What Does a Perfect Blood Pressure Meter Look Like from a Clinician Point of View?

Shin-ichi Ando

In our usual busy cardiology clinic, we always measure the blood pressure (BP) of our patients hundreds of times each week. At this moment, many physicians are still using a mercury sphygmomanometer in outpatient and inpatient clinics, and our hands lose gripping power by evening (Fig. 1). On the other hand, for a patient who comes to my office complaining of high BP for the first time, I always ask them to measure their BP at home or to wear an ambulatory BP monitoring device to obtain as exact and precise BP data as possible. However, such patients sometimes complain about the cumbersomeness or discomfort of frequent home BP measurements. Thus, I feel that the way of measuring BP (to pressurize a cuff manually or mechanically, to release it, and to read the value of BP) has not changed drastically for a long time even under this digital and computerized world. In this article, I give an overview of some problems faced in measuring BP, and propose an ideal BP measurement machine or mechanism for a clinician to measure BP as efficiently and comfortably as possible.

Introduction

Hypertension is one of the biggest medical problems worldwide. Especially for the Japanese, it is a more serious problem because as a group, they have had more cerebrovascular disease (CVD) than those in the western countries, and hypertension is well known risk to be most closely related to CVD. For example, in the Hisayama study, the relationship between hypertension and incidence of CVD is clearly shown (Fig. 2) [1]. The study, which has been continuously performed on almost all of the residents of Hisayama town including surveys of their medical conditions, causes of death and incidence of many diseases, has been produced for 52 years.

Of course, hypotension is another serious problem for some patients. However, the number of patients with hypotension is far smaller than the number of hypertension patients.

The Purpose of Measuring Blood Pressure

First of all, why should we measure BP? There are many answers for this question, as listed below according to the physician or to the situation. In most instances, the common purpose is to improve the quality of treatment by:

- determining whether the patient really has hypertension (sometimes hypotension);
- confirming the cause of complaint of the patient, for example, headache;
- knowing the circadian BP pattern of the patients;
- knowing the effect of the treatment; or
- to facilitate medical work by recording medical data of a patient and collecting data for some research.

An ideal BP meter or measurement for clinicians should cover many of these needs, although I understand that fulfilling all of these needs in one machine would be basically impossible.

Fig. 1. Image of a mercury sphygmomanometer.

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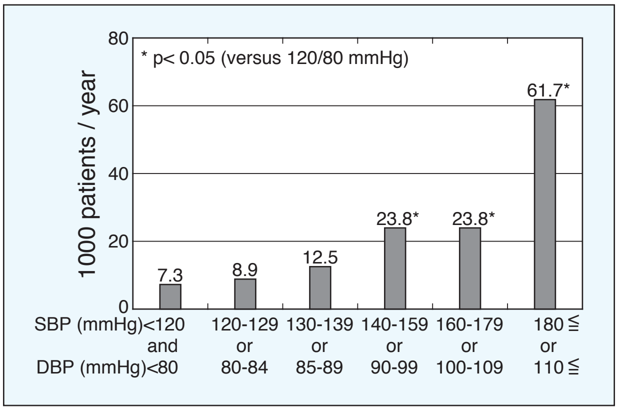

Fig. 2. Incidence of cerebrovascular disease (CVD) in different groups of initial BP in 32-years of follow up [1]. The rate of new CVD increases as the BP at the time of initial measurement is higher. Especially, the rate is significantly higher statistically in those whose initial BP was >140/90 mm Hg compared with those with <120/80 mm Hg: the p-value was 0.05. (SBP- systolic blood pressure. DBP- diastolic blood pressure.)

Time Span of BP Changes

There are different interests in BP measurements, and each of them is related to a different time span, as listed in Table 1. The BP meter may have a different shape or different mechanisms for each particular time span of interest. However, it may be difficult to attain the correct averaged BP for a long time span without causing pain or restricting the patient because to wear a current BP meter for such a long time would be very uncomfortable. Consequently, we have to inevitably measure BP intermittently and use these values as a surrogate averaged BP.

