Stroke

TOPICAL REVIEW

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Digital Health in Primordial and Primary Stroke Prevention: A Systematic Review

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ABSTRACT: The stroke burden continues to grow across the globe, disproportionally affecting developing countries. This burden cannot be effectively halted and reversed without effective and widely implemented primordial and primary stroke prevention measures, including those on the individual level. The unprecedented growth of smartphone and other digital technologies with digital solutions are now being used in almost every area of health, offering a unique opportunity to improve primordial and primary stroke prevention on the individual level. However, there are several issues that need to be considered to advance development and use this important digital strategy for primordial and primary stroke prevention. Using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines we provide a systematic review of the current knowledge, challenges, and opportunities of digital health in primordial and primary stroke prevention.

Key Words: cardiovascular disease ■ digital technology ■ risk factors ■ smartphone ■ systematic review

The fast-growing stroke burden across the globe shows a clear trend towards increasing incidence rates in younger people and substantial regional race and ethnic disparities in stroke risk,[1–4] suggesting that current health care is failing to reduce modifiable risk factors in people at risk of stroke.[5–7] Therefore, the importance of effective, far-reaching, and equitable primary stroke prevention strategies targeted to individuals is greater than ever.[8] Despite strong evidence for the benefits of primary stroke prevention targeted at individuals, access to and participation in such primary prevention strategies is low,[9] particularly in low- to middle-income countries.[10–12]

Digital technology, including smartphones and gadgets, which has become an integral part of our everyday life, could augment access to primary stroke and cardiovascular disease (CVD) prevention services (eg, access to primary care, cost of visiting health professional)[13,14] and can support attainment of the health and well being–related Sustainable Development Goals, especially Sustainable Development Goals 3.[15–17]

A recent comprehensive review by the American Heart Association of the evidence of use of mobile health technologies for improving prevention of CVD clearly showed the great potential of such technologies to aid lifestyle modification.[18] Supported and guided by the World Health Organization, health-related digital technologies[16,19] represent a new paradigm for global health,[20] including primary stroke prevention.[21] However, several issues need to be considered to further advance this important strategy of primary stroke prevention. This systematic review aims to provide an overview of the current knowledge, challenges, and opportunities of digital health in primordial and primary stroke prevention using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement as a guide.[22]

DEFINITIONS

Digital technology for primordial and primary stroke prevention was defined as the mobile (smartphone), computer, or Web-based technologies to support the

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Nonstandard Abbreviations and Acronyms

CVD	cardiovascular disease
LDL	low-density lipoprotein

achievement of stroke prevention. This definition encompasses a wide range of tools ranging from applications (apps) and text messaging to mobile Health (mHealth) telemedicine, and artificial intelligence used for stroke prevention. Similar to the definition of primordial prevention of CVD,[23] primordial stroke prevention refers to activities to avoid the development of risk factors for stroke, whereas primary stroke prevention refers to activities to treat or reduce exposure to risk factors for stroke.

SEARCH STRATEGY

We searched Scopus, MEDLINE, and PubMed for reports published in English up to September 31, 2021, using the title, abstract or key words search terms "stroke," transient isch(a)emic attack," "cerebrovascular disease," "cardiovascular disease," or "CVD" AND "prevention" or "preventative" AND "digital technology," "digital tool," "digital health," "telemedicine," "mobile health or mHealth," "eHealth," "mobile," "artificial intelligence," "app," "smartphone," or "software." We also searched Google and references of the retrieved articles for other relevant publications. In addition, we searched Apple Store, Google Play, and Android Stores for primary stroke prevention applications on September 31, 2021, using keywords: stroke, brain attack, cerebrovascular accident. The search was limited to the past 10 years. The content of the applications was analyzed independently by the authors of this review. We excluded from the analysis digital tools and digital-based interventions in people with established stroke, transient ischemic attack, or CVD (ischemic heart disease, myocardial infarction, or peripheral artery disease) as well as digital tools not based on scientific evidence, focused on individual risk factors, duplicates or aimed at improving general fitness/wellbeing.

