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REVIEW ARTICLE

Telemedicine and M-Health in Hypertension Management: Technologies, Applications and Clinical Evidence

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Abstract Electronic processes and communication technologies are more and more often employed to provide healthcare services to caregivers and their patients. Such solutions are currently referred as e-health, the most popular and widely distributed being those based on telemedicine and mobile health (m-health). A specific application of telemedicine for hypertension management is blood pressure telemonitoring (BPT), which allows remote data transmission of BP and additional information on patients' health status from their living site or from a community setting to the doctor's office or the hospital. Several randomized studies have documented a significant BP reduction with regular BPT compared to usual care, particularly in high risk hypertensive patients. Additional benefits are observed when BPT is offered under the supervision of a team of healthcare professionals, including a community pharmacist. BPT may also be provided in the context of m-health solutions, which commonly include wireless diagnostic and clinical decision support tools. M-health has the potential to promote patient's self-management, as a complement to the doctor's intervention, and encourage greater participation in medical decision making. Current statistics show that half of smartphone owners gather health information through their phone and 19 % use a health app. In case of hypertensive patients the most popular apps are those with tracking function, including BPT. Thus, e-health, and in particular BPT and m-health, are progressively gaining a key role in the management of hypertensive patients, having the potential to improve the quality of the delivered care and to more effectively prevent cardiovascular consequences of high BP.

Keywords E-health · Telemedicine · M-health · Hypertension · Blood pressure telemonitoring · Quality of life · Healthcare costs · Apps

1 Introduction

The use of digital or electronic technologies in medicine is defined as e-health, a term specifically referring to the use of electronic processes and communication technologies to provide more efficient healthcare services and improve the quality of care [1]. By definition, e-health encompasses a range of services or systems that are at the edge of healthcare and information technology, and which are summarized in Table 1.

Among all the possible e-health services the most popular and widely distributed among healthcare professionals and general public are those based on telemedicine and mobile health (or m-health). Telemedicine basically allows exchange of medical information (e.g. health parameters, biological signals, diagnostic images, etc.) from one site to another via electronic communications [2]. It aims at providing diagnosis and care at a distance in order to improve a patient's clinical health status and it is often referred to as "telehealth" or "telecare". When mobile communication devices, such as mobile phones, tablet computers and personal digital assistants (PDA) are used to communicate between doctors and patients, the specific term "mobile health" or m-health is used [3]. M-health is widely employed in the practice of medicine and public health and

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Table 1 Main categories of e-health solutions and services

Electronic health records (EHR)
Clinical decision support tools
Web-based technologies and services (e.g. interactive education programs on lifestyle, on-line discussion groups for patients)
Virtual healthcare (teleconsultation and remote diagnosis), robotics, computer assisted surgery
Medical research support technologies (grid technologies)
Administrative and clinical information systems
Telemedicine and telecare services
M-health

the term broadly encompasses the use of mobile telecommunication and multimedia technologies to deliver healthcare.

In this review we will attempt to update and critically assess the current role of telemedicine, and in particular of blood pressure telemonitoring (BPT), and of m-health, in the management of the hypertensive patient.

2 Benefit of E-Health in Hypertension Management

E-health solutions, and more specifically telemedicine, may help to establish and build an enduring and long-term relationship between patients and their doctors, a particularly important feature in case of hypertension, a lifetime condition needing continuous medical supervision [4]. The use of e-health may help empowering hypertensive patients, influencing their attitudes and behaviors, and improving their medical condition. E-health can reinforce and empower the physician-patient relationship, may even try to individualize it, and thus improve BP and cardiovascular risk control. E-health allows physicians and health facilities to expand their reach, beyond their own offices, and to easily provide services to an increased number of patients, with a consistent savings in time demands, and with the same content quality of traditional in-person consultations [5]. E-health services allow hypertensive patients to easily and rapidly communicate to their doctors the occurrence of acute symptoms or sudden BP raises. E-health, and in particular telemedicine, also enhances the monitoring, tracking, and communication of various biometric information, enabling greater engagement and partnership of patients in their care, reducing their stress. Finally, e-health services offer hypertensive patients the access to diagnostic procedures that might not be available otherwise, without the need to travel long distances [4].