What Kind of BP do Clinicians Need, if Possible?

Though blood pressure readings should be correct, there are so many serious noise sources that impact BP measurements. They include body motion, arrhythmia, body position, baseline drift, arterial stiffness, and electrical noise. To measure Ambulatory BP (ABPM), patients wear a BP meter which automatically takes measurements intermittently, according to the designated time spans. This method has been widely used and gives us ample important information about the patient's BP. However, because patients move around during the daytime and even during sleep, these *body motions* inevitably make many serious noises. This type of noise sometimes results in confusion for the interpretation and can make the treatment by clinicians inappropriate.

When a ventricular or atrial premature contraction (a most frequent type of *arrhythmia*) occurs, actual BP goes up and down. If this type of arrhythmia occurs once in a while, it does not make big problem. However, if it occurs very frequently, BP values fluctuate widely. With the ABPM device currently used, the average BP values are only estimated by the physician. Furthermore, with a growing aged population, atrial fibrillation (AF), an arrhythmia with absolutely irregular heartbeats, has been observed more frequently. This condition makes correct measurement of BP very difficult because the irregular arterial pressure waveform associated with AF results in different BP values on every different systolic and diastolic BP reading. Clinicians need to define: what is a clinically meaningful *correct BP* in this setting? An ideal BP meter should show this kind of meaningful value.

By the nature of pressure, BP is deeply affected by *body position*, i.e., by the difference in height between the point of BP measurement and the patient's heart position. Sometimes, the variation of readings reaches 20 mm Hg, especially during ABPM measurement and even during one time measurement. Automatic correction of the difference caused by such positional changes would be ideal.

Over long continuous BP measurement, some factors result in a *base line drift* of measured values. For example, there might be chronic distortion of skin or other subcutaneous tissues or a minor leak of air or expansion of a tube in the instrument. These should be minimally suppressed or automatically compensated in an ideal BP meter.

In a small number of very elderly patients, *arteries have become very stiff* and need strong pressure to completely stop blood flow. This causes an inappropriate diagnosis known as *false hypertension* (pseudo-hypertension) in such patients. As rapid growth in the elderly population occurs, this might become a big problem in the near future, and the traditional way of compressing the brachial artery of the arm should be reconsidered for this group of patients.

Central BP

As many of the readers would know, the shape of the BP wave is widely different according to the point where the BP is measured (Fig. 3). This phenomenon derives from the fact that the waveform consists of at least two types of wave: one incidental or forward pulse wave and one reflected or retrograde wave (Fig. 4). The reflection of the wave occurs somewhere in

Table 1 – The time span of different interests in BP measurements

Time-span	Purpose
1 second	To detect acute BP changes in emergency room or operating room.
1 minute	To measure the response to change in position or to intravenous administration of drugs.
1 hour	To measure response to acute oral drugs.
1 daytime, 1 nighttime	To know the pattern of hypertension.
1 week	To confirm stability of BP during days to 1 week.
1 month	To detect the chronic effect of medication or seasonal change in BP.
1 year	To know BP change relating to prognosis.

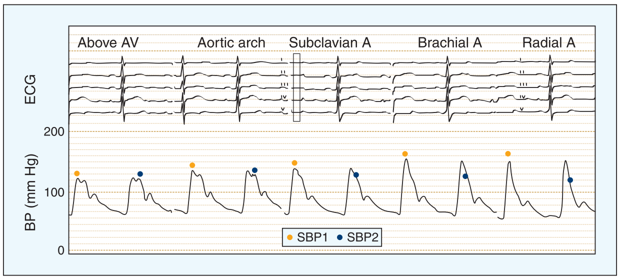

Fig. 3. BP contours. As the point moves to more peripheral from just above the aortic valve of heart to the wrist (radial a) the first peak of arterial wave (SBP1) increases and, conversely, the second peak (SBP2) increases relative to SBP1 as the place of measurement comes more central. AV- aortic valve. A- Artery. SBP- systolic blood pressure.

the peripheral arteries and causes the central arterial pulse to be higher, a BP value called the central BP (SBP). It is a reading of a peaked value, not the way of measurement. The reason why we clinicians are interested in the central SBP is that this pressure is more closely correlated to the prognosis of the patients.

