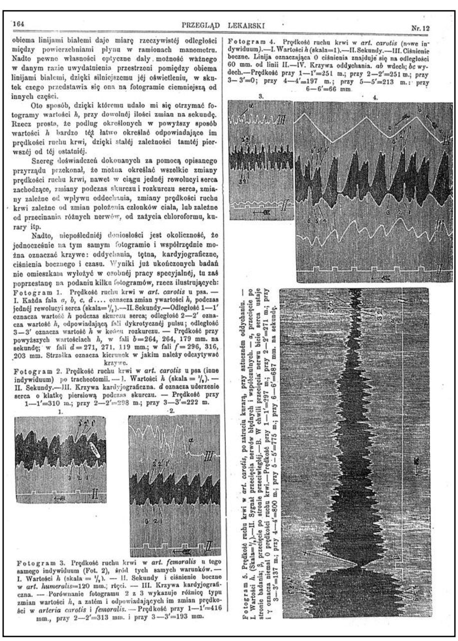
и. д. Прозектора въ Имп. Военно-Медицинской Академіи при каѳедрѣ Физіологіи.

С. ПЕТЕРБУРГЪ.

Типографія Н. А. Лебедева, Невскій просп., д. № 8.

1885.

Fig. 2. Cybulski's PhD thesis on the photohemotachometer published in St Petersburg in 1885 (13).



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obiema linijami białemi daje miarę rzeczywistéj odległości między powierzchniami płynu w ramionach manometru. Nadto pewne własności optyczne dały możność ważnego w danym razie uwydatnienia przestrzeni pomiędzy obiema linijami białemi, dzięki silniejszemu jéj oświetleniu, w skutek czego przedstawia się ona na fotogramie ciemniejszą od innych części.

Oto sposób, dzięki któremu udało mi się otrzymać fotogramy wartości *h*, przy dowolnéj ilości zmian na sekundę. Rzecz prosta, że podług określonych w powyższy sposób wartości *h* bardzo téż łatwo określać odpowiadające im prędkości ruchu krwi, dzięki stałéj zależności tamtéj pierwszéj od téj ostatniéj.

Szereg doświadczeń dokonanych za pomocą opisanego przyrządu przekonał, że można określać wszelkie zmiany prędkości ruchu krwi, nawet w ciągu jednéj rewolucyi serca zachodzące, zmiany podczas skurczu i rozkurczu serca, zmiany zależne od wpływu oddechania, zmiany prędkości ruchu krwi zależne od zmian położenia członków ciała, lub zależne od przecinania różnych nerwów, od zażycia chloroformu, kurary itp.

Nadto, niepośledniéj doniosłości jest okoliczność, że jednocześnie na tym samym fotogramie i współrzędnie można oznaczać krzywe: oddychania, tętna, kardyjograficzne, ciśnienia bocznego i czasu. Wyniki już ukończonych badań nie omieszkam wyłożyć w osobnéj pracy specyjalnéj, tu zaś poprzestanę na podaniu kilku fotogramów, rzecz ilustrujących:

Fotogram 1. Prędkość ruchu krwi w *art. carotis* u psa. — I. Każda fala *a, b, c, d*.... oznacza zmian ywartości *h*, podczas jednéj rewolucyi serca (skala=1/2).—II. Sekundy.—Odległość 1—1′ oznacza wartość *h* podczas skurczu serca; odległość 2—2′ oznacza wartość *h*, odpowiadającą fali dykrotycznéj pulsu; odległość 3—3′ oznacza wartość *h* w końcu rozkurczu. — Prędkość przy powyższych wartościach *h*, w fali *b*=264, 264, 179 mm. na sekundę; w fali *d*=271, 271, 119 mm.; w fali *f*=296, 316, 203 mm. Strzałka oznacza kierunek w jakim należy odczytywać krzywe.

