Josep Solà · Ricard Delgado-Gonzalo
Editors

The Handbook of Cuffless Blood Pressure Monitoring

A Practical Guide for Clinicians, Researchers, and Engineers

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Preface

Let us start with a typical scenario from clinical practice today.

During an annual physical exam:

143/97, Mr. Vailet, I have the feeling you are developing hypertension.

The day after, at Mr. Vailet's home:

134/88

Two days after:

129/84

No further measurements until the day before the next physical exam, at Mr. Vailet's home:

148/95

Back to the physician's office:

Mr. Vailet, where are the weekly blood pressure readings I asked you to do?

Measuring arterial blood pressure is a fundamental action when checking a patient's overall health. Nowadays, physicians and patients alike still rely on a century-old technology that requires the inflation of a cuff around the arm. This leads to intermittent, sparse, or nonexistent monitoring of a patient's health status over long periods of time. As a result, millions of individuals are being wrongly treated, underdiagnosed, or simply not diagnosed at all.

For more than a decade, an assembly of scientists, physicians, researchers, and engineers have been working on the development and validation of novel technologies to overcome the burden of cuff-based blood pressure measurements. This book is a tribute to this collective effort.

In 2017, we started crafting *"The Handbook of Cuffless Blood Pressure Monitoring: A Practical Guide for Clinicians, Researchers, and Engineers"* that you have now in your hands. From the beginning, we aimed at creating the first comprehensive publication providing an overview of the emerging field of cuffless blood pressure monitoring. We gathered the most knowledgeable authors around the world who could summarize the basics, the medical context, the potential, and the technical challenges of cuffless blood pressure monitoring. This work is now done.

Dear reader, if you are a researcher, clinician, engineer, journalist, investor, or student who wants to get into the field of cuffless blood pressure, we are convinced you will enjoy diving into these chapters.

Neuchâtel, Switzerland

Josep Solà
Ricard Delgado-Gonzalo

Acronyms

AAMI	Association for the Advancement of Medical Instrumentation
ABPM	Ambulatory blood pressure monitoring
AI/AIx	Augmentation index
ANSI	American National Standards Institute
AP	Augmented pressure
APG	Acceleration plethysmogram
BCG	Ballistocardiography
BHS	British Hypertension Society
BP	Blood pressure
CT	Computed tomography
DBP/DIA	Diastolic blood pressure
DIA	Diastolic blood pressure
DL	Deep learning
DNN	Deep neural network
DPTI	Diastolic pressure-time index
DT	Diastolic time
ECG	Electrocardiography
EHS	European Home Systems
EMAT	Electromechanical activation time
ESH	European Society of Hypertension
ESP	End-systolic pressure
FDA	Food and Drug Administration
FF	Form factor
FQP	Four-quadrant plot
GCP	Good clinical practice
GTF	Generalized transfer function
HR	Heart rate
ICG	Impedance cardiography
IDE	Investigational device exemption
IEEE	Institute of Electrical and Electronics Engineers
IPG	Impedance plethysmography

IR	Infrared
ISO	International Organization for Standardization
IVCT	Isovolumic contraction time
LED	Light-emitting diode
LSTM	Long short-term memory
LVET	Left ventricular ejection time
MAD	Mean absolute differences
MAP	Mean arterial pressure
MAPD	Mean absolute percentage difference
MDBP	Mean diastolic blood pressure
ML	Machine learning
MSBP	Mean systolic blood pressure
NIBP	Noninvasive blood pressure
NN	Neural network
NPMA	N-point moving average
PAT	Pulse arrival time
PCG	Phonocardiography
PDA	Pulse decomposition analysis
PEP	Pre-ejection period
PMA	Premarket approval
PP	Pulse pressure
PPG	Photoplethysmography
PTT	Pulse transit time
PWA	Pulse wave analysis
PWD	Pulse wave decomposition
PWTT	Pulse wave transit time
PWV	Pulse wave velocity
RI	Reflection index
RMSE	Root mean square error
RNN	Recurrent neural network
SBP	Systolic blood pressure
SCG	Seismocardiography
SD	Standard deviation
SEVR	Subendocardial viability ratio
SI	Stiffness index
SPTI	Systolic pressure-time index
SVM	Support vector machine
SVR	Support vector regression
SYS	Systolic blood pressure

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Chapter 1
Cuffless Blood Pressure Monitoring and the Advent of a New Era in Medicine and Society