LIMITATIONS OF CURRENT PRIMARY STROKE PREVENTION STRATEGIES TARGETED AT INDIVIDUALS

Recent research showed several important gaps in individual primary stroke prevention that may hamper effective reduction of stroke burden in the world, such as lack of stroke awareness,[24,25] false reassurance of low stroke/CVD risk,[6,26–28] absolute risk treatment thresholds for blood pressure–lowering and lipid-lowering therapies,[29–32] missing important stroke risk factors from high CVD risk screening,[6,33] low generalizability of predicting algorithms,[6,34,35] and lack of effectiveness of high-risk CVD screening[36–38] (Supplemental Material).

For individual primary stroke prevention to be effective, the current emphasis on high-risk prevention should be shifted to prevention at any level of CVD risk,[39,40] with the focus on awareness of behavioral risk factors and early life preventative interventions.[41] Screenings for stroke/CVD risk must be accompanied by effective preventative interventions (eg, behavioral counseling, pharmacological treatment as appropriate, and linkage to community programs) to reduce stroke/CVD risk.[42] Preventative interventions on the individual level will only be effective if they sufficiently motivate people to reduce their exposure to risk factors and maintain their risk through life at the lowest possible level.[41] Incorporating widely accessible, motivational, educational, affordable, person-specific, and validated digital health technologies for primary prevention into health systems for use by health professionals and laypeople offers a promising way to enhance primary stroke/CVD prevention strategies.[41]

DIGITAL TECHNOLOGIES AND TOOLS FOR PRIMORDIAL STROKE PREVENTION

There is accumulating evidence that primordial prevention in infancy and across the childhood via healthy diet and behavior is feasible and effective for the reduction of prevalence of the metabolic syndrome and improved risk factors later in life.[23,43–48] Given the time required for testing such interventions and the relative recency of introduction of health-related digital technologies, it is not surprising there is limited evidence supporting the use of digital technologies for primordial stroke/CVD prevention.[23,49] However, such technologies (eg, smartwatches, mobile applications, wearable digital devices for monitoring physical activity, heart rate, dietary habits, sleep patterns, stress level) aimed at healthy behavior and lifestyle (eg, healthy eating, sufficient physical activity, weight control, sleep hygiene, tobacco avoidance, etc) from the time of fetal development and maternal environment, infancy, and childhood across the lifespan could potentially be useful for primordial stroke prevention. Activity trackers like Fitbit have huge user bases (recent filings indicate there are ≈19 million registered users with over 9 million active users[50]), and research indicates that usage of wearable devices such as these does show an increase in physical activity.[51,52] Similarly, diet trackers and calorie counters such as MyFitnessPal also show efficacy when used on a regular basis.[53]