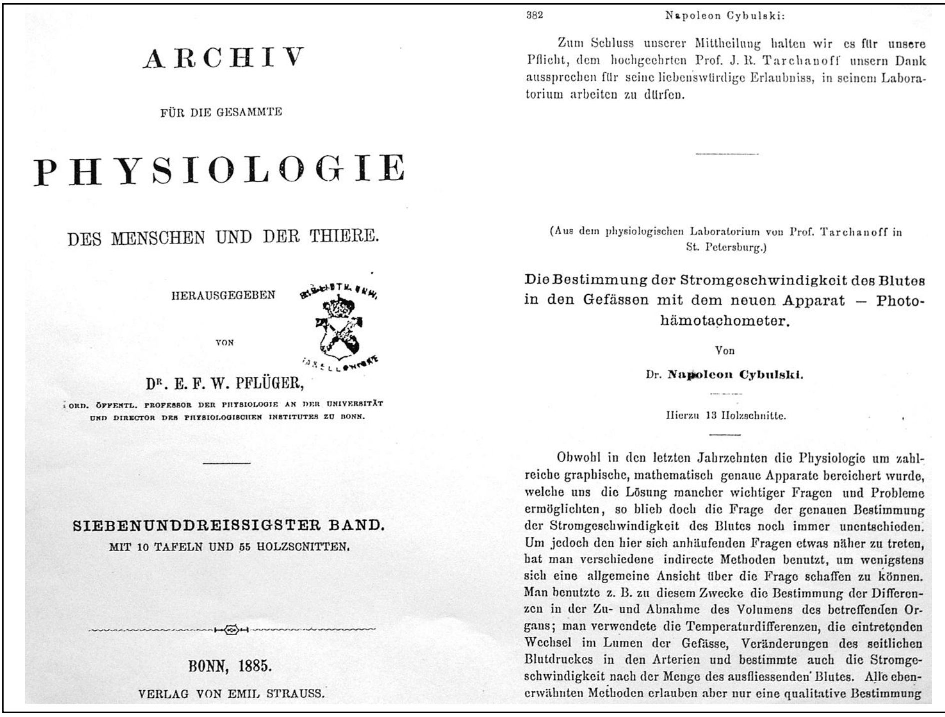
Fotogram 2. Prędkość ruchu krwi w *art. carotis* u psa (inne indywiduum) po tracheotomii. — I. Wartości *h* (skala = 1/3). — II. Sekundy.—III. Krzywa kardyjograficzna. *d* oznacza uderzenie serca o klatkę piersiową podczas skurczu. — Prędkość przy 1—1′=310 m.; przy 2—2′=298 m.; przy 3—3′=222 m.

Fotogram 3. Prędkość ruchu krwi w *art. femoralis* u tego samego indywiduum (Fot. 2), śród tych samych warunków. — I. Wartości *h* (skala = 1/2). — II. Sekundy i ciśnienie boczne w *art. humeralis*=120 mm. rtęci. — III. Krzywa kardyjograficzna. — Porównanie fotogramu 2 z 3 wykazuje różnicę typu zmian wartości *h*, a zatém i odpowiadających im zmian prędkości w *arteria carotis* i *femoralis*. — Prędkość przy 1—1′=416 mm., przy 2—2′=313 mm. i przy 3—3′=193 mm.

Fotogram 4. Prędkość ruchu krwi w *art. carotis* (nowe indywiduum).—I. Wartości *h* (skala=1).—II. Sekundy.—III. Ciśnienie boczne. Linija oznaczająca 0 ciśnienia znajduje się na odległości 60 mm. od linii II.—IV. Krzywa oddychania. *ab* wdech; *bc* wydech.—Prędkość przy 1—1′=251 m.; przy 2—2′=251 m.; przy 3—3′=0; przy 4—4′=197 m.; przy 5—5′=213 m.; przy 6—6′=66 mm.

Fig. 3. Cybulski's first paper describing the photohemotachometer in Polish in the *Przegląd Lekarski* in 1885 (14).

in German in an important international journal *Pflügers Archiv für die gesammte Physiologie des Menschen und der Thiere ed. by Pflüger* (16) (*Fig. 4*). In 1886 Cybulski published in *Kosmos* an extensive report in which he discussed



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FÜR DIE GESAMMTE

PHYSIOLOGIE

DES MENSCHEN UND DER THIERE.