Alberto Avolio, Fatemeh Shirbani, Isabella Tan, and Mark Butlin

Abstract Measurement of arterial blood pressure (BP) by the brachial cuff sphygmomanometer has been a cornerstone of modern medicine, and notwithstanding its limitations of intermittent BP monitoring, the cuff sphygmomanometer has not been surpassed by any other noninvasive methodology. However, advances in sensor technology for arterial pulse detection have paved the way for the potential development of devices for cuffless measurement of BP, with the prospect of continuous monitoring. Just as the cuff sphygmomanometer could be considered as having provided a significant step in establishing elevated BP as a major factor of cardiovascular risk since the turn of the twentieth century, cuffless BP monitoring might be considered a disruptive technology for continuous BP monitoring in healthy individuals during daily living and could become an integral component of modern digital health platforms in the twenty-first century. This volume of the *Handbook of Cuffless Blood Pressure Monitoring* addresses the significant challenges faced by this methodology. The underlying physiology and hemodynamic principles involved in the generation of the arterial pressure pulse are complemented by the clinical relevance of the novel cuffless methodologies in relation to the conventional cuff sphygmomanometer. The underlying pressure dependency of arterial properties, which is at the base of the cuffless technique employing pulse transit measurement as a surrogate measure of BP, is addressed in association with instrumentation, measurement techniques, calibration procedures, device validation and regulatory requirements. This book provides a timely and comprehensive platform on how to approach the critical question of whether cuffless is the future of BP monitoring.

Keywords Arterial stiffness · Pulse wave velocity · Pulse transit time · Sphygmomanometer · Blood pressure · Cuffless techniques · Peripheral pulse · Arterial hemodynamics · Big data

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Introduction

There is a notable coincidence between the accepted dates marking the publication of the first clinical use of the cuff sphygmomanometer by Scipione Riva-Rocci (15 December 1896) in Turin, Italy and the first projection of cinema to a paying audience by brothers Auguste and Louis Lumière (28 December 1895) in Paris, France. In addition to the remarkable proximity of the official dates, only 1 year apart, the two milestone events have a common origin through the work of French physiologist Étiene-Jules Marey in his studies of the circulation of blood. His evolving attempts to obtain quantitative representation of the force of the arterial pulse as detected and registered by graphic means paved the way for the invention of the *sphygmograph,* This led to the construction of devices for achieving time-lapsed photography to capture movement, culminating in series of ground-breaking publications and in the coining of the term c*hronophotography*, a technique used to study movement in flight [1] and which influenced the seminal flight experiment of the Wright brothers in 1903 at Kitty Hawk, marking the birth of modern aviation.

Although the arterial pulse has been used in medical diagnoses and described qualitatively since antiquity, the use of the sphygmograph enabled the first ever quantitative registration of any physiological parameter—a cuffless measure of arterial pressure, and long before the registration of the electrocardiogram. It was the efforts of many scientists and inventors such as Marey in the search for mechanical devices capable of producing an image of the varying morphology of the arterial pulse, coupled with advances in photography, that enabled the evolution and convergence of *sphygmography* and *chronophotography.* The one resulting in the advent and clinical use of the cuff sphygmomanometer by the Italian physician Riva-Rocci and the other in the promotion of cinema by French scientists and entrepreneurs such as the Lumière brothers in the late nineteenth century. With the dawn of the twentieth century, technological advances in the form of the cuff sphygmomanometer and cinema produced respective fundamental changes in the way medicine was practiced and in the way the moving image was used for enhanced communication and enrichment of the human experience. Both have had an immeasurable impact on human health and culture in society.

Cuffless Monitoring of Blood Pressure: A Disruptive Step in Health Management

The above advances were not made in isolation, but were integral component parts of a movement of progressive development of ideas and concepts that revolutionized scientific thinking and technological applications in the eighteenth and nineteenth centuries. History is rich with iconic milestones such as James Watt's development of the steam engine (cc 1780s) that was a major driving force for the industrial revolution. Perhaps one of the most significant fundamental unifying concepts in human history, the description of electromagnetic radiation by James Maxwell in 1865, has extended the application of human endeavor beyond the Newtonian view of the world to Einstein's concepts of relativity and to quantum mechanics. In modern parlance, and given the significant impact these developments have made on society as a whole, they might be described as highly "disruptive" in comparison to what came before.