3 Blood Pressure Telemonitoring

A specific application of telemedicine in hypertension management is represented by BPT, which allows remote data transmission of BP and additional non-vital parameters, from the patient's living site or from a community setting (e.g. primary care clinic or pharmacy store) to the doctor's office or to a hospital [4, 6]. BP readings, are collected in a professional healthcare environment, or at home over several days or over the 24-h, in ambulatory conditions, through electronic automated BP monitors. Measurements are stored in the device memory and then forwarded to a remote computer host (usually through the web) where they are reviewed by the referring physician for treatment adjustments, as further detailed below.

Several BPT systems are available on the market, which are characterized by the different modalities of data collection, transmission and reporting, and by additional features such as reminding facilities for BP measurement to be performed and/or for medication intake, and automatic data reporting. Among the available data transmission technologies, wireless systems, at present mostly based on bluetooth, wi-fi, zigbee or near field communication (NFC) technologies, seem to be particularly promising because they are user-friendly and not limited by the user's appliances. They allow linking the medical devices to interfaces with built-in mobile telephone-based transmission systems (e.g. smartphones, PDAs or tablets) or to wi-fi access points more and more often available in many users' dwellings. Alternatively, data can be downloaded onto a desktop or laptop computer, though a wired (usually USB or serial cable) or wireless connection. Data are then forwarded to a remote computer (central server) of the telemedicine provider through a telephone line (wired or wireless), by a modem or an acoustic coupling system, or, as done in most of the recent systems based on smartphones or personal computers, through the Internet. Data transmission is usually achieved through a landline broadband or mobile network and security is ensured by encryption transmission protocols (S-FTP or S-HTTP). When data are received at the central telemedicine server they are stored and analyzed. Reports are automatically generated and then reviewed by case managers (usually a healthcare technician or a nurse or a pharmacist), before they are submitted to the reporting physician. At the end of this process a medical report is forwarded to the patient and referring primary physician through a website, via e-mail or through dedicated smartphone apps. During all these processes the case manager may also interact with the patient in order to obtain feedbacks on his/her health status and adjust treatment according to the indications of the managing physician. A diagram describing a typical BPT solution is depicted in Fig. 1.

