Section of the History of Medicine

President F F Cartwright FFARC S

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Paper

A Short History of Blood Pressure Measurement[1]

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The evolution of clinical sphygmomanometry has been well documented, but differing degrees of emphasis have been placed on the various personalities and ideas which form part of the history of blood pressure measurement. The aim of this short history is to present a collated, succinct, yet personal account of the ideas which have led to the present-day approach, which involves compression of the brachial artery, and auscultation over the cubital fossa to determine the systolic and diastolic pressures.

Eighteenth Century: The Experiments of a Country Parson

Although there can be little doubt that simple palpation of the pulse was carried out by the early Egyptians (Gispen 1957), actual mensuration of the pressure in parts of the circulation really started in the middle of the eighteenth century with the experiments of Stephen Hales (Fig 1) (*Janus* 1913, Burget 1925).

It is most surprising that the common occurrence of blood spurting from torn vessels did not arouse the curiosity of physiologists long before the eighteenth century. However, it took the enquiring mind of Hales to investigate this phenomenon and to him can be attributed the discovery of blood pressure. One of the greatest physiologists of the nineteenth century, Johannes Müller, said that 'the discovery of the blood pressure was more important than the discovery of the blood'. That a man of such scientific stature should rank Harvey's discovery with that of Hales, whose experiments came more than a century after the profound observations of Harvey, gives an indication of the impact of Hales' labours on the scientific world at that time.

Hales was born at Bekesbourne in Kent on 7 September 1677. In 1696 he entered Cambridge University, where he was elected to a fellowship in 1702. Whilst at Cambridge Hales became keenly interested in natural history and always carried a copy of Ray's 'Catalogue of Plants' with him. Together with his friend William Stukeley he would dissect specimens of the local fauna.

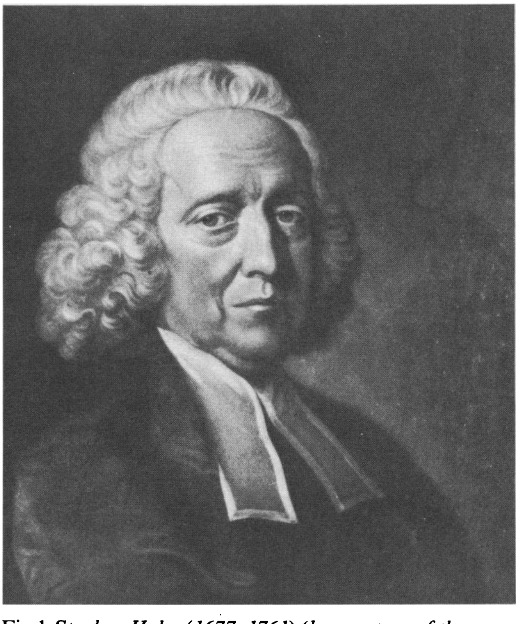

Fig 1 *Stephen Hales (1677–1761) (by courtesy of the Wellcome Trustees)*

[1] Submitted for the Student's Essay Prize, presented by Dr F F Cartwright, President of the Section of the History of Medicine during the 1976/77 session, and selected to be read to the Section

Astronomy was another subject which Hales studied avidly, and while still a student he constructed a brass machine which illustrated the movement of the planets. In about 1710 Hales, having been in Cambridge for twelve years, became perpetual curate of Teddington. Hales numbered among his friends Horace Walpole and Alexander Pope; the former decribed him as a 'poor, good primitive creature'. He was also something of a wit, as can be seen from his Statical Essays of 1727. Apparently some people found the algebra in this work difficult to understand, and so in the preface to the 2nd edition Hales gave the following explanation:

'Whereas some complain that they do not understand the signification of those short signs or characters, which are here made use of in many of the calculations, and which are usual in Algebra; this mark + signifies more, or to be added to; ... this mark × or cross signifies multiplied by; the two short parallel lines signify equal to ...'