The Ascot Trial

The ASCOT trial confirmed the importance of central BP. In this trial, two kinds of antihypertensive agents were administered: a beta-blocker (BB: atenolol) and a calcium channel blocker (CCB: amlodipine) [2] and [3]. BPs measured at the radial position were the same in both groups, but the estimated central SBPs were different, as shown in Fig. 5a. After a long follow up time, it was revealed that the patients who were treated with a BB had more adverse cardiovascular events when compared to those given CCB (Fig. 5b). Though, now that many clinicians are aware of the importance of measuring the central SBP, however, the use of this technique has not spread widely due to several problems. One is that the

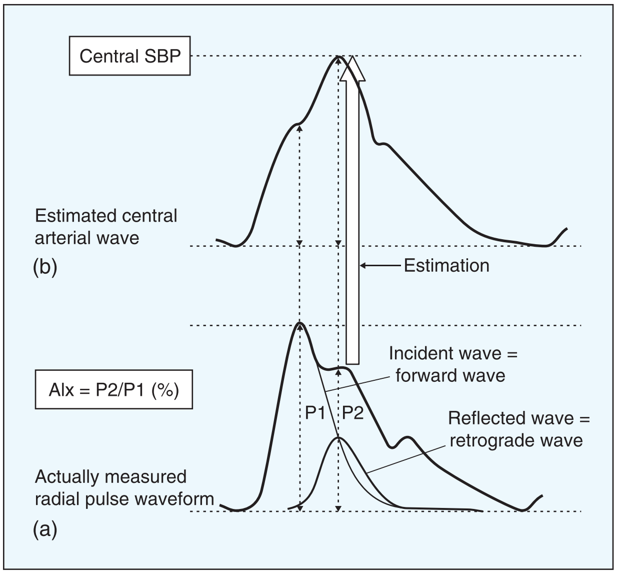

Fig. 4. (a) Components of arterial waves. (b) Estimation of central SBP. Because the central SBP cannot be actually measured non-invasively, this value is estimated using a formula from the actually measured second peak (reflected wave) in the radial arterial waveform.

measurement is basically cumbersome. Unlike the use of a usual mercury sphygmomanometer, which can take a BP measurement in a minute, the measurement of central SBP involves the time for making sure the radial part of patient's arm is exactly and firmly positioned on a special machine and this process can take 3–5 minutes even by a trained examiner. Second, the estimated value of central SBP is widely influenced by factors such as the patient's age and the intake of food or beverage before the measurement. As we know the importance of central SBP, we would like to obtain an easy and robust central SBP meter in the future.

Home BP

In many countries including Japan, hypertension (HT) is defined as SBP $\geqq$ 140 mm Hg or diastolic BP (DBP) $\geqq$ 90 mm Hg *in office* after many epidemiological studies. However, office BP does not accurately reflect the real BP of the patients in many cases. As illustrated in Fig 6, 59% of untreated patients who were defined as *hypertensive* in office were not really