HERAUSGEGEBEN

VON

DR. E. F. W. PFLÜGER,

ORD. ÖFFENTL. PROFESSOR DER PHYSIOLOGIE AN DER UNIVERSITÄT UND DIRECTOR DES PHYSIOLOGISCHEN INSTITUTES ZU BONN.

SIEBENUNDDREISSIGSTER BAND.

MIT 10 TAFELN UND 55 HOLZSCHNITTEN.

BONN, 1885.

VERLAG VON EMIL STRAUSS.

382 Napoleon Cybulski:

Zum Schluss unserer Mittheilung halten wir es für unsere Pflicht, dem hochgeehrten Prof. J. R. Tarchanoff unsern Dank aussprechen für seine liebenswürdige Erlaubniss, in seinem Laboratorium arbeiten zu dürfen.

(Aus dem physiologischen Laboratorium von Prof. Tarchanoff in St. Petersburg.)

Die Bestimmung der Stromgeschwindigkeit des Blutes in den Gefässen mit dem neuen Apparat — Photohämotachometer.

Von

Dr. Napoleon Cybulski.

Hierzu 13 Holzschnitte.

Obwohl in den letzten Jahrzehnten die Physiologie um zahlreiche graphische, mathematisch genaue Apparate bereichert wurde, welche uns die Lösung mancher wichtiger Fragen und Probleme ermöglichten, so blieb doch die Frage der genauen Bestimmung der Stromgeschwindigkeit des Blutes noch immer unentschieden. Um jedoch den hier sich anhäufenden Fragen etwas näher zu treten, hat man verschiedene indirecte Methoden benutzt, um wenigstens sich eine allgemeine Ansicht über die Frage schaffen zu können. Man benutzte z. B. zu diesem Zwecke die Bestimmung der Differenzen in der Zu- und Abnahme des Volumens des betreffenden Organs; man verwendete die Temperaturdifferenzen, die eintretenden Wechsel im Lumen der Gefässe, Veränderungen des seitlichen Blutdruckes in den Arterien und bestimmte auch die Stromgeschwindigkeit nach der Menge des ausfliessenden Blutes. Alle ebenerwähnten Methoden erlauben aber nur eine qualitative Bestimmung

Fig. 4. Cybulski's first paper describing the photohemotachometer in German in the *Archiv für die gesammte Physiologie* in 1885 (16).

the results of other investigators measuring the velocity of blood flow in the vessels, described the theoretical background of photohemotachometer work, and provided the results of experimental studies performed with the use of this device (17).

In the first year of his appointment to the Chair, Cybulski was asked by such prominent investigators as Pavlov, Nencki (later Nobel prize winners) and **Zaleski** to determine the velocity of blood flow in the portal vein (in relation with studies on the role of the liver in the synthesis of urea). To understand the revolution caused by introduction of the photohemotachometer to experimental physiology, one should be aware of the manner of conducting studies before Cybulski. Apart from the inventor himself, studies on blood velocity in the vessels were reviewed by **Pruszynski** in a paper summarizing Cybulski' s achievements on the 25 th anniversary of his work in Krakow (18). At that time the only reliable methods were based on the determination of the time necessary for the passage of a substance e.g. potassium ferrocyanide solution from the moment of its injection into the proximal cardiac segment of the vein until the moment of its appearance in the peripheral segment of the same vein. (in the same department **Wachtel** studied the effect of potassium ferrocyanide on erythrocytes - 19). However, none of the methods commonly used at that time