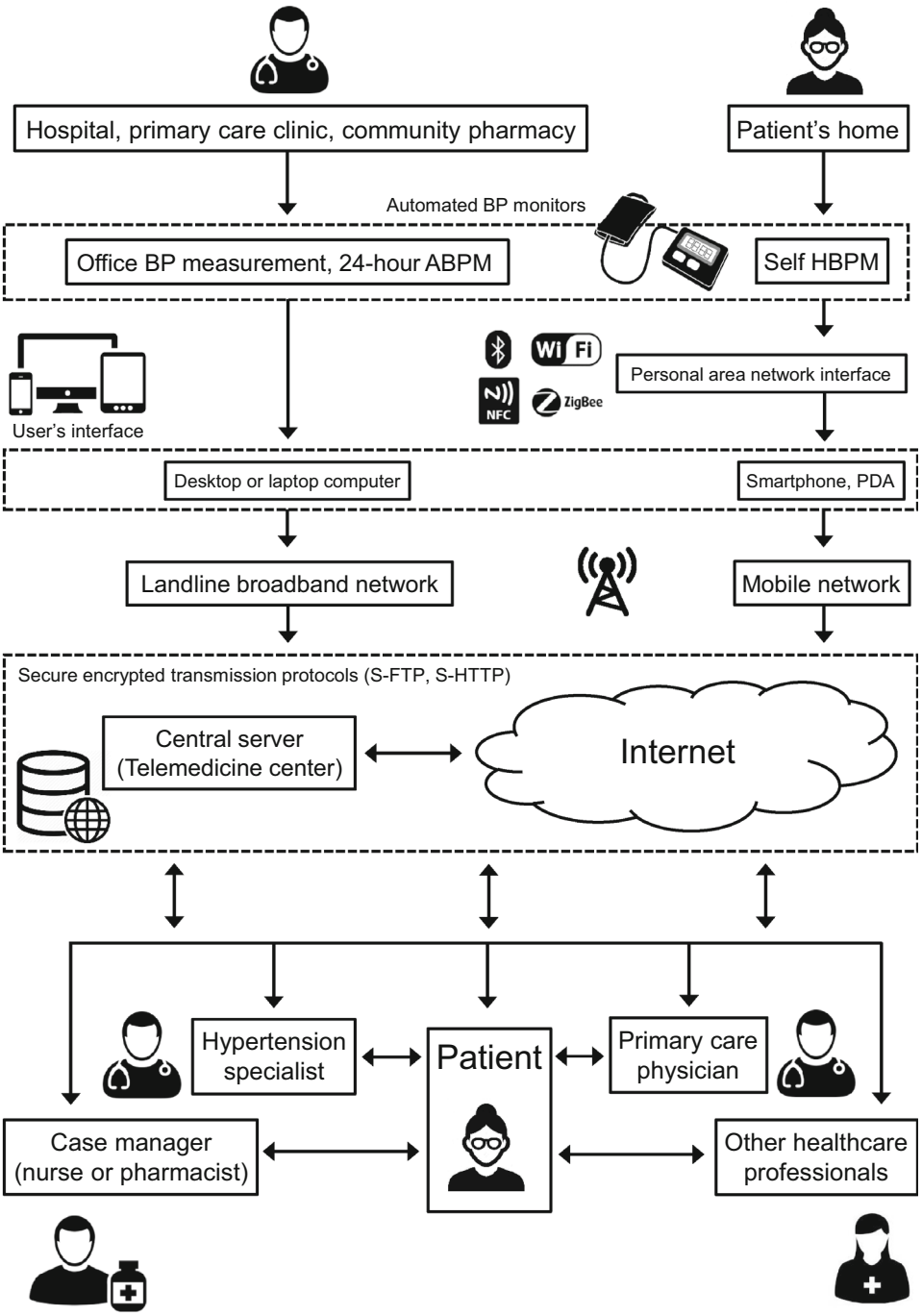

Fig. 1 Diagram of a typical blood pressure telemonitoring service. For explanation see text. *BP* blood pressure, *ABPM* ambulatory blood pressure monitoring, *HBPM* home blood pressure monitoring, *PDA* personal digital assistant, *S-FTP* secure file transfer protocol, *S-HTTP* secure hyper text transfer protocol

4 Clinical Usefulness and Cost-Effectiveness of Blood Pressure Telemonitoring

BPT has the potential for improvement of hypertension control and associated healthcare outcomes, as documented in numerous meta-analyses [5, 7–13]. In one of such publication, we reviewed data collected in 7037 hypertensive patients enrolled in 23 selected high quality randomized controlled studies [13]. Overall, regular BPT at home was associated with a significantly larger reduction in both office and ambulatory BP as compared to usual care (based on periodic BP measurements and visits at the doctor's office, with no remote BP monitoring). As shown in Fig. 2, the mean office systolic (S) and diastolic (D) BP reductions were 4.7 and 2.5 mmHg larger in the BPT group. The reduction in ambulatory BP was smaller than that observed for office BP, but still greater in the intervention group (Fig. 2). Additionally, a significantly

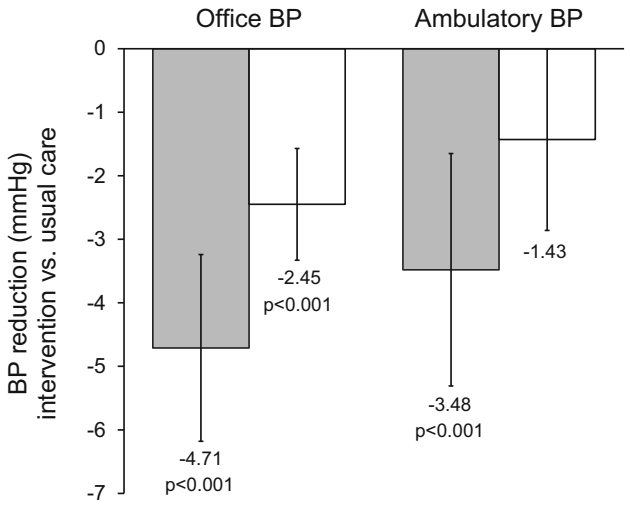

Fig. 2 Weighted mean differences (and 95 % confidence intervals) in office and ambulatory systolic (SBP) and diastolic blood pressure (DBP) changes between patients randomized to intervention (home blood pressure telemonitoring) and patients followed by their healthcare givers in the usual clinical setting (usual care). P values refer to the statistical significance of the difference (redrawn from [13] by permission)