Hales' experimental data before 1719 has yet to be found, but he must have made significant contributions to science before then as he was elected to the Royal Society in 1718. In 1719 he read a paper to the Society concerning the effects of the sun's rays on raising the sap in trees. The Society thanked Hales for this paper, and encouraged him to continue his work. In 1727 his results were published under the following, rather long-winded title:

'Vegetable Staticks; or, an Account of Some Statical Experiments on the Sap in Vegetables; being an essay towards a Natural History of Vegetation. Of use to those who are curious in the culture and improvement of Gardening etc. Also a specimen of an attempt to analyse the air by a great variety of chymiostatical experiments, which were read at several meetings of the Royal Society.'

Hales continued his experiments with the idea of making additions to his 'Vegetable Staticks'. In 1733 his additional observations merited the publication of a second volume, which he called 'Hæmostaticks', also known as Volume II of the Statical Essays (Hales 1733), in which the first experiments concerned with blood pressure are described – one of which as follows:

'In December I caused a mare to be tied down alive on her back; she was fourteen hands high, and about fourteen years of age; had a fistula of her withers, was neither very lean nor yet lusty; having laid open the left crural artery about three inches from her belly, I inserted into it a brass pipe whose bore was one sixth of an inch in diameter ... I fixed a glass tube of nearly the same diameter which was nine feet in length: then untying the ligature of the artery, the blood rose in the tube 8 feet 3 inches perpendicular above the level of the left ventricle of the heart; ... when it was at its full height it would rise and fall at and after each pulse 2, 3, or 4 inches ...' (*see* Fig 2)

Thus it was in 1733 that the first measurements of blood pressure, and incidentally of pulse pressure, were made – albeit rather crude measurements, and a far cry from the techniques of the twentieth century.

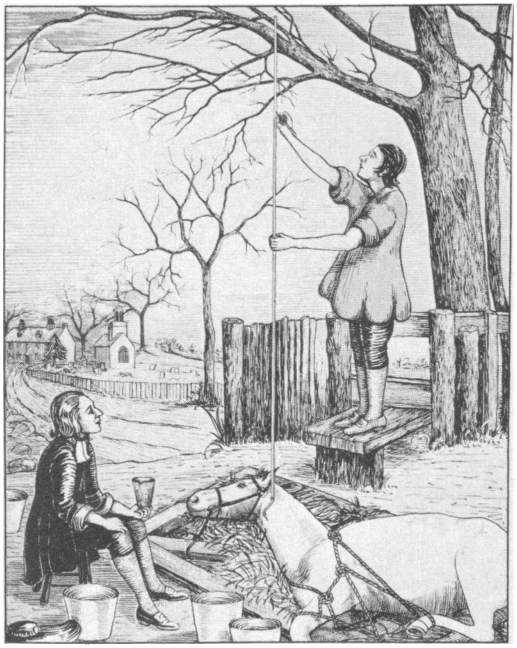

Fig 2 *Artist's impression of Hale's experiments to determine the blood pressure of a horse.* (*Reproduced from Medical Times 1944 by kind permission*)

The fact that Hales does not figure very prominently in the theological literature of his time does not imply that his work was neglected. He had some of the highest scientific honours of the country bestowed upon him, and as well as being made a Fellow of the Royal Society, he was awarded its Copley Medal in 1739. His work was held in high regard in Europe and he was elected to the Foreign Associateship of the French Academy of Sciences, made vacant by the death of Sir Hans Sloane in 1753 (Major 1930).

Hales did not continue immediately with his blood pressure experiments owing to the 'disagreeableness of Anatomical dissections'. Later, however, he did resume his inquiries by studying the capacity of the ventricles and many other features of the circulation. Yet it was not until a century later that the accurate study of blood pressure began, with the introduction by Poiseuille in 1828 of a mercury manometer.