DIGITAL TECHNOLOGIES AND TOOLS FOR PRIMARY STROKE PREVENTION

There is an increasing body of evidence suggesting sufficient acceptability, feasibility, and efficacy of various digital technologies for management of stroke risk factors and primary stroke and CVD prevention. Although there is suggestive evidence of benefits of digital health interventions for blood pressure control,[54] smoking cessation,[55] behavioral patterns,[56] physical activity,[57] and weight loss,[58] conclusive evidence concerning the benefit of such interventions on stroke occurrence is lacking. A meta-analysis of digital health interventions for primary prevention of CVD (39 trials and cohort studies) compared to usual care[59] showed their efficacy for weight reduction (mean difference, −3.35 lbs [95% CI, −5.22 to −1.48]), body mass index (−0.29 kg/m² [95% CI, −0.5 to −0.09]), systolic blood pressure (−2.12 mm Hg [95% CI, −4.15 to −0.09]), total cholesterol (−5.39 mg/dL [95% CI, −9.80 to −0.99]), LDL (low-density lipoprotein) cholesterol (−4.96 mg/dL [95% CI, −8.54 to −1.38]), and glucose (−1.38 mg/dL [95% CI, −2.13 to −0.63]) but not CVD incidence, with the positive effect on risk factors increased when 3 modalities (Web-based, telemedicine, and Short Message Service text) of interventions were used. Another primary and secondary stroke prevention randomized controlled trial (RCT)[60] showed even greater positive effects of a computerized phone-based lifestyle coaching intervention on systolic blood pressure (−9 mm Hg [95% CI, −17.29 to −0.71]) and triglyceride values (−12.5 mg/dL [95% CI, −26 to −0.5]) and increase in fruit/vegetable intake (5.4 servings/wk [95% CI, 0.5–10.5]) and decrease in sweets (−2 servings/wk [95% CI, −4 to 0.00001]). A comprehensive analysis by the American Heart Association concerning current science on consumer use of digital tools for primary CVD/stroke prevention also suggests efficacy of such tools for management of various lifestyle risk factors,[18] especially if such interventions are supported by other methods (eg, coach telephone calls, private peer groups, or other lifestyle programs). There is also evidence that coach-supported self-management of CVD risk factors using an interactive internet intervention is feasible in an older population, and leads to a modest improvement in CVD risk profile,[61] creating the potential for scalability at low cost across a variety of health care settings.[62] Findings of a recent large community-based cluster-randomized trial in 30 communities[63] suggest that an mHealth-enabled, nonphysician health worker-led intervention led to substantially improved blood pressure control and reduced CVD risk in individuals with hypertension. mHealth interventions for stroke prevention were shown to be feasible and efficient even in resource-limited settings, such as Sub-Saharan Africa.[64]

CURRENTLY AVAILABLE DIGITAL TECHNOLOGIES FOR PRIMARY STROKE PREVENTION

Our search for scientifically grounded mobile and Web app digital technologies specifically aimed at primary stroke prevention (including CVD where stroke was included as one of the outcomes) yielded 2369 tools (PRISMA search flow diagram is shown in Figure 1) of which only 20 met our inclusion criteria (for quality characteristics of digital tools for primary stroke and CVD [including stroke] prevention see Table 1). Although all apps were properly validated, the majority of the apps (18/20 provided mainly stroke/CVD prediction estimates, and only 2 apps (HeartScore and Stroke Riskometer) and one Web app (PreventS-MD) met most of the requirements for an ideal mHealth primary stroke prevention tool. Of those 3, only the Stroke Riskometer[80,86–89] was tested in an RCT that demonstrated the feasibility, acceptability, and preliminary efficacy of the app,[90] and only 2 apps (Stroke Riskometer and PreventS-MD) are specifically designed for both primary and secondary stroke prevention and applied "motivational primary prevention strategy"[91] regardless of the level of stroke/CVD risk,[6,39] thus bridging the gap between high absolute CVD risk and population-wide primary prevention strategies.[50,56]

RECOMMENDATIONS FOR EFFECTIVE APPRAISAL, USE, AND EVALUATION OF DIGITAL TOOLS FOR PRIMORDIAL AND PRIMARY STROKE PREVENTION

In 2019, the World Health Organization released the first evidence-based guidelines for digital health that included the statement "To achieve the goal of reducing stroke burden, digital technologies for primary stroke prevention have to be proven clinically effective, scalable to reach a global population, and are affordable."[92] The clear advantages of digital tools for primary stroke prevention are their wide availability, affordability, and increasing usage by individuals across the globe. In 2021, 65.6% of the world population were internet users[93] and 6.4 billion were smartphone users.[94] In 2020, there were ≈318 000 health-related apps (plus 200 being added to the market daily), with an annual download of >204 billion in 2019.[95] There has also been an explosion of various medical data-driven artificial intelligence prediction techniques (deep/machine learning, artificial neural networks)[96,97] that have the potential to be used in primary stroke prevention.[98–100] Mobile technologies, particularly those that allow measurement of risk factors, outcomes,[80] and various physiological parameters[101] are being increasingly used in stroke epidemiology and CVD health and fitness. There is also a trend towards increasing use of mobile applications by health professionals for stroke prevention[102,103] and for encouraging individuals and patients to participate in their own personalized health care; for example, as E-patients (eg, Electronically Equipped, Enabled, Engaged, Empowered and Equal partners with their health care professional[s]).[104]