And it is precisely the notion of "disruption" that is at the center of the transition from blood pressure being measured intermittently as a clinical parameter by the cuff sphygmomanometer to blood pressure being monitored continuously by cuffless devices. Just as the intellectual and scientific pathways that led to the development of the cuff sphygmomanometer were intertwined with advances and pitfalls in other avenues of scientific and technological endeavor in the nineteenth century, the development of cuffless blood pressure technology will tread similar ground in the twenty-first century. The difference being that the disruptive elements in the cuffless journey are supported and boosted by the immense power of all that is digital—the Internet, global positioning systems, satellite communication, cloud computing, miniaturization of computer chips and electronic circuits, intelligent algorithms, developments in sensor technology supported by intelligent materials. The difference will also extend to the use of the devices. Whereas the cuff sphygmomanometer, virtually unchanged since its inception, has been essentially used for detection of markers associated with pathology (hypertension), cuffless monitoring of blood pressure will be incorporated in wearable devices, thus enabling collection of data in normal daily living of individuals in society, in the form of "big data." It is yet not known in what way this form of data collection will modify the practice of medicine and how it will affect the understanding of blood pressure profiles with daily habits or lead to phenotypic classifications of normal individuals in the context of genetic analysis and precision medicine. However, there is a precedent. When brachial cuff blood pressure values were systematically collected using pen and paper by life insurance companies in the early twentieth century [2], it led to the understanding of how asymptomatic high blood pressure can be one of the most powerful factors of cardiovascular risk.

Underlying Principles of Cuffless Methodology

An important overarching concept underlying cuffless measurement of blood pressure is the fundamental relationship between transmural pressure and mechanical properties of the arterial wall which influence wave propagation phenomena [3]. This is the pressure dependency of the material stiffness of all blood vessels. This property is present in all species with pressurized circulatory systems and is a fundamental evolutionary property of arterial design [4]. Since, in any physical system, wave propagation is determined by the bulk modulus of the material, the speed of any disturbance (due to cardiac contraction and ejection) that travels along the arterial wall is directly related to vessel stiffness. And given the essential relationship of arterial stiffness and distending pressure, any measure of the velocity of the travelling pulse wave would be a measure of arterial pressure. This is an important consideration because pulse wave velocity (PWV) is *directly* related to blood pressure and so an accurate measurement of PWV should theoretically deliver a measure of blood pressure, provided that the relationship of PWV and blood pressure of the specific arterial path length is known. Changes in blood pressure would then be registered as changes in PWV, or more specifically, for a fixed distance, as changes in pulse transit time (PTT) [3]. Hence, on theoretical considerations, cuffless measurement of blood pressure using PTT could be considered to be a more robust measure of intra-arterial pressure than that obtained by using indirect surrogate signals such as appearance of a distal pulse (palpatory method), Korotkoff sounds (auscultatory method) or features of the envelope of the oscillation of cuff pressure during cuff deflation (oscillometric method).

The Handbook of Cuffless Blood Pressure Monitoring

This volume of *The Handbook of Cuffless Blood Pressure Monitoring*, the first of its kind, promises to be a guide in the modern twenty-first century journey of novel developments of methods and technology for monitoring of blood pressure, methodologies and techniques which go beyond the traditional cuff sphygmomanometer. It is a timely endeavor, and its publication will be an important milestone in this new field. It is both important and essential. Wearable, mainly wrist-worn devices are being produced that purport to measure blood pressure. Being connected to the Internet, they transmit data to databanks that log blood pressure values for individuals during daily activities. Being consumer devices, there is generally little or no regulatory requirement for the blood pressure measurement, other than device safety. With increasing use of these devices, it is conceivable that blood pressure data will be mined from big data sources and potentially "useful" knowledge will be extrapolated. However, there is no guarantee that the information from such data has any reliable relation to continuous blood pressure or any potential physiological significance. This is because of the inherent complexity in translating the noninvasive cuffless surrogate signal to a physiological arterial pressure. That is, the reliability of the basic methodology of calibration [5, 6]. This is in contrast to the cuff sphygmomanometer, where the cuff pressure is actually measured with high precision, and specific levels of cuff pressure are associated with arterial phenomena, such as appearance and disappearance of Korotkoff sounds associated with systolic and diastolic pressure, although to a varying degree of association and correlation.

The chapters in this book are comprehensive and cover a wide range of topics, all of which are highly relevant to the scientific, technological, industrial, and clinical aspects of the field of cuffless and continuous measurement of arterial blood pressure. The material presented in all the chapters offers a robust platform on which to launch this new field and which builds on the large amount of published work based on basic concepts of the circulation involved in the genesis of the pressure pulse, sensor technology, device development and fabrication, signal processing, deep learning strategies, modelling, calibration procedures, in vivo, in vitro, and in silico experimentation, and methods of validation.