Nineteenth-century Experiments: the First Physician-Physicist

Poiseuille may be described as one of the first physician-physicists. His work on viscosity is well known to engineers and physicists, but his earlier use of the mercury manometer and his work on resistance in the cardiovascular system are less well known. Poiseuille was born in 1799 and was brought up amid the aftermath of the French Revolution. He qualified as a doctor in 1828 in Paris. However, once he qualified he was not directly associated with a medical school, since in 1794 new medical schools were created by the revolutionaries. These schools numbered such people as Laennec, Dupuytren and Corvisart (who was physician to Napoleon I, and stressed the importance of percussion in chest examinations) among their members. The medical sciences were placed in special institutions, and did not attract as much help from the government as the clinical schools. So Poiseuille, as well as contemporaries such as Magendie and Claude Bernard, did not have a direct, official contact with a school of clinical medicine (Klopp 1974). In 1828 Poiseuille won the gold medal of the Royal Academy of Medicine for his doctoral dissertation on the use of a mercury manometer for the measurement of arterial blood pressure. He connected the manometer to a cannula filled with potassium carbonate which acted as an anticoagulent and the cannula was inserted directly into an artery in the experimental animal. Arteries as small as 2 mm in diameter were cannulated and Poiseuille was able to demonstrate that arterial pressure was maintained in the smaller arteries. He also proved that the blood flow through the mesenteric capillary bed did not depend on venous pressure changes, but varied directly with arterial pressure. Therefore, it was Poiseuille who made the first significant advance in clinical blood pressure measurement since the time of Stephen Hales.

Poiseuille's innovation enabled Carl Ludwig to develop the kymograph in 1847. In his article 'A contribution to the knowledge of the influence exerted by the respiratory movements on the course of the blood in the aortic system', Ludwig, who was Professor of Comparative Anatomy at Marburg, founded the graphic method of recording clinical data, which was to have profound effects on experimental physiology and medicine in the latter half of the nineteenth century (*Ciba* 1939). Ludwig described the following modifications to Poiseuille's equipment: the cannula and mercury manometer remained the same, but a float with a writing pen attached was buoyed up by the open mercury column and the pen arranged to write on a revolving, smoked drum. E H Starling said of Ludwig that he 'had the genius to cause this float to write on a recording cylinder, and thus at one coup gave us the kymograph, or wave-writer, and the application of the graphic method to physiology' (*see* Fig 3).

The kymograph (Gk. Kyma = wave; grapheion = stylus), therefore, become the basic design for a range of similar instruments, recording other physiological parameters. Amongst this range were the myograph, developed by Helmholtz in 1850 for recording muscle movements, and the sphygmograph, developed by Vierordt of Tubingen who was the first to monitor the pulse by this new graphic method.

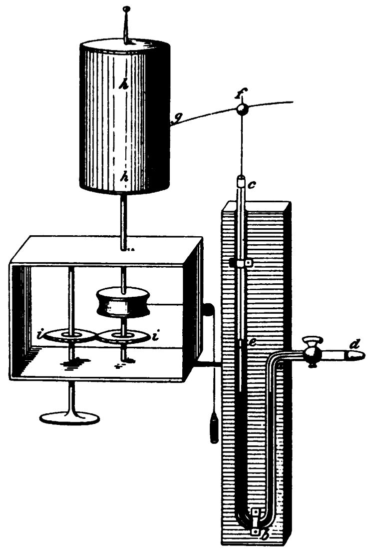

Fig 3 *Ludwig's kymograph, invented 1847. The bent glass tube, abc, contains mercury and connects by d with the artery. The slender upright rod, ef, swims on the surface of the mercury and bears at its free end, f, a brush, g, which registers the movements of the mercury on the revolving cylinder, hh.* (*Reproduced from Brunton 1908 by courtesy of the Wellcome Trustees*)

Noninvasive Techniques: the First Sphygmomanometer

Until 1855 no method had been found of determining the arterial pressure in the clinical situation other than by operation, since puncture of an artery was necessary before a reading could be obtained on the currently available apparatus. In 1855 Vierordt postulated that an indirect, noninvasive technique might be used, by measuring the counter pressure which would be necessary to cause the pulsation in an artery to cease. Vierordt