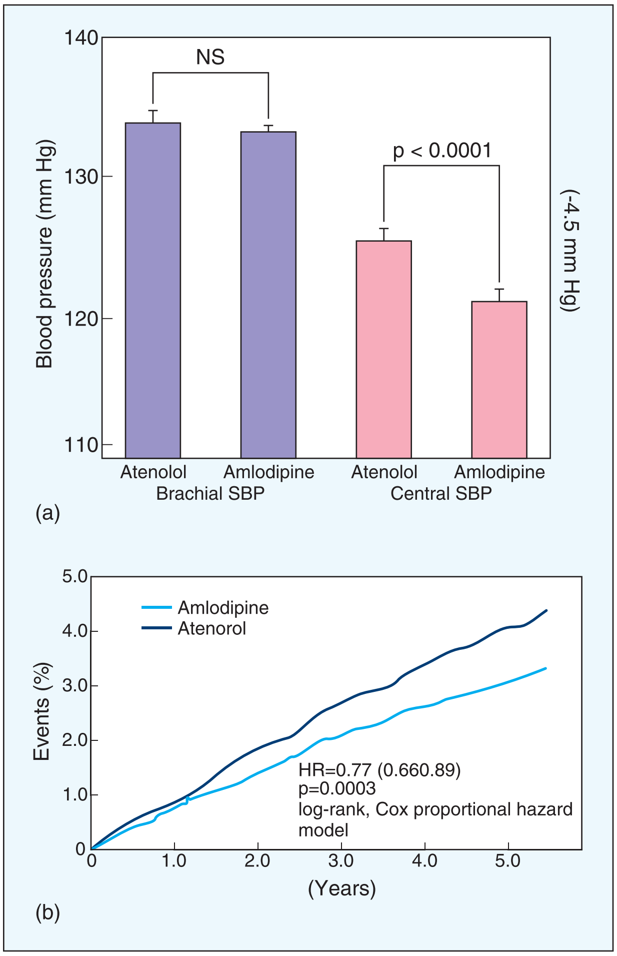

Fig. 5. The importance of central SBP from the ASCOT study [2], and [3]. (a) Even with same brachial arterial BP (usually measured BP), the estimated central BP is different according to the kind of antihypertensive drugs used. (b) This resulted in the significant increase in the cardiovascular events in a long-term study of the group on which atenolol was used compared to the patients on amlodipine. Thus, to predict the prognosis of patients under antihypertensive medication, central BP more correctly provides the risk of the patient.

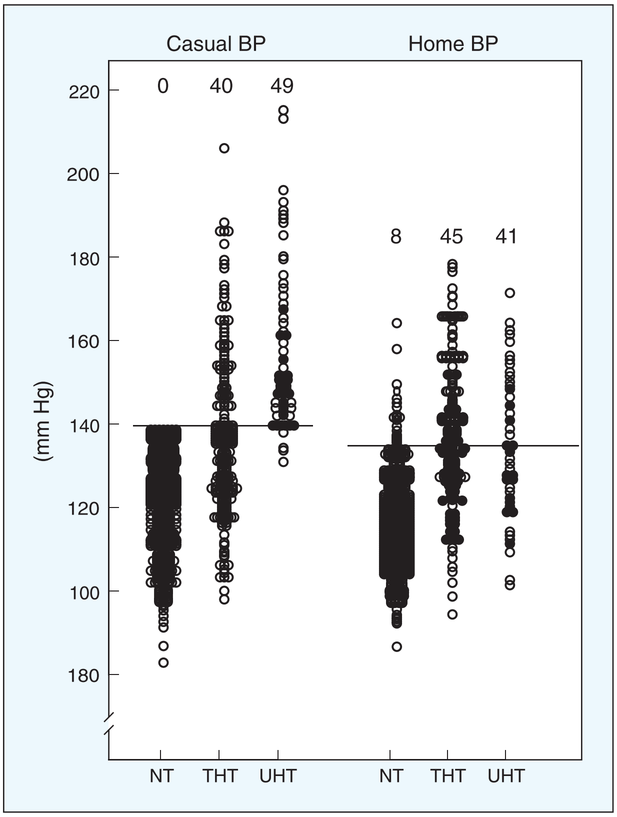

Fig. 6. Casual BP at office and home BP [4]. (NT- Patient with Normal BP, THT- Patients with HT under treatment, and UHT- Patients with untreated HT.)

hypertensive at home [4]. We also found that SBP was higher in the clinic especially in older patients (data are not shown).

Currently, hypertension (HT) is sub-categorized as simple hypertension for patients who exhibit high BP in both home and office settings, masked hypertension where only the home BP is high, and white coat hypertension where only the office BP is high. Of these, masked hypertension has become recognized as dangerous as simple hypertension, though the risk of white coat hypertension is more or less close to normotensives. Therefore, fully understanding what kind of hypertension is present or how BP fluctuates in a given patient is of fundamental importance in the actual treatment of a hypertensive patient.