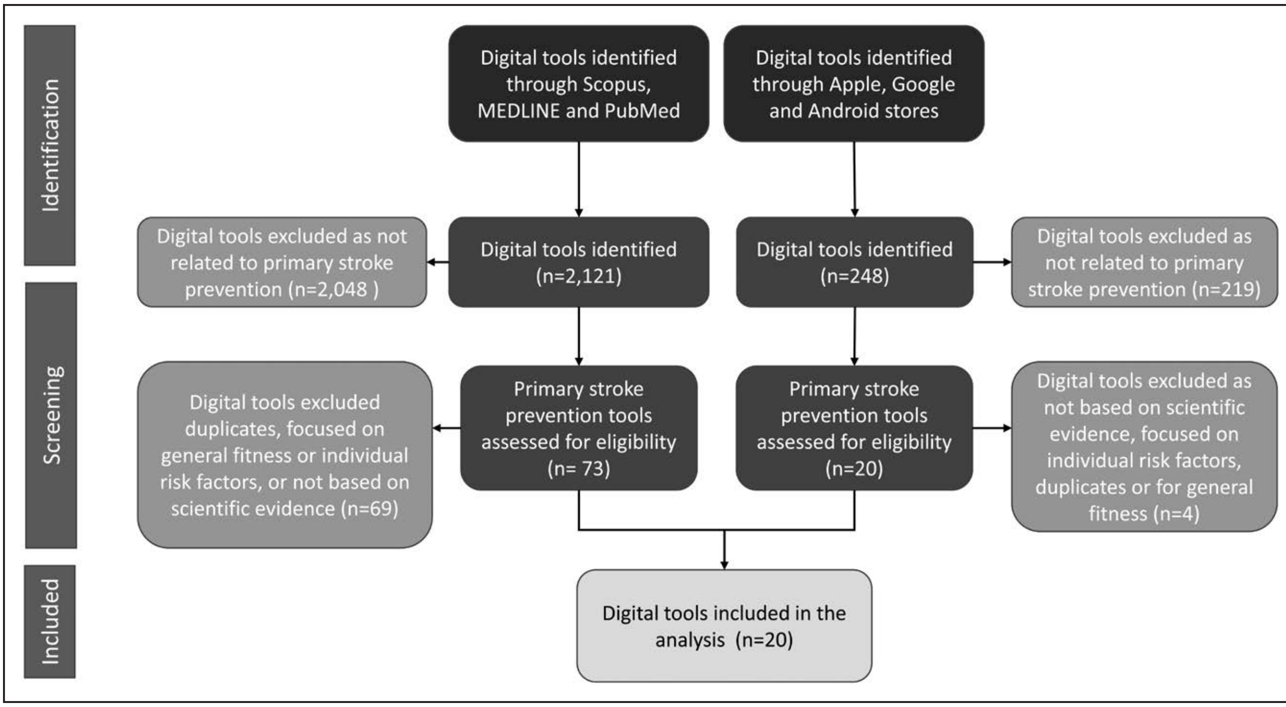

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) search flow diagram for digital tools for primary stroke prevention.