This book addresses critical aspects relevant to the monitoring of blood pressure using cuffless techniques in 12 chapters. The following 11 chapters can be divided into three broad topic sections:

Topic Section 1 (Chaps. 2 and 3) describes the underlying physiology and hemodynamic principles involved in the generation of the arterial pressure pulse and the clinical relevance of the novel cuffless methodologies in relation to the conventional cuff sphygmomanometer. The important distinction between the new and old techniques for blood pressure monitoring is that the cuff sphygmomanometer is usually associated with the detection, treatment and management of hypertension, thus a pathological condition. Novel, cuffless techniques, embedded in wearable devices, will be associated with monitoring continuous changes in blood pressure predominantly in normal individuals during daily activities. This will undoubtedly have an impact on the meaning of such things as blood pressure thresholds that separate the "normal" state from the "pathological" state. This suggests significant "disruption" in the actual understanding of what constitutes "hypertension" in association with a plethora of other health data obtained by wearable devices and interpreted by data analytics.

Topic Section 2 (Chaps. 4–9) describes the areas of cuffless devices involving instrument components, measurement techniques and calibration procedures. This Topic Section is critical to the fundamental understanding of the essential components of what constitutes a cuffless device for monitoring of arterial blood pressure. The basic requirement is the detection of the arterial pulse, with sensor modality being key for reliable pulse detection. An important distinction between sensors used for cuffless devices is that they do not necessity need to provide a quantitative measure of the force of the arterial pulse, but rather a fiducial signal which is in synchrony with the beating heart. The measurement of arterial pressure is based in temporal characteristics, so there is no requirement for absolute grading of measured signals. This enhances the capacity of available sensors for signal detection and the scope for instrumentation to be adapted to wearable devices. However, while sensors may be sufficiently robust for signal detection, the conversion of a measured time delay (irrespective of the degree of accuracy) to a physiologically relevant blood pressure remains one of the most challenging aspects of this field. To date, calibration issues remain unresolved, particularly in terms of stability, frequency of performing calibrations, procedures involved in obtaining adequate ranges of blood pressure and the differences in relationships between pulse transit time and arterial pressure for different arterial sites, or even at different levels of blood pressure. The limitations related to inconsistent physiological relationships can be addressed using data-driven procedures involving machine learning techniques [7]. However, it is not yet known how different databases can be sufficiently regulated to produce reliable training platforms for a broad range of algorithms applied to machine learning approaches for blood pressure monitoring.

Topic Section 3 (Chaps. 10–12) addresses the important area of device validation in the context of regulatory requirements and standards. To a certain extent, there is a conceptual overlap between “cuffless” and “continuous” techniques for blood pressure monitoring which is not adequately addressed by the current standards. Hence, there is a need for clear and definite guidance for evaluation from regulatory authorities so as to provide sufficient certainty for the medical devices industry. Finally, with appropriate validation, future projections are made on the expectations of the use of cuffless devices for diagnosis and management of hypertension. However, this will need to be in the context of the potential disruption to the concept of hypertension and blood pressure thresholds.

All chapters are comprehensive and authoritative. They cover a broad range of relevant topics that enable and enhance understanding of the field of cuffless blood pressure monitoring at a considerable depth. While there will be some necessary and unavoidable repetition of some sections in different chapters, this is a positive aspect as it highlights their relative importance and contributes to placing this new field in the historical, technological and social continuum.

Is “Cuffless” the Future of Blood Pressure Monitoring?

The comprehensive nature of this volume brings out the advances as well as the formidable challenges facing the journey of device development for reliable and continuous monitoring of blood pressure using cuffless techniques. The “state of the art” suggests that some milestones have already been achieved. Sensor technology for pulse detection is highly evolved and robust. Advances in component miniaturization and complex chip design have enabled the explosion of wearable devices incorporating measurement and processing of physiological signals, providing information on metrics that can guide decisions on health management. However, while some of these metrics are highly reliable (e.g., heart rate, blood oxygen levels, and many others) and have been available for some time, accurate, reliable continuous, cuffless monitoring of blood pressure has presented insurmountable challenges. There have been many patent submissions, start-up companies, and scientific publications, but to date there is no device that is universally accepted by the wider community beyond research laboratories and company boardrooms.