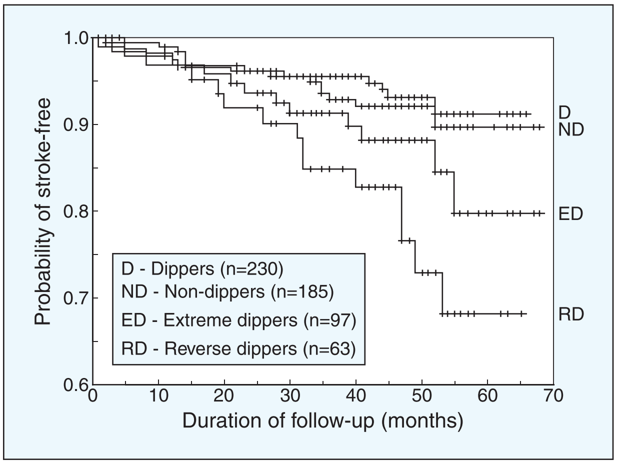

Fig. 8. Stroke free survival curve according to the nocturnal BP pattern [6]. Compared to dipper patients, patients with reversed dipper (riser) or extreme dipper had poorer prognosis.

Nocturnal BP

Recently, the patterns of nocturnal BP alteration are classified as dipper (decrease in BP by 10–20 mm Hg), non-dipper (decrease in BP less than 10 mm Hg), extreme dipper (decrease in BP more than 20 mm Hg), and riser (increase in BP) (Fig. 7) [5]. Accumulated evidences show that the pattern of nocturnal (during sleep) BP is closely related to the prognosis of the hypertensive patients or even that of non-hypertensive patients during the daytime (Fig. 8) [6]. Furthermore, the other two types of BP pattern, i.e., continuous morning HT (occurs from the beginning of sleep through morning) and morning surge pattern hypertension (occurs only in the morning) are recognized as independent categories of nocturnal hypertension. Evidence has shown that nocturnal hypertension affects more on the prognosis of the patient than daytime hypertension (Fig. 9) [7]. Therefore, to measure nocturnal BP which is usually hidden from daytime clinicians is becoming more and more important.

Apart from BP patterns, the antihypertensive effect of drugs has been known to be affected by the time of their administration. For example, a study by Martino, et al. showed that BP could be more lowered by nocturnal administration compared with morning administration, and fibrosis of the heart caused by pressure overload using the experimental aortic banding was less prominent after nocturnal administration (Fig. 10) [8]. Our group has also reported similar results in human subjects [9]. These time dependent drug effects can be recognized only by nocturnal or 24-hour BP monitoring.

Recently, sleep apnea syndrome (SAS) where a patient experiences frequent stopped or near-stopped breathing during sleep that results in

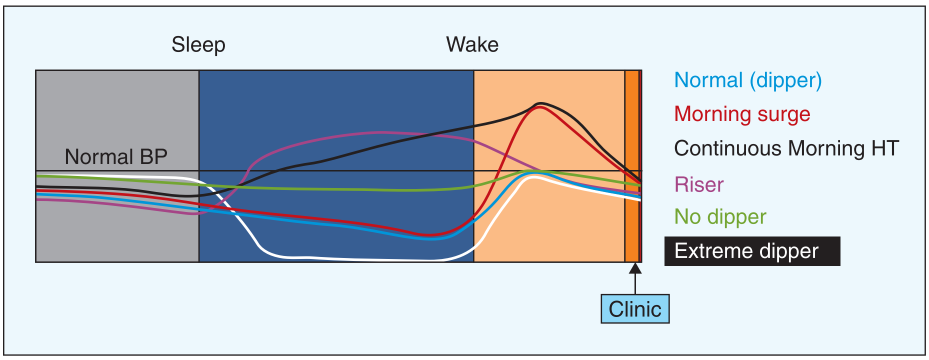

Fig. 7. Types of nocturnal and morning BP [5].