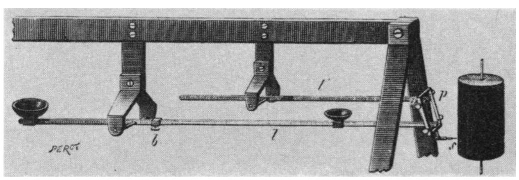

Fig 4 *Vierordt's sphygmograph, invented 1854. The pad, b, is applied over the radial artery. Weights are placed in the large cup until a pulse wave is traced out, then weights are placed in the smaller cup which acts as a fine adjuster* (*by courtesy of the Wellcome Trustees*)

endeavoured to put his theory into practice by attempting to measure the pressure which was needed to cause obliteration of the radial pulse, by a weight attached to the lever of a sphygmograph. He did not, however, meet with very much success, due largely to the cumbersome design of his apparatus (Fig 4).

Vierordt's sphygmograph was considerably improved by Etienne Jules Marey in 1860. Marey not only bettered the technique of graphic recording of the pulse, but also improved the accuracy of establishing the blood pressure in patients. Marey applied Vierordt's principle of applying counter pressure to overcome the arterial pressure, but in his apparatus the arm was enclosed in a glass chamber filled with water, which was connected both to a sphygmograph and to a kymograph which recorded the arterial pulsations in the arm. The chamber was also supplied with a moveable reservoir of water so that the pressure in it could be varied, and with a manometer. The determination of the blood pressure was done by first noting the pressure given by the mercury manometer at which the greatest peak to peak distance of the sphygmographic tracings occurred, and then gradually increasing the pressure by raising the reservoir. The pressure at which no more movement of the sphygmograph took place was recorded as the systolic pressure. Although Marey's device was a masterpiece of ingenuity, it was regrettably far too complicated for most doctors to use routinely, and it was also rather unwieldy (Marey 1881) (Fig 5).

However, Marey's sphygmograph gained widespread acceptance in the medical world for recording and studying the pulse. In England, as elsewhere, it underwent various modifications, for which R E Dudgeon, a London homeopath, was mainly responsible. Those responsible for pioneering its use in this country were Dr Burdon-Sanderson, later to become Regius Professor of Medicine at Oxford, and Dr Anstie of the famous Brown Institution. People other than Marey tried to record the blood pressure accurately. Generally their efforts involved the attaching of weights to the spring of the manometer, the pressure being considered as being equal to the force needed to overcome manometric movement. However, Potain observed that the force needed to move the spring in the manometer depended not only upon the pressure of the blood but also upon the resistance of the arterial wall, and that the latter interferes unacceptably with the readings obtained. He concluded, therefore, that spring manometers should be avoided in blood pressure measurement.

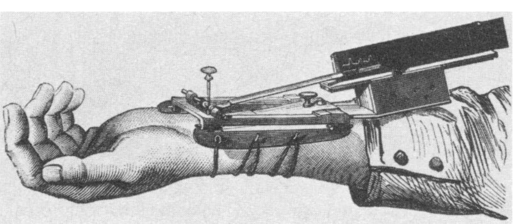

Fig 5 *A direct sphygmograph attributed to Marey, invented about 1881 (by courtesy of the Wellcome Trustees)*

The first truly accurate estimation of the blood pressure in man was made by the surgeon Faivre, in 1856; he connected an artery to a mercury manometer at operation and was thus able to obtain direct readings. He found the femoral artery blood pressure to be 120 mm Hg and the brachial artery pressure to be between 115 and 120 mm Hg. These, and other direct readings, were of great value in establishing a normal range for blood pressure. However, this method was obviously impracticable for routine measurements, since clearly no method involving direct connection between cannula and artery could have widespread use.