This book will make a significant contribution to providing an informed answer to this important question.

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Chapter 2
Clinical Relevance of Continuous and Cuffless Blood Pressure Monitoring

Gianfranco Parati

Abstract The assessment of dynamic features of blood pressure, which represent a response of cardiovascular control mechanisms to environmental stimulations and to daily life challenges, not only offers important insights into cardiovascular regulation patterns but also carries clinically relevant information. Availability of tools for continuous blood pressure monitoring represents a key step to make such an assessment possible, but its implementation in daily practice requires noninvasive, simple and minimally intrusive methods. These methods are expected to overcome the well-known limitations characterizing the conventional approach to blood pressure measurement based on discontinuous blood pressure readings obtained through repeated arm cuff inflations. In such a perspective, techniques able to provide continuous blood pressure monitoring without the need of a cuff inflation would be welcome.

Keywords Continuous blood pressure monitoring · Blood pressure variability · Arm cuff inflation · Cuffless blood pressure measurement technology

Introduction

Blood pressure (BP) is one of the most dynamic physiologic variables among those routinely measured in clinical practice, consisting of a series of pulse waves continuously changing in terms of both frequency and amplitude. BP is indeed characterized by continuous and significant changes occurring over different time windows, with beat-by-beat oscillations being intertwined in a complex manner with

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fluctuations occurring from minute to minute and from hour to hour, at the time of the different behaviors which occur over the day and night, Further complexity is added by additional and more long-lasting fluctuations which may be observed over different days, over different seasons, and at the time of consecutive visits by a physician even in a time window of several years [1].

In physiological conditions these BP variations largely represent a response of cardiovascular control mechanisms to environmental stimulations and to daily life challenges, aimed at maintaining the so-called cardiovascular "homeostasis," being additionally influenced by food, physical exercise, or sleep patterns.

Moreover, sustained increases in BP variability may also reflect intrinsic alterations in cardiovascular regulatory mechanisms or the effect of underlying pathological conditions responsible for a dysregulation of neural and humoral factors involved in modulating cardiac and vascular functions.

The interest in the assessment of these BP variations comes from the evidence that they may have important clinical significance and prognostic implications, as demonstrated by a series of experimental, clinical, and population studies. Indeed, enhanced BP fluctuations have been associated with a higher risk of subclinical organ damage, cardiovascular events, and cardiovascular and all-cause mortality independently and on top of what determined by elevated average BP values [2–4].

Thus, theoretically there is no doubt that the most accurate and detailed approach to the assessment of BP behavior in daily life would benefit from the possibility of performing continuous beat by beat recording of BP over 24 h.

However, such continuous recordings are not easy to implement in daily practice, where discontinuous BP measurements obtained through repeated arm cuff inflations still represent the method routinely applied. In fact, BP assessment in daily practice is currently based on two main methods. The first is the auscultatory method, based on the occlusion arm cuff-based technique introduced in 1896 by Scipione Riva-Rocci, coupled with use of Korotkoff sounds. The second is the oscillometric method, which makes use of the application of repeated automated cuff inflations to directly measure mean BP and then systolic and diastolic BP values are estimated through proprietary algorithms.

It is by means of these measurements that in year 2019 we are still currently managing hypertensive and cardiovascular patients in daily practice. Although these approaches have been shown to carry important clinical diagnostic and prognostic information when applied either in a clinic environment or in daily life conditions out of a clinic setting, they are not free from major limitations, which include the inherent inaccuracy of the techniques used, the inability to account for the dynamic nature of blood pressure and for its fluctuations over time and the difficulty in obtained undisturbed readings that might reflect subjects' actual BP patterns both during wake and sleep.

In fact, the arm cuff inflation is often itself responsible for difficulties, as it may be responsible for discomfort and sometimes even pain in patients in whom high levels of air pressure might be required for a proper BP measurement. These problems are in particular relevant when focussing on nighttime BP measurement, that is, on the measurements of BP obtained during sleep which have been shown to carry highly relevant clinical information. Nocturnal cuff inflations may indeed significantly disturb sleep of the subjects in whom they are performed, and may importantly interfere with the BP levels they are aimed at assessing. This is exemplified by the fact that conventional 24 h ambulatory BP monitoring, which is based on discontinuous and frequent BP measurements (typically every 15–30 min), in spite of its acknowledged clinical value is poorly accepted by many patients due to discomfort associated with repeated cuff inflations, which during the night may significantly worsen the quality of sleep [5]. Even if in many patients this does not affect BP levels [6], in some, an increase in nocturnal BP can be induced, leading to an artifactual reduction in BP dipping pattern with a loss of its prognostic significance, as reported previously for untreated hypertensive patients with significant sleep deprivation during 24 h BP monitoring [7].