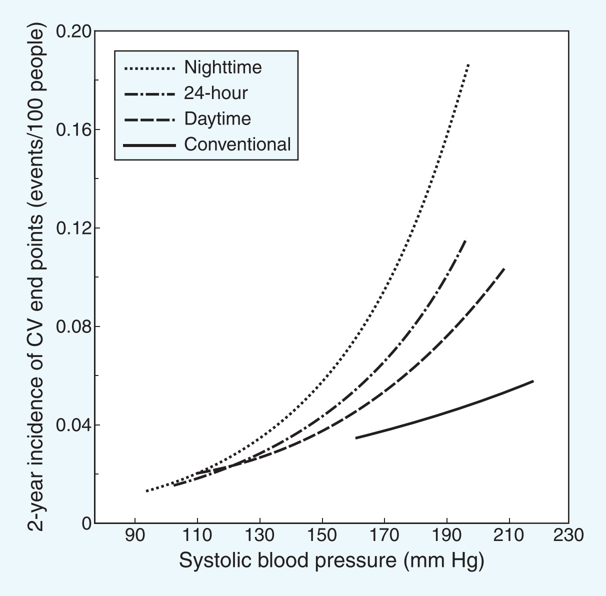

Fig. 9. Blood pressure readings and a two-year prognosis of CV end points (fatal and nonfatal heart failure, fatal and nonfatal myocardial infarction, or sudden death) (events/100 people) [7]. Nighttime BP is most closely related to cardiovascular endpoints.

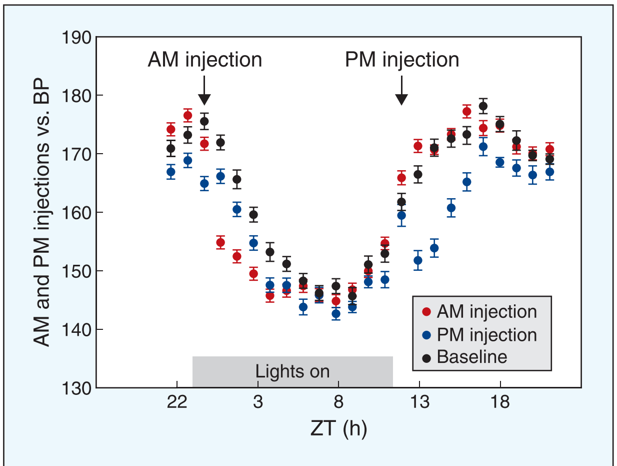

Fig. 10. Difference of effects according to the timing of administration of antihypertensive drugs. [8]. Administration of a BP-decreasing drug after lights were off (simulated evening- PM injection) decreased SBP more than the same amount of administration of the drugs during light-on time, simulated morning-AM injection.) ZT- time of day.

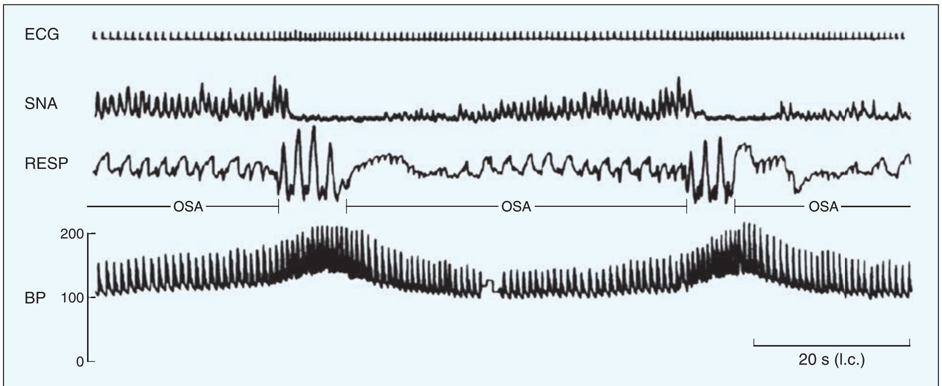

Fig. 11. Big changes in hemodynamics and sympathetic nervous activity in a patient with severe sleep apnea syndrome [9]. ECG- electrocardiogram. SNA- sympathetic nervous activity. OSA- Obstructive sleep apnea.

a decrease in oxygen saturation has been recognized as one of the major risk factors of developing HT. In SAS patients, nighttime BP elevates or swings markedly along with the respiratory effort associated with apnea or hypopnea and results in non-dipper or riser patterns of nocturnal hypertension [10]. Because SAS is treatable by the use of a continuous positive airway pressure device or mouthpiece, these patients should be properly diagnosed and treated.