However, there are some limitations of currently available digital tools for health and wellness. First, there is a lack of motivation and long-term engagement of the users, a sustainability issue.[105–107] Apart from the need to use persuasive technologies and various motivational strategies,[108–112] previous research also identified several factors that influence a user's decision to continue use of such digital tools.[113] Second, there is a lack of scientifically accurate and valid digital tools specifically aimed at primary stroke prevention and virtually no evidence for the ability of digital tools to improve long-term health behaviors.[92,114] In one of the recent surveys of mobile health-related apps, it was shown that many apps have no scientific evidence to support their use or are inaccurate in estimating the risk.[95] Third, the quality of digital technologies for primary stroke/CVD prevention varies significantly, with most of th of low quality[115] or simply providing information about risks, with no interactive functionality or information on how to reduce the risk.[116] Fourth, although modern digital health technologies have the potential to reduce inequalities in primary stroke and CVD prevention, there are challenges for their use by elderly people and people in low socioeconomic groups. As health care information, social service resources, and remote outpatient visits by video increasingly move online to provide improved education and to overcome time and distance barriers, digital access and skills are emerging as additional social determinants of health. Ensuring equity of access to digital infrastructure (device ownership and broadband availability and affordability) and tools that are usable (appropriate language and literacy) will be crucial to realize the hope that digitization of health care will reduce, rather than increase, health inequity challenges.[117] Finally, there are the challenges of the ethical and legal issues for privacy protection; in addition, regulation of digital technologies for primary CVD prevention by health care authorities (eg, Food and Drug Administration in the United States[118] or Medical Device Coordination Group in the European Union[119]) is limited and needs to be improved.[13,114,120] Although there is still no clear criteria for digital health-related tools for health professionals requiring and not requiring regulation,[120] a simplified pathway for their approval by health care authorities could be exercised for generally low-risk digital tools aimed at primary stroke/CVD prevention (not diagnosis or treatment) to support health care providers in optimizing individual stroke risk assessment and management.

Based on the literature review and previously recommended requirements for mHealth tools[13,95,113,120,121] in Table 2, we suggest criteria for basic, advanced, and ideal digital technologies for primary stroke and CVD prevention as well as an ecosystem for such technologies (Figure 2). The suggested infrastructure (ecosystem) will support the transformation of the organization-centered health care model into a patient-centered model to allow interoperability and improve communications among various stakeholders.

STRENGTHS AND LIMITATIONS

This is the first systematic review of currently available digital technologies for primordial and primary stroke prevention. As far as we are aware, this is also the first

Table 1. Quality Characteristics of Mobile and Webapp Tools for Primary Stroke and CVD (Including Stroke) Prevention*