These methodological problems with currently available techniques for BP assessment make it difficult to clarify a number of still pending clinical issues, such as the definition of the actual link between obstructive sleep apnea and hypertension; the understanding of why heart attacks and stroke mostly happen during sleep, especially in early morning; the definition of whether periodic leg movements and snoring might actually cause a BP increase; and the demonstration of the real ability of continuous positive air pressure (CPAP) ventilation to reduce BP levels in hypertensive patients with obstructive sleep apnea.

To avoid such inconveniences and to get rid of the related clinical difficulties, techniques able to provide continuous BP monitoring without need of a cuff inflation would be required.

Currently, a few techniques for continuous BP recordings without cuff inflation are indeed available, but are rarely employed for difficulties in their applicability. The first of such techniques, available since many years, is the possibility of intra-arterial beat-by-beat BP recordings, which have allowed to make the first important progress in understanding BP variability phenomena and the dynamics of cardiovascular control mechanisms [8–10]. This method however is based on invasive recordings, and even if it was extremely useful in former experimental studies, it cannot obviously be proposed for a clinical application. Another approach to noninvasive continuous cuffless beat by beat BP recordings is based on the volume-clamp method described by Jan Penaz and implemented in the Finapres© and Portapres© devices by Karel Wesseling. This approach has turned out to be useful in research [11] but has not found an application in clinical practice due to methodological difficulties in its daily use, to problems in calibration of the BP values provided and to its high cost. Some other recent approaches have been proposed making use of mobile health technologies. Indeed, several smartphones apps have been developed to measure BP. However, validation studies for most of these smartphone-based BP measurement techniques have not been conducted. To date, mobile health BP monitors have shown poor accuracy compared with oscillometric readings [12–15].

Other approaches are based on assessment of pulse transit time, which can derive BP levels from pulse transit time (PTT) measurement on the basis of a stretch–strain relationship model, calibrated with BP from a single initial conventional BP measurement [16–18]; or on pulse wave analysis, and are currently under investigations and development [19]. There is increasing interest towards thee modern approaches, because the cuffless and thus less interfering nature of the devices may render them particularly useful in patients who poorly tolerate traditional ambulatory BP monitoring and whenever undisturbed assessment of sleep BP is of importance, for example, in patients with sleep disordered breathing.

There is therefore a strong need for research and development of reliable and accurate continuous cuffless blood pressure measuring technologies, able to face the yet unmet need of accurate and at the same time noninterfering repeated BP measurements.

The present book offers an interesting and up-to-date insight into the progress made by technology in this stimulating and highly dynamic field.

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Chapter 3
A Historical Journey on the Physiology of Blood Pressure Monitoring

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Abstract The arterial pulse has been the most basic sign of life for centuries. The radial pulse palpation has been pictured in the crest of the Royal Academy College of Physicians since 1628. The history of the arterial pulse entails the discovery of pulse, blood pressure and/or flow, and their measurements. This chapter begins with a review the description of the pulse and the related discoveries of pulse and blood pressure and/or flow since the ancient period until the late 1970s where the concept of haemodynamics and importance of pressure and flow pulsatility as well as methods to analyse the pulse in both time and frequency domains gained wider acceptance. Human aging is associated with an increase in blood pressure, particularly systolic and pulse pressures, and this is attributable to the loss of distensibility of the human aorta of which its function is to cushion pulsation from the ejecting heart. Stiffening of the major elastic arteries due to aging will cause the speed of the travelling pulse to be higher, and the reflected pulse wave from periphery to occur earlier, therefore will increase the amplitude of pressure. To understand how arterial haemodynamics is altered by the ageing process and cardiovascular disease is vital and this involves accurate measurement of central (or aortic) pressure. Finally, the chapter briefly considers the demand and technology to develop cuffless blood pressure measuring devices. This development could allow a device that can measure blood pressure accurately, with ease, comfortably and continuously.

Keywords Systolic pressure · Diastolic pressure · Mean pressure · Pulse pressure · Pressure pulse wave · Sphygmocardiography · Aging · Hypertension · Arterial stiffness

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