Continuous BP

In a patient with SAS, sympathetic nervous activity (SNA) surges with marked BP elevation during an obstructive sleep apnea (OSA) period in Fig. 11. If the BP measurement is acquired only at discrete times (e.g., every hour), this kind of important information would be lost. Even now, some devices can record BP continuously, but such a machine is too bulky to use in usual daily life. The current continuous BP meter also needs frequent calibration and if used during the night, it would disturb sound sleep. Thus, the actual use is very limited for a usual clinician.

The More Ideal BP Meter

An ideal BP meter should possess portability and ease of daily use, be non-invasive, and maintain easy data transfer. It should be able to be carried without giving any stress to the patient and contact to skin should be soft and minimal as well as not irritable to the skin. Even if some kind of calibration is necessary, the pressure should be limited to a little bit more than sensing limit. BP change occurs, of course, during bathing time or swimming, and to know the changes in BP in such situation may be very important for the precise understanding of hypertensive status. Therefore, an ideal BP meter should be water proof and resistant to high and low temperature as well as to the shock that might occur to the instrument in daily life.

Other data like ECG, body temperature, sleep status, or electroencephalography may be simultaneously recorded. Combined analysis with these data may enhance the quality of data interpretation and understanding of mechanism or precise status of the disease. Even now, simultaneous recording is possible but it usually takes too much time or effort to combine the data for a busy clinician. This combination, therefore, should be easily done with a single click in an ideal BP meter (Fig. 12).

Final Proposal

I would like to have a BP meter that is worn like a light wristwatch without any sensible pressure. If the patient can look at the summarized BP data easily on a smartphone, for example, the motivation of the patient to control BP will be enhanced and result in better

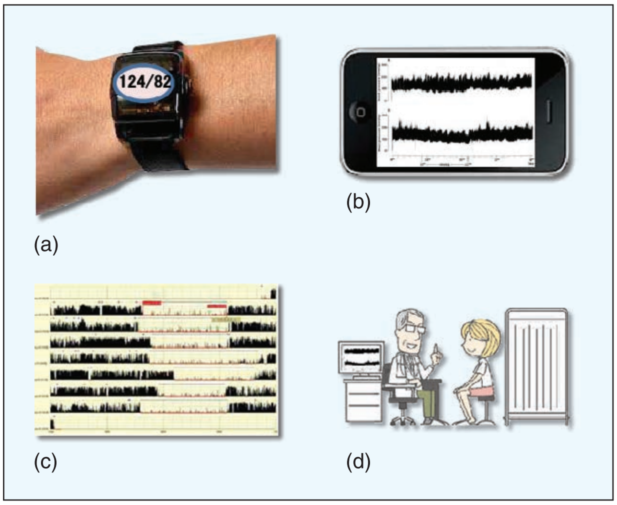

Fig. 12. A Clinician's Dream. (a) A waterproof wrist type BP meter which never makes the patient feel uncomfortable without noise and can estimate central BP. (b) can easily display measured results on a smart phone. (c) can smoothly transfer data and display them on the screen in an outpatient clinic. (d) and enables discussion with a patient looking at the recorded one month BP together (CBP).

BP control over time. If clinicians and patients can simultaneously and instantaneously look at the BP data (with other data) on screen in the clinic by just one click, we can discuss about the better BP control and collaborate to improve their prognosis. If such data can be transferred directly and easily to an electronic medical chart and be combined with other data, it would be very useful for the treatment of the patient and any kind of clinical research.

Editor's note: A clinician with a dream… I invite you all to send me your remarks and suggestions so that together we can make Prof. Shin-Ichi Ando's dream come true. Your reactions will be posted on our website. This way some fruitful collaborations may arise and a dream can come true!

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