Marketing name and Weblink to the app or relevant publication (in alphabetic order)	Countries/ populations for which scientific evidence of risk prediction exists	Target population and purpose	Risk factors included	Scalability	Interactivity and engagement	Limitations
ASCVD/Omnibus Risk Estimator, ASCVD Risk Estimator Plus[65]	Mixed USA populations	General population and health professionals. Estimates 10-y CVD* risk in men and women of 40–79 y old, White, Black, and other races. Reassesses risk at follow-up visits. Forecasts the potential impact of aspirin, blood pressure, and statin lowering treatments	Gender, age, race, TC, HDL-C, LDL-C, SBP, DBP, on BP, statin or aspirin medication, diabetes, smoking	Requires blood lipid testing, thus limiting its use in resource-poor settings. No translations	Provides lifetime risk estimates for people 40 to 59 y of age	Does not provide user's risk profile-based actionable preventative recommendations.
CardioCal[66]	Andean, Caribbean, Central, North, South, and Tropical Americas regions	General population and health professionals. Estimates 10-y risk of myocardial infarction, stroke, or cardiovascular* death in men and women aged 40 to 75 y old	Gender, smoking, TC, age, diabetes, SBP	Limited to six regions of the Americas in 3 languages: English, Spanish and Portuguese	Shows estimates of the risk when smoking habit, SBP, and weight are different	Does not include many important lifestyle risk factors for stroke. No graphical visualization of risks.
CVD Check,[67] PREDICT[27]	Primarily white Americans, mixed NZ population	For health professionals. Estimates 5 and 10-y CVD* risk for men and women of 35–74 y old	Gender, age, SBP, TC, HDL-C, diabetes, ECG LVH (family history of CVD, TC/HDL-C ratio, NZ deprivation index, AF by ECG, on BP, lipid-lowering or antithrombotic medications – in PREDICT only)	Requires ECG, thus limiting its use in resource-poor settings	Has graphical presentation of the CVD risk, allows comparison with results of previous assessment, has printing out option	Does not provide user's risk profile-based actionable preventative recommendations. No RCT evidence of either feasibility, acceptability, or efficacy/effectiveness
U-Prevent,[68] ESC CVD Risk Calculation App,[69] SCORE and SCORE2[70]	European population	For health professionals. Estimates 10-y and lifetime CVD* risk for men and women of 40–69 y old without previous and with previous CVD*	Gender, age, smoking, SBP, TC, LDL-C, antithrombotic and lipid-lowering medications	Provides CVD risk estimates for European countries and North America	Provides lifetime CVD risk estimates, can be used also for secondary CVD prevention. Shows estimates of the risk when SBP and LDL-C are treated to different targets	Does not provide user's risk profile-based actionable preventative recommendations.
Globorisk[71,72]	GBD populations (aggregated data)	General population. Estimates 10-y risk of heart attack or stroke	Country, height, weight, gender, age, smoking, SBP	Global (country-specific estimates for 182 countries)	Shows predicted risk in graph	Estimates risk by 5-y age groups (not individual precise age), does not include many important medical (eg, AF, history of diabetes, treatment of hypertension) and lifestyle (eg, diet, physical activity, stress) stroke. Does not provide user's risk profile-based actionable preventative recommendations.
FINRISK[73]	Finland	For health professionals. Estimates 10-y risk of myocardial infarction and stroke (separately and combined) for men and women aged 30–74 y old	Gender, age, smoking, TC, HDL-C, SBP, diabetes, family history of CVD	For Finnish population. Requires blood lipid test, thus limiting its use in resource-poor settings	Shows the risk compared to a person of the same age and sex, but without risk factors	Does not include many important stroke risk factors, particularly lifestyle risk factors. Does not provide user's risk profile-based actionable preventative recommendations.
Framingham Calc,[74] Framingham Stroke Risk Score,[75] Framingham CardioRisk 2020[76]	Primarily white Americans	General population and health professionals. Estimates 10-y CVD* risk in men and women of 30–75+ y old (5-y age bands)	Gender, age, SBP, TC, LDL-C, HDL-C, on BP-lowering medication, diabetes, AF, smoking	Primarily for white people	Shows vascular age. No graphical visualization of the data	Does not include many important stroke risk factors, particularly lifestyle risk factors. Risk factors are presented in categorical values/ranges. Does not provide user's stroke risk and risk profile-based actionable preventative recommendations.

(*Continued*)