Advancement of Noninvasive Techniques

It was Samuel Siegfried Karl Ritter von Basch who finally dispensed with the arterial puncture and the direct registration of the blood pressure by a column of fluid. Von Basch was born in Prague in 1837 and graduated from Vienna in 1862. He was working mainly in the late 1870s (Bett 1957). Von Basch's method used an inflatable rubber bag which was filled with water. The edges of the bag were tightly drawn up around the neck of a manometer bulb which was mercury filled. A hollow column ran up from the bulb so that any

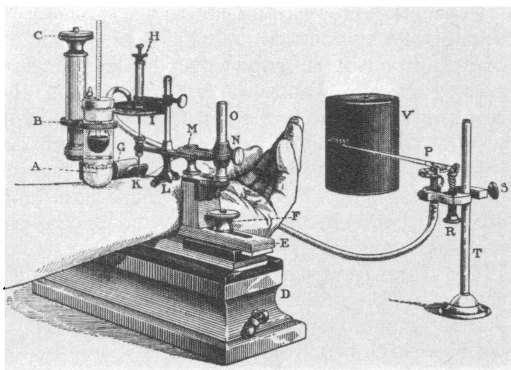

Fig 6 *Von Basch's sphygmomanometer and stand, invented about 1881. Despite its unwieldy appearance this is a simple device. The india rubber cap, A, rests on the radial artery and the arm is clamped between E and G. K is a fine pad which also rests against the artery. H is a fine screw by which the tambour of the sphygmograph can be adjusted and P is one of Marey's tambours which communicates by a piece of elastic tubing with the tambour of the sphygmograph (by courtesy of the Wellcome Trustees)*

pressure created in the water bag would be transmitted to the bulb, mercury would rise up the tube and hence the pressure could be recorded (Fig 6).

Von Basch, therefore, brought into clinical use the principles of Vierordt made fifteen years earlier. The new apparatus had none of Marey's unwieldy attachments; its virtue lay in its simplicity. The bag was pressed over the pulse until pulsations distal to the point of application ceased, and the height of the mercury column then recorded the systolic pressure. This apparatus was also much more accurate than previous devices. Zadek, in experiments on dogs, carried out cannulation of the carotid artery and simultaneously used the von Basch apparatus on a limb. The two results agreed with each other to a considerable extent. It was von Basch's apparatus that was used when the first investigations into hæmodynamic pathology were undertaken. Both Zadek and von Basch noted that in patients suffering from arteriosclerosis there was a demonstrable increase in their blood pressure over that of normal people. Similarly, they showed that in patients with fever there was a lowered blood pressure.

The introduction of the sphygmomanometer into clinical medicine was accepted by some doctors as a valuable aid to diagnosis, but the *British Medical Journal* held the view that by using the sphygmomanometer 'we pauperize our senses and weaken clinical acuity'. Despite the accusation of weakening clinical acuity, Potain made his second contribution towards making the sphygmomanometer more amenable to clinical use when, in 1889, he replaced water with air for compression. Potain's device consisted of a bulb which was used for compression of the artery. This was inflated by means of a second bulb, and the pressure recorded by a portable aneroid manometer.

It is misleading to think of the evolution of clinical sphygmomanometry as a series of jumps from one apparatus to the next. From 1847, the time of Ludwig, there was a gradual improvement in the style of measuring blood pressure, with new methods slowly becoming accepted – taking over from previous ones – until they too were superseded by yet more improvement. However, in the mid 1890s one very important character emerged; he was Scipione Riva-Rocci.

Development of Present-day Technique: the Ideas of an Italian Doctor

In 1896 Riva-Rocci reported the method upon which present-day technique is based. His researches were published in two papers, both under the title 'Un nuovo sfigmomanometro'. They were published in the *Gazetta Medical di Torino* (Riva-Rocci was awarded his MD degree at Turin six years previously) in numbers 50 and 51 of volume 47, appearing on 10 and 17 December. Dr W H Lewis gives a summary of a translation of these reports in his paper on clinical sphygmomanometry (Lewis 1941). In these reports Riva-Rocci recorded the purpose of his research on arterial pressure and then described the physical principles involved. He then went on to review the literature, describing the various types of commercially available von Basch sphygmomanometers. Apparently Riva-Rocci favoured one of the early instruments which incorporated a mercury manometer, rather than the later designs which had non-mercury manometers. He described his new design of instrument as:

'a sphygmomanometer likewise based on the principle established by Vierordt and improved on by Marey and von Basch in turn. In other words it is an instrument affecting manometric measurement of the force necessary to impede the progression of the undulation of the pulse. Sphygmomanometry is then applied to one of the large aortic branches, to the humeral. Since the humeral is the direct continuation of the axillary (since the region contains no collateral branch large enough to be considered as a branch of the bifurcation), the measurement gives the total charge of a point fairly close to the aorta or, if you like, of the charge of pressure either in the aorta itself (if the left humeral is concerned) or of the brachiocephalic trunk (if the right humeral is concerned).'

Riva-Rocci considered the advantages of his device to be: ease of application; rapidity in action; precision; and harmlessness to the patient. His technique involved compression of the arm around its whole circumference and not just one of its aspects. A rubber bag, surrounded by a cuff of some inexpansible material, was wrapped round the whole girth of the arm and was inflated with air by means of an attached rubber bulb. The pressure in the cuff was registered by the usual mercury manometer, and was increased until the radial pulse could no longer be palpated. When the pressure was slowly released the mercury level in the manometer fell, and the reading at which the pulse reappeared was taken as the systolic blood pressure. An important advantage inherent in this new design was that the brachial artery was compressed from all sides equally, thus eliminating the unilateral pressure of the von Basch technique. Riva-Rocci was most assiduous in testing his new device to ensure that it measured the 'total charge' of the arterial pressure. He performed experiments on animals, on the human cadaveric arm and with an artificial circulation constructed from rubber tubing. There was, however, one main defect in Riva-Rocci's method; he used a narrow cuff only 5 cm wide. This caused an acute angle to form between the upper and lower edges of the cuff and the skin, which resulted in local areas of high pressure building up and rendering the reading mildly inaccurate. This error was realized and corrected by von Recklinghausen in 1901, who replaced the narrow armband with one about 12 cm wide.

At this time the method used for determining whether or not pulsation was present beyond the region of arterial constriction was that of palpation. This was quite all right for systolic pressure measurements, and is the technique still used today, but it was useless for an accurate determination of the diastolic pressure. In order to overcome this deficit so that both systolic and diastolic pressures, and hence pulse pressures, could be recorded clinicians started to use the oscillatory method. This involved observing the oscillations which were transmitted to the mercury in the manometer from the artery, since when the cuff pressure was equal to the arterial pressure the compressed artery would throb, thus causing small regular fluctuations in the cuff pressure. The appearance of definite oscillations defined the systolic pressure, and the transition from large to small oscillations, the diastolic pressure. In England, Hill and Barnard invented a device which had a needle pressure gauge which was sensitive enough to record the diastolic phase. Their apparatus was portable and easy to use. Hill and Barnard's sphygmomanometer did much to further the measurement of blood pressure in this country (Hill & Barnard 1897, Singer & Underwood 1962).

Twentieth Century: the Work of a Russian Surgeon

At the turn of the century yet another technique was devised for determining the systolic and diastolic pressures. In 1905 N C Korotkoff, a Russian surgeon, reported that by placing a stethoscope over the brachial artery at the cubital fossa, distal to the Riva-Rocci cuff, tapping sounds could be heard as the cuff was deflated, caused by blood flowing back into the artery. Korotkoff communicated the discovery of this auscultatory method to the Imperial Military Medical Academy in St Petersburg in December 1905, in a brief paper 207 words long; rather humble beginnings for a technique which was to be used by doctors the world over and to which anybody who has ever been a patient has probably been subjected. The only available copy of Korotkoff's original communication outside Russia, is in the Slavonic division of the New York public library. This copy is contained in *Izvestiya Voennomeditsinskaie Akademiia* (*Bulletin of the Imperial Academy of Medicine*). The report is entitled 'on methods of studying blood pressure (from the Clinic of Prof. Feodeoreff)'. A full translation appears in Lewis's paper on clinical sphygmomanometry (1941), as follows:

'On the basis of this observation, the speaker came to the conclusion that a perfectly constricted artery under normal conditions, does not emit any sounds. Taking this fact into consideration, the speaker proposed the sound method for measuring blood pressure on human beings. The sleeve of Riva-Rocci is put on the middle third of the arm; the pressure in this sleeve rises rapidly until the circulation below this sleeve stops completely. At first there are no sounds whatsoever. As the mercury in the manometer drops to a certain height, there appears the first short or faint tones, the appearance of which indicates that part of the pulse wave of the blood stream has passed under the sleeve. Consequently, the reading on the manometer when the first sound appears corresponds to the maximum blood pressure; with the further fall of the mercury in the manometer, there are heard systolic pressure murmurs which become again sounds (secondary). Finally all sounds disappear. The time of disappearance of the sounds indicated the free passage or flow of the blood stream; in other words, at the moment of disappearance or fading out of the sounds, the minimum blood pressure in the artery has surpassed the pressure in the sleeve. Consequently, the reading of the manometer at this time corresponds to the minimum blood pressure. Experiments conducted on animals gave positive results. The first sound tones appear (10–12 mm) sooner than the pulse which (1 ar. radialis) can be felt only after the passage of the major portion of the blood stream.'

After he had delivered his paper Korotkoff entered into lively discussion with Dr Ivanov and Dr Bojovski, in which he ably defended the use of his technique in the clinical field.

The widespread use of the auscultatory technique had the spin-off effect of popularizing the binaural stethoscope or phonendoscope. Korotkoff originally used the monaural device which was a direct descendant of Laennec's rod. However, when he had to control the pressure in the Riva-Rocci cuff at the same time as listen for the arterial sounds, he found the procedure rather clumsy. The binaural stethoscope was far more convenient and after this Korotkoff advocated its use (Segall 1975).

Not only is the late Dr Korotkoff's paper hard to come by, but biographical details also seem to be scant. There are no notes about his life contained in any non-Russian source, as listed in the *Index Medicus*. However, Dr Harold Segall quotes the late Professor Boris Babkin, Research Professor of Physiology at McGill University in the late 1930s and a contemporary of Pavlov at the Imperial Military Medical Academy at the turn of the century, as remembering Korotkoff as a tall, slender, studious young man (Segall 1965). There is a brief biography of Korotkoff in the Russian journal *Clinical Medicine* (1956, **4**, No. 11). Dr Segall provides a translation which includes the following details. Korotkoff was born in 1874 and graduated in medicine from Moscow University in 1898, when he became resident surgeon at the Surgical Clinic of Moscow. From 1902 to 1904 he worked as an assistant in the women's department of the Clinic of the Military Academy of Medicine, under Professor Feodorov. It was during the Russo-Japanese war of 1904, when he was serving as a surgeon in Manchuria, that he became interested in blood vessels. When he returned to Russia he went to St Petersburg where he studied the surgical treatment of arterial injuries. It was whilst busy with this work that he discovered, in 1905, the auscultatory method for which he is famous. His work on the vascular system is embodied in his thesis 'Experiments for Determining the Strength of Arterial Collaterals', for which he was awarded a doctorate in 1910. After the Russian Revolution he became senior physician of the Metchntkov Hospital in Leningrad. He died in 1920, aged 46.

Korotkoff's important contribution to medicine was the devising of an accurate and easy method of determining the blood pressure. His technique has stood the test of time as it has been used for more than half a century with practically no changes made to it. Korotkoff laid the foundations from which such distinguished cardiovasuclar physicians as Paul Wood and William Evans could deduce the underlying pathology.

Now, in the 1970s, blood pressure can be monitored continually by sensors worn on the patient's thumb; inflatable cuffs are coupled to a servo-mechanism which maintains suitable cuff pressure. Strain gauges, photocells and semiconductors are coming into use in the recording of blood pressure (Longmore 1969). Yet our realization of the importance of blood pressure might not have been as alert as it is had it not been for the early pioneers such as Hales, Ludwig and von Basch.

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