($p < 0.001$) larger proportion of patients achieved office BP normalization (<140/90 mmHg for non-diabetic and <130/80 mmHg for diabetic patients) in the intervention group [relative risk and 95 % confidence interval: 1.16 (1.04, 1.29)]. The meta-analysis also showed interesting additional results, which are summarized in Table 2. The use BPT resulted in significantly larger prescription of antihypertensive medications, but therapeutic adherence and rate of office consultations similar to usual care. Healthcare costs were significantly larger in the BPT group [+662.92 (+540.81, +785.04) euros per patient], but were similar to those sustained by the patients in the usual care group when costs of technology were removed and only medical costs were considered [−12.4 (−930.52, +906.23) euros]. Use of BPT helped to improve the physical component of quality of life, but not the mental one. Our meta-analysis and those published in previous years all confirm that BPT may represent a useful tool to improve hypertension management. However a current limitation of all the randomized studies based on BPT is the extremely high level of heterogeneity among studies, which reduces the strength of the evidence provided. Future well-designed, large-scale, prospective, controlled trials are mandatory in order to understand the long-term benefit of BPT, beyond BP control and its actual cost effectiveness [13, 14]. Such studies should be focused on high risk hypertensive patients, for whom an optimal BP control is particularly difficult to attain, but extremely required to effectively prevent cardiovascular complications.

5 Telehealth Networks in Hypertension and the Role of Community Pharmacies

As mentioned above, future studies based on BPT should try to assess the clinical benefit of this intervention integrated with nurse- or pharmacist-led support and personalized recommendations on life style. As a matter of fact, a key point for a successful hypertension management by BPT is the networking among healthcare providers, namely a new patient-centered model for hypertension management based on web services [15].

Of particular interest is the counseling between a primary doctor or a specialist and a community pharmacist. Web-based telemedicine platforms may be used to provide

Table 2 Clinical outcomes in a large meta-analysis of randomized controlled blood pressure telemonitoring (BPT)-based studies. *SF* short form, *ICER* incremental cost effectiveness ratio, *SBP* systolic blood pressure, *DBP* diastolic blood pressure [13]

Number of comparisons	Number of subjects	Endpoint	Outcome
9	2691	Antihypertensive medication	Significantly ($p < 0.001$) larger use of BP-lowering drugs in the BPT group [+0.40 (+0.17, +0.62)]
3	773	Adherence to treatment	Slightly, but not significantly ($p = 0.481$) better adherence with BPT [91.8 vs. 89.8 % usual care; +1.30 (−2.13, +4.90) %]
10	3257	Office consultations	Number of office visits nearly significantly ($p = 0.055$) smaller in the BPT [−0.18 (−0.37, 0.00)]
5	3130	Fatal or non-fatal adverse events	Risk of adverse events slightly, but not significantly ($p = 0.263$) larger in the BPT group [13.1 vs. 11.8 % usual care; +1.22 (+0.86, +1.71)]
5	1262	Quality of life (SF-12 or -36)	Physical component of quality of life was significantly ($p < 0.001$) improved in the BPT group [+2.78 (+1.15, +4.41)]. This was not the case for the mental component [−0.11 (−1.65, +1.43); $p = 0.890$)]
8	4227	Healthcare costs	ICER after excluding technology costs were small: 32 euros per additional 1 mmHg SBP reduction and 25 euros per additional 1 mmHg DBP reduction

home or 24-h ambulatory BP monitoring through community pharmacies, extending the screening for hypertension and providing a quick, accurate and professional feedback and adjustment of care plans in treated hypertensive patients, with the support and supervision of the general practitioner or the specialist [16]. The effectiveness of such a telemedicine-based approach for hypertension management has been shown in a number of randomized or observational studies, whose results are summarized in Table 3.