Table 1. Continued

Marketing name and Weblink to the app or relevant publication (in alphabetic order)	Countries/ populations for which scientific evidence of risk prediction exists	Target population and purpose	Risk factors included	Scalability	Interactivity and engagement	Limitations
HeartScore[77]	European population	For health professionals. Estimates 10-y risk of myocardial infarction and stroke (separately and combined) for men and women aged 20–100 y old	Age, gender, SBP, TC, HDL-C, smoking	Available in 17 languages. Requires blood lipid test, thus limiting its use in resource-poor settings	Gives management advice (shows target SBP, cholesterol, HDL-C, general health advice), allows to see patient's progression in graphs	Does not include many important stroke risk factors, particularly lifestyle risk factors.
QStroke/QRisk 3-2018 risk calculator[78]	UK population	For health professionals. Estimates 10-y CVD* risk in men and women of 25–84 y old	Age, gender, ethnicity, smoking, diabetes, family history of CVD, chronic kidney disease, AF, on BP-lowering medication, migraine, rheumatoid arthritis, systemic lupus erythematosus, severe mental illness, atypical antipsychotic medication, on steroids, erectile dysfunction, TC/HDL-C ratio, SBP, SBP variability, height and weight	Specifically developed for UK	Graphical visualization of the risk. By choosing different values for risk factors the user can see effect of the change on the CVD	Does not include many important stroke risk factors, particularly lifestyle risk factors. Does not provide user's risk profile-based actionable preventative recommendations.
Stroke Riskometer,[79,80] PreventS-MD[81]	Primarily white Americans, GBD INTERSTROKE populations (aggregated data)	General population (Stroke Riskometer) and health professionals (PreventS). Estimates 5 and 10-y absolute and relative stroke risks in men and women aged 20+ y old	Age, gender, ethnicity, SBP, smoking, dietary habits, physical activity, presence of heart disease, family history of CVD, medication use for blood pressure lowering, diabetes, height, weight, psychosocial stress, history of traumatic brain injury, memory problems and dementia	Global (18 translations for 5.3 billion people in native languages)	Provides both absolute and relative risks of stroke. Goal setting option. Reminders and alerts. Various motivational techniques. Graphical visualization of risks, progress, and targets in risks control. User's risk profile-based actionable preventative recommendations for self-management of not only medical but also lifestyle and behavioral risk factors	Effectiveness of the tools in reducing stroke incidence is being tested in full-scale trials. Two large full-scale trials in Australia, New Zealand [https://www.cochranelibrary.com ACTRN12621000211864] and Brazil[82] are currently underway
WHO/ISH Risk Prediction Calc[83]	GBD populations (aggregated data)	General population and health professionals. Estimates 10-y CVD* risk in men and women of 40–79 y old (10-y age bands)	Country, gender, age, SBP, TC, smoking, diabetes	Global (by country), estimates with and without cholesterol data	By choosing different values for risk factors the user can see effect of the change on the CVD	Does not include many important stroke risk factors, particularly lifestyle risk factors. Risk factors are presented in categorical values/ ranges. Does not provide user's stroke risk and risk profile-based actionable preventative recommendations.
MyRisk_Stroke Calculator[84]	Canadian (Santé Québec) population	General population. Estimates 10-y stroke risk in men and women aged 20–75 y	Age, sex, education, renal disease, diabetes, congestive heart failure, peripheral arterial disease, blood pressure, ischemic heart disease, smoking, alcoholic intake, physical activity, and indicators of anger, depression, and anxiety	Does not provide accurate 10-y risk estimates for people aged 75+. Needs validation in other populations	By choosing different values for risk factors the user can see effect of the change on the stroke risk	No graphical representation of the stroke risk. Does not provide user's stroke risk and risk profile-based actionable preventative recommendations.

Only digital tools with scientifically accurate and properly validated prediction algorithms are included in the table. All selected digital tools provided clear interface, were easy to use, have privacy protection, and no advertisements. None of the digital tools except one (Stroke Riskometer app)[85] have randomized controlled trial (RCT) evidence of either feasibility, acceptability, or efficacy/effectiveness. AF, atrial fibrillation; app, application; ASCVD, atherosclerotic CVD; BP, blood pressure; CVD, cardiovascular disease; DBP, diastolic BP; ECG, electrocardiography; ESC, European Stroke Society of Cardiology; FINRISK, Finland Cardiovascular Risk Study; GBD, Global Burden of Disease; HDL-C, high-density lipoprotein cholesterol; INTERSTROKE, International Study of Risk Factors for First Acute Stroke; ISH, International Society of Hypertension; LDL-C, low-density lipoprotein cholesterol; LVH, left ventricular hypertrophy (by ECG); NZ, New Zealand; SBP, systolic BP; SCORE, Systematic COronary Risk Evaluation; TC, total cholesterol; and WHO, World Health Organization.

*CVD or cardiovascular, including stroke.