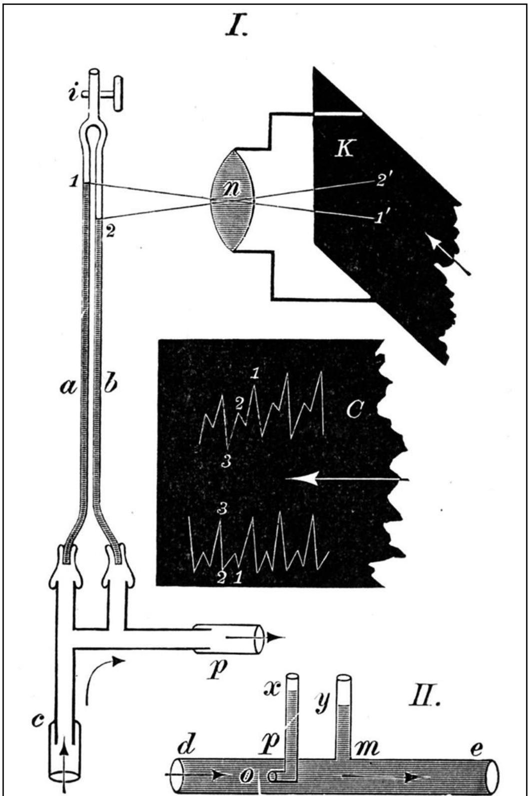

Bild 45. I. Schema des Photohämotachometers von *Cybulski*. — II. *Pitots* Röhre.

Fig. 5. The principle of Pitot's tube and schematic representation of differential manometer with optical recording of blood flow according to the book of physiology by Landois - Rosemann in the 23rd and 24th edition in 1943 (20).

allowed for measuring linear velocity of blood flow in the observed vessel, and especially for continuous recording of velocity changes under various conditions, e.g. in particular phases of heart cycle (systole and diastole), during inspiration, expiration, as well as circulatory disorders. Furthermore, the fact that the blood could mix with a foreign body, such as oily fluid and the presence of factors altering blood flow velocity in the instrument during an experiment were major disadvantages of these methods. The velocity of the blood flow was usually measured with a bloodstream - meter (Stromuhr) invented by **Ludwig** in 1867. The velocity of the blood flow was defined from the blood volume that passed from the artery to the calibrated glass reservoir that was connected to it. Two glass reservoirs of equal volume connected to each other were mounted on the metal platform with the aid of tubes. The platform rotated around its axis, which allowed for measurement of the volume of the blood that flowed out of the artery within a given time. Another disadvantage of this method was the necessity of using oil that was displaced by the blood and was in direct contact with it in the glass reservoir. Moreover, it was not always possible to define the moment of filling the reservoir with the blood.

Cybulski' s photohemotachometer

The instrument underwent several modifications within the years and the description below refers to its improved version which is consistent with the one presented in the well-known course book of physiology by Landois - Rosemann in the 23rd and 24th edition in 1943 (20). Schematic representation of the photohemotachometer (*Figs 5I* and *5II*) comes from this course book.

The photohemotachometer works on the principle of Pitot's tube (*Fig. 5II*). When the fluid flows in the horisontal tube in the *d*→ *e* direction, the fluid column level in the first vertical (lateral) cannula p is higher than in the distal cannula *m*. The difference in fluid levels in both lateral cannulas increases with increasing velocity of fluid flowing in the horisontal cannula de. The device can be calibrated solely empirically. The Pitot's cannula in Cybulski's instrument (*Fig. 5I*) *cp*, was modified as it was bent at 90°. Its c end was attached to the central segment of the transected vessel, whereas the *p* end to its distal segment.

When liquid (blood) flows freely, its level in manometer a located axially to the direction of fluid stream is higher than in manometer *b*. To avoid excessive length of manometric tubes *a* and *b* and to make the instrument more useful, Cybulski connected manometers *a* and *b* through a thin cannula filled with air which could be closed by tap *i* located above the bent. The liquid was allowed to reach level 1 and 2. When tap i was closed, the tubes represented an air manometer in which differences in level 1 and 2 were clear-cut. Variations in levels of fluid columns (blood) were photographed on a rapidly moving surface *K*, i.e. light sensitive paper driven by a clock mechanism. The photohemotachometer is displayed in *Fig. 6* with its schematic representation below (A = optic system, B = photographic cassette, C = clock mechanism).