In Italy, we have setup the TEMPLAR (TEleMonitoring of blood Pressure in Local phARmacies) an observational, cross-sectional, multicenter study aiming at assessing the potential advantage of BPT in community pharmacies for evaluation of BP control in untreated and treated subjects undergoing 24-h ambulatory BPT in such setting for screening or follow-up purposes, upon general practitioners' prescription. From 2010 to 2015, we collected recordings in 9834 subjects visiting 394 pharmacies, evenly distributed over the territory. Most subjects (85 %) were untreated, and half of them had controlled 24-h BP (average <130/80 mmHg). Also in the small proportion of treated subjects (16 %) adequate 24-h BP control was achieved in half of the sample (54 %). Interestingly, in the whole study population, 15 % of subjects had only nocturnal hypertension, supporting the key role of ambulatory BPT for unmasking potentially dangerous situations which cannot be detected in other settings, as at home, during waking hours, or in resting conditions in the doctor's office [30].

Thus current evidence from randomized or observational studies suggests that the synergy between BPT and pharmacist case management of hypertensive patients may facilitate high BP screening and detection. Furthermore, adding web-based pharmacist care to BPT and web-provided education on life style may be particularly effective for improving BP control in treated hypertensives.

6 M-Health in Hypertension Management

According to current statistics, at the end of 2015, half of the world's population (3.8 billion people) had at least one mobile subscription, being estimated that by 2020, around three-fifths (4.6 billion people) of the global population will have a mobile subscription, with nearly one billion new subscribers (+4.0 % compound annual growth rate) added over the period [31]. In conjunction with the increasing diffusion of mobile phone users, an acceleration is observed in the shift of the technology towards mobile broadband networks: connections based on 3G and 4G technologies accounted for just under 40 % of total connections at the end of 2015, but by 2020 they will increase to almost 70 % of the total [31]. The growth of mobile communication technologies has been paralleled by an increase in the diffusion of m-health applications. A survey carried out in 2012 in the USA has shown that 31 % of all the 2581 cell phone owners used their phone to look for health information. Smartphone users lead this activity, with 52 % of them gathering health information on their phones, compared with 6 % of non-smartphone owners. In this survey, younger highly educated users were more likely to gather health information this way. Caregivers, those who recently faced a medical crisis, and those who experienced a recent, significant change in their physical health were more likely than other cell phone owners to use their phones to look for health information. Interestingly, some 19 % of smartphone users had at least one health app on their phone (exercise, diet and weight app).

M-health comprises a continuum of solutions, used by consumers or healthcare providers, for monitoring health status or improving health outcomes, and includes wireless diagnostic and clinical decision support tools, as summarized in Table 4.

Smartphone apps can empower patients with accurate medical information, provide tools to promote self-management, and encourage greater participation in medical decision making. A recent review of 107 mobile health applications designed for the management of hypertension has found that most of the hypertension apps help individuals monitor various physiologic parameters, such as BP and heart rate, and change their lifestyle through diet and exercise, as well as remind patients to take their medications (Fig. 3) [32]. Of the 107 apps, 72.0 % had tracking functions, 22.4 % were designed to provide tools for enhancing medication adherence and 37.4 % provide general information on hypertension. Of the 77 tracking apps, 74 (69.2 %) were capable of detecting BP and heart rate, 27.1 % were capable of measuring weight and/or body mass, 2.8 % were also capable of tracking salt intake and 4.6 % daily calories. Concerning the use of the app as a BP measuring device, none of the 57 made for the iOS operating system was actually capable of measuring BP, whereas 7 of the 50 (14.0 %) made for the Android market could work as a medical device. These Android apps were downloaded as many as 2.4 million times by consumers, receiving high ratings. Unfortunately, only 2.8 % of the apps were developed by healthcare professional agencies, none provided any documentation of validation against a gold standard in patients with hypertension, and none formally obtained approval for use as a measuring device by the US Food and Drug Administration or EC.

Thus, the smartphone can now be easily transformed into a mobile health device capable of accurately

Table 3 Summary of randomized controlled studies based on integrated blood pressure telemonitoring (BPT) of hypertensive patients in a pharmacy setting. *BP* blood pressure