Table 2. Suggested Criteria for Primary Stroke/CVD Prevention Digital Tools

Domains	Core criteria for basic digital tools	Supplementary criteria for advanced digital tools	Supplementary criteria for ideal digital tools
Scientific evidence	Scientific accuracy of the prediction algorithm or risk factors and credibility of data source	Confirmed validity of the prediction algorithm by a study published in peer-reviewed journal	Cross-country or cross-cultural (ethnic/race) validation of the tool
	Scientific appropriateness of the risk factors criteria used	Efficacy, acceptability, and feasibility of the tool is confirmed in a pilot trial	Effectiveness of the tool in reducing stroke incidence confirmed in a full-scale trial
	Preventative recommendations are evidence-based	Theory-based cognitive-behavioral techniques employed	Proven cost-effectiveness
Target population and purpose of the tool	Selected and specified age or gender rage	Age range 20+ y	Specific for various ethnic/race populations or countries
	For use by general population (self-assessment) or health professionals (clinical assessment)	For use by both general population and health professionals	
	Just general information about stroke/CVD risk factors or predicting CVD risk or risk of stroke, or both	User's risk profile-based actionable preventative recommendations for self-management of not only medical but also lifestyle and behavioral risk factors	Culturally appropriate and individual-specific actionable preventative recommendations reinforced by health professional
			Predicting other major NCDs occurrence
			Ability to be used as a research tool
Scalability	Sub-national or national level	Regional level with appropriate translations	Global level with multiple-language translations
	Runnable on computer, laptop, smartphone/gadgets, internet	Runnable on virtual machine	Able to be integrated with other digital tools (interoperability)
	Searchable on the internet	Accessible and affordable for the users	Free or government-subsidized access to the tool
	No need for extra device	Laboratory tests are not mandatory for risk prediction	Addressing primary prevention of multiple major NCDs
Interface, usability, and privacy protection	Clean and simple interface, easy to use tool	Easy to understand navigation menu and smooth flow between screens	Availability of prompts or instructions
	No overwhelming advertisements	No advertisements	Automatic/semi-automatic or prepopulated data entry
	Sufficient data security and privacy protection	Summarize user's data and provide easy to understand report	Easy to understand progress analysis
Interactivity and engagement		Notifications (alerts and reminders triggered by the tool)	User-manageable frequency and type of notifications
		At least one motivational technique is used	Two or more motivational techniques are used
		Goals setting options with progress notifications	Interactivity between user and health professional
		Easy to understand graphical visualization of risks and progress in risk control	Graphical visualization of risks, progress, and targets in risks control

CVD includes stroke. CVD indicates cardiovascular disease; and NCDs, noncommunicable diseases.

review to suggest criteria for basic, advanced, and ideal digital tools for primary stroke and CVD prevention that can be used by health professionals and health care policymakers for qualitative assessment of newly appearing digital tools in this area. We think that with some modifications, these criteria could apply to the assessment of digital tools in other areas of health. However, as with any piece of research, our review was not free from limitations. Although our search strategy to identify and review digital technologies for primordial and primary stroke prevention was conducted using guidelines for a systematic review, our search strategy was limited to English language literature, therefore, we may have missed important digital technologies and advances for primary stroke prevention presented in non-English languages. Also, we did analyze clinical trials using digital technologies for primary stroke prevention but did not provide a quantitative analysis of the identified digital tools for primary stroke prevention. As only one multifactorial digital tool (Stroke Riskometer app) was tested in an RCT, a meta-analysis was not indicated.

CONCLUSIONS

The growing adoption and acceptance of digital technologies for primary stroke/CVD prevention by laypeople, physicians, health care policymakers and regulators combined with their relative safety, affordability (no or low cost) and worldwide growing use makes them one of the most promising strategies to reduce stroke burden in the world. Effective primordial and primary stroke prevention strategies by means of various digital tools should be implemented together with population-wide and other primary stroke/CVD/noncommunicable