Usefullness of photohemotachometer in experimental studies

Due to the use of photohemotachometer, Cybulski became a pioneer in study of blood circulation (2, 3, 15, 17). He was first to graphically present the variations of blood flow velocity in various phases of heart cycle. An interesting observation was that the dicrotic wave in the carotid artery but not in the femoral artery was more pronounced during the diastolic phase as compared with systole. Cybulski also demonstrated the variations of blood flow velocity related to respiration.

Cybulski explained the phenomenon of "**dicrotic acceleration**" that in contrast to the femoral artery more distant from the heart and without the dicrotic acceleration, in the carotid artery closer to the heart, with the arrival of the dicrotic wave the diastolic slowing down of blood flow is still slight and for this reason the increase in velocity caused by this exceeded the systolic acceleration of blood flow.

A German physiologist **Frank** questioned the sensitivity of the photohemotachometer which was not enough to conduct this type of studies, however, neither he nor later **Rein** used a better instrument for measurements of blood flow velocity in the vessels in each phase of the cardiac cycle.

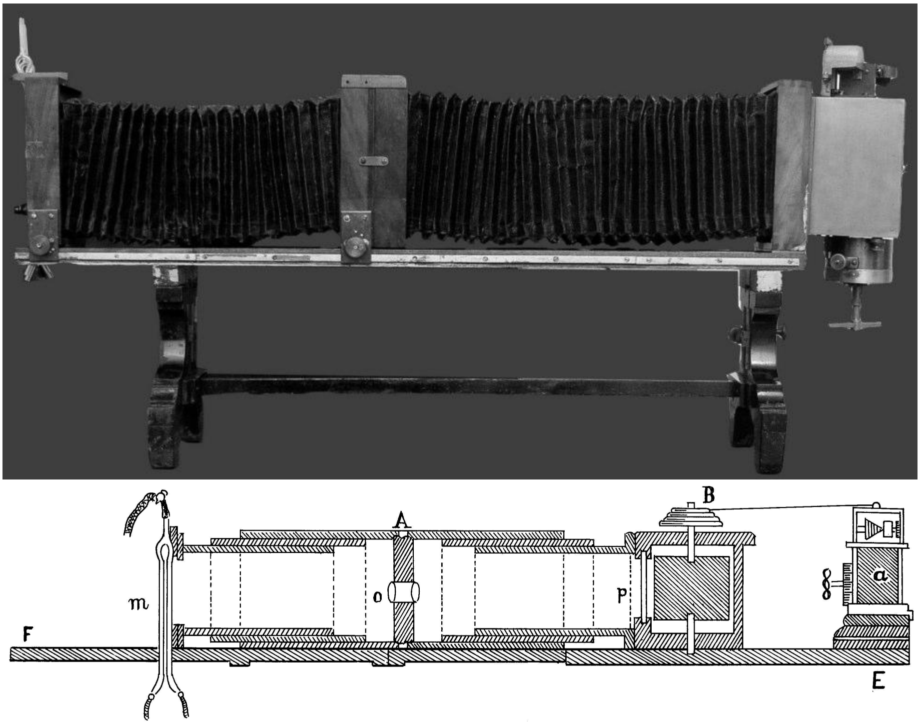

Fig. 6. A general view of Cybulski's photohemotachometer and schematic representation of the device.

Apart from studying blood flow velocity in the arteries during systole and diastole, and respiration, Cybulski measured blood flow velocity in the veins. He made attempts to explain variations of blood flow velocity in relation to pharmacological factors, neural (especially vagal) effects, asphixia, posture, blood loss and infusion of defibrinated blood. Cybulski also used his device to study blood flow velocity in the internal carotid artery during cerebral compression and found out that the velocity was decreased.