Author or study [ref.]	Study design	No. of hypertensive subjects	Comorbidities	Duration of follow-up (months)	Type on intervention	Main outcome
Electronic Communications and Home Blood Pressure Monitoring (e-BP) Study [17–22]	Three-group randomized controlled study	778	None	12	Pharmacist care management delivered through web communication together with home BPT and education	After 1 year significant improvement of BP control in patients managed by the pharmacist plus web communication compared to usual control (56 vs. 31 %; $p < 0.001$) and BPT and web training only (36 %; $p < 0.001$) Persistence of the effect due to the pharmacist-led care 1 year after withdrawal of the intervention (60 vs. 52 % usual care and 48 % BPT only; $p = 0.110$ and $p = 0.010$) A 1 % improvement in BP control rate with BPT and web-based pharmacist care cost 15.26 euros relative to BPT and web training alone Barriers to implementation into community practices included a pharmacist unfamiliar to the subject, lack of information technology resources, provider resistance to use a single management protocol The effect of the web-based pharmacist care is mostly explained by home BPT, secure messaging and antihypertensive medication intensification
Home Blood Pressure Telemonitoring and Case Management to Control Hypertension (Hyperlink) Study [23–26]	Randomized controlled study	450	18 % diabetes 17 % chronic kidney disease 9 % cardiovascular disease	6–18	In-person intake visit and phone visits, and antihypertensive therapy adjustment after receiving transmitted home BP data, under a collaborative practice agreement with the clinics' primary care team	Improved BP control with pharmacist's intervention after 6 months (BPT 72 % vs. usual care 45 %; $p < 0.001$) and 12 months (71 vs. 53 %; $p = 0.005$) Persistence of the effect during 6 months of post-intervention follow-up (72 vs. 57 %; $p = 0.003$) High adherence to BPT and phone case management visits in the BPT group Most of the explained BPT effect attributable to the combination of self-monitoring and medication intensification

Table 3 continued

Author or study [ref.]	Study design	No. of hypertensive subjects	Comorbidities	Duration of follow-up (months)	Type on intervention	Main outcome
Improving Blood Pressure in Colorado [27]	Randomized controlled study	283	55 % diabetes or chronic kidney disease	6	Clinical pharmacist management with physician oversight plus patient education and home BPT	Greater systolic and diastolic BP reductions achieved over 6 months in the intervention group (−13/−7 vs. −7/−4 mmHg usual care) Intervention patients had a greater increase in medication regimen intensity
Magid et al. [28]	Randomized controlled study	348	49 % diabetes or chronic kidney disease	6	Home BPT plus clinical pharmacy specialist reviewing BP medication regimen, providing counseling on lifestyle changes and adjusting or changing antihypertension medications as needed	At 6 months the proportion of patients attaining BP control was significantly ($p < 0.001$) higher in the intervention than in the usual care group (54 vs. 35 %) The impact of the intervention was larger in the subgroup of subjects with diabetes mellitus or chronic kidney disease The intervention group had more e-mail and phone contacts, and greater medication regimen intensification The satisfaction rate was larger in the BPT group (58 vs. 42 %; $p < 0.001$)
James et al. [29]	Observational, non-randomized study	1698	Not reported	None	Ambulatory BPT linked to a medical reporting service	Uncontrolled ambulatory hypertension more common in community pharmacies than in primary care
TEleMonitoring of blood Pressure in Local phARmacies Study (TEMPLAR) [30]	Observational, non-randomized study	9834	Not reported	None	Ambulatory BPT linked to a medical reporting service	Elevated rates of uncontrolled ambulatory hypertension in both treated and untreated subjects

Table 4 The continuum of m-health solutions (from [32] by permission)

Measurement
On-person or embedded sensor sampling in real time
Ecological momentary assessment
Global positioning system
Diagnostic
Point-of-care diagnostics
Portable imaging
Biomarker sensing
Clinical decision support
Sensor sampling for diagnostics
Treatment and/or prevention
Prevention and wellness interventions
Remote behavioral treatment
Medication adherence tracking
Chronic disease management
Dissemination of health information
Disaster support and/or care
Global
Access to healthcare services
Remote behavioral treatment
Dissemination of health information
Disease surveillance
Medication tracking and safety
Prevention and wellness interventions

measuring BP. This has the potential of making it possible for billions of people to regularly check their BP status and to turn a mobile appliance into an important tool for improving BP control. Even if smartphones are not used as BP-measuring devices, hypertension patients might appreciate other app features such as tracking and showing trends in BP data transferred from other devices, providing medication lists and reminders (e.g. alarm reminders to take medications, in order to improve adherence to treatment), monitoring physical activity, and sharing data with healthcare providers [33, 34].

7 Issues with Telemedicine and M-Health Solutions

Although e-health solutions may help improving hypertension management, it must be admitted that their implementation in the clinical practice may be difficult due to technological barriers, high costs, heterogeneity of solutions and technologies, and lack of standards. Furthermore, the evidence provided so far by studies on the clinical efficacy and economic benefit of BPT is incomplete. Concerning tools available on smartphones, it is unquestionable that the increasing use of m-health technologies will circumvent the technical challenge of electronic health systems and provide more flexible and cheap platform to enhance patient care. However, development and diffusion of these solutions have to be done taking care of security and privacy flaws which may occur with data sharing between patients and their health managers. Since smartphone apps provide tools to promote self-management, they should also be properly validated by healthcare professionals.

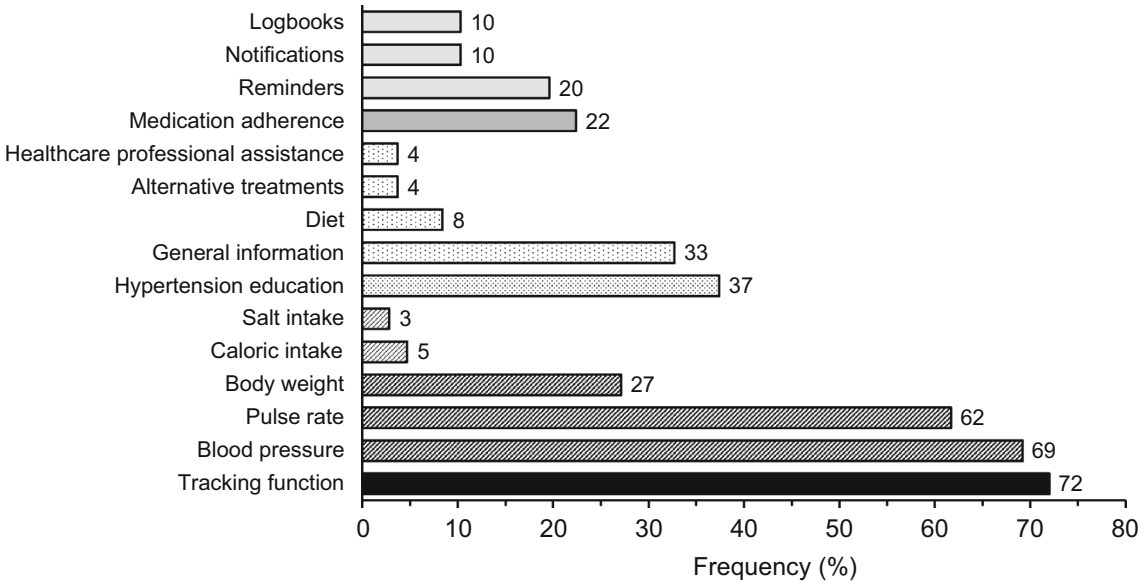

Fig. 3 Main services provided by hypertension smartphone apps according to a recent survey (redrawn from [33] by permission)

8 Conclusions

In conclusion, current evidence suggests that e-health, and in particular telemedicine and BPT, may be useful in hypertensive patients needing a tighter BP control, such as those at high-risk. It may help support the doctor in order to allow a closer and continuous follow-up of the hypertensive patient and in situations requiring monitoring multiple vital signs. The diffusion of m-health solutions among the general public will help patients' caregivers to improve the quality and the effectiveness of the delivered care. E-health solutions will favor creation of networks between healthcare professionals for improving the screening and management of hypertension and related comorbidities and put into practice an effective prevention of cardiovascular diseases.

9 Perspectives

The diffusion of information communication technology and the shortage in the provision of healthcare will favor the progressive use of e-health solutions in forthcoming years, with the advantage of more efficiently managing hypertensive patients. These solutions will merge traditional in-office consultation and remote patient monitoring, according to a revolutionary healthcare model including different case-managers and personalized healthcare delivery. This will hopefully help to improve the quality of care and to more effectively prevent cardiovascular consequences of arterial hypertension.

Compliances with Ethical Standards

Disclosure SO received consultancy fees from Biotechmed Ltd., provider of telemedicine services, and from Microlife, manufacturer of blood pressure measuring devices. None of the other authors has any conflict of interest to declare.

Conflict of interest None.

Research involving human participants and/or animals This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study formal consent is not required.

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