Cybulski's students carried out a number of studies using his photohemotachometer (2, 3). **Rosner** e.g. demonstrated that the velocity of blood flow was markedly attenuated in pregnant women with jaundice. Beck studied blood flow in the portal vein carrying the blood from the abdominal viscera to the liver. Fluctuations in blood flow velocity in this important vein were not large in normal conditions, but markedly increased during digestion, or during dyspnea when elevated peripheral blood pressure and increased heart rate occurred. **Kirkor** demonstrated a marked acceleration of blood flow in working muscles.

Later when the profile of Cybulski's laboratory changed and there were fewer studies on the circulation and more on other important physiological issues, the photohemotachometer was applied less frequently.

However, other laboratories still used photohemotachometer, frequently with modifications, for instance **Fleisch** employed it in Dorpat (later in Lausanne). Sometimes the device was modified and used without even informing its inventor (2, 3).

In Poland, **Andrzej Klisiecki** initiated his studies using the photohemotachometer in Lvov in the 1920s (21) which were continued with his co- workers for many years, later in Breslau.

In 1943 i.e. during World War II, the hand book of physiology by Landois-Rosemann, as already mentioned, contained a description and scheme of the original Cybulski's photohemotachometer, indicating the wide spread use of this device in Europe.

After World War II extensive studies using the photohemotachometer, usually in its modified version, were resumed in three centers in Poland. In Breslau its use was continued by Andrzej Klisiecki and his students (22, 23). In Lublin **Wiesław Hołobut** (24) continued his former studies carried out in co-operation with Klisiecki, which were then taken over by **W. Stążka** (24). In Krakow, studies were supervised by **Wincenty Wcisło** (25, 26).

In these studies of the systemic and organ hemodynamics, especially the pathophysiology of the circulation in the limbs, kidneys, brain, viscera and especially coronary circulation, were examined by photohemotachometer as the basic device to measure blood flow velocity. The studies provided important data to explain the role of the heart and vessels in the mechanism underlying histamine shock (Klisiecki -22, Hołobut - 24). Hołobut (24) and Stążka (25) obtained important results providing an insight into neurohormonal mechanisms controling of cerebral blood flow. In Breslau the photohemotachometer was also used to study blood flow in the brain, kidneys and coronary vessels (**Paradowski**, **Juzwa** et al., 23).

Important studies of the coronary circulation using the photohemotachometer were carried out in 60s and 70s by Wcisło, an acting chairman of the Chair of Physiology in Krakow. The device was applied to investigate coronary blood flow and coronary sinus outflow in animals with intact thorax. Precise measurements of coronary blood flow in this experiment provided a better understanding of the physiology and pharmacology of coronary circulation and myocardial metabolism. It may be important to mention that the results of these studies were published by W. Wcisło in the "Journal of Applied Physiology" at the time of a relatively wide use of electromagnetic blood flowmeters. This should be regarded as an international recognition of the reliability of photohemotachometer for measurements of blood flow (26). The device was also applied in studies which demonstrated that in experimental acute coronary insufficiency catecholamines are released by the heart into the coronary venous blood (27).

In close collaboration with **Gryglewski's** team of Department of Pharmacology photohemotachometric measurements of blood flow velocity were especially useful in studies of the effects of vasoactive substances on different vascular beds. The technique was applied to evaluate receptor-mediated and nonspecific effects of propranolol on coronary circulation in anesthetized dogs (28) and effects of nicotine on myocardial function, metabolism and coronary circulation (29). **Pawlik** employed this device was to assess blood flow in gastric and mesenteric artery. These studies demonstrated major gut hormones such that gastrin, secretin and cholecystokinin are capable to increase blood flow in the visceral bed (30), suggesting their physiological role in gut hyperemia under postprandial conditions.

Cybulski's photohemotachometer had been used in some centers in Poland until the 1970s when it was replaced by electronic devices. Thus, serving for almost a century it with stood the test of time.

By extending the photographic technique to provide measurements in other parts of the circulatory system, Cybulski developed **a new manometer** to record variation in venous blood pressure (31). Beck used this manometer to study extensively changes in venous blood pressure in various conditions (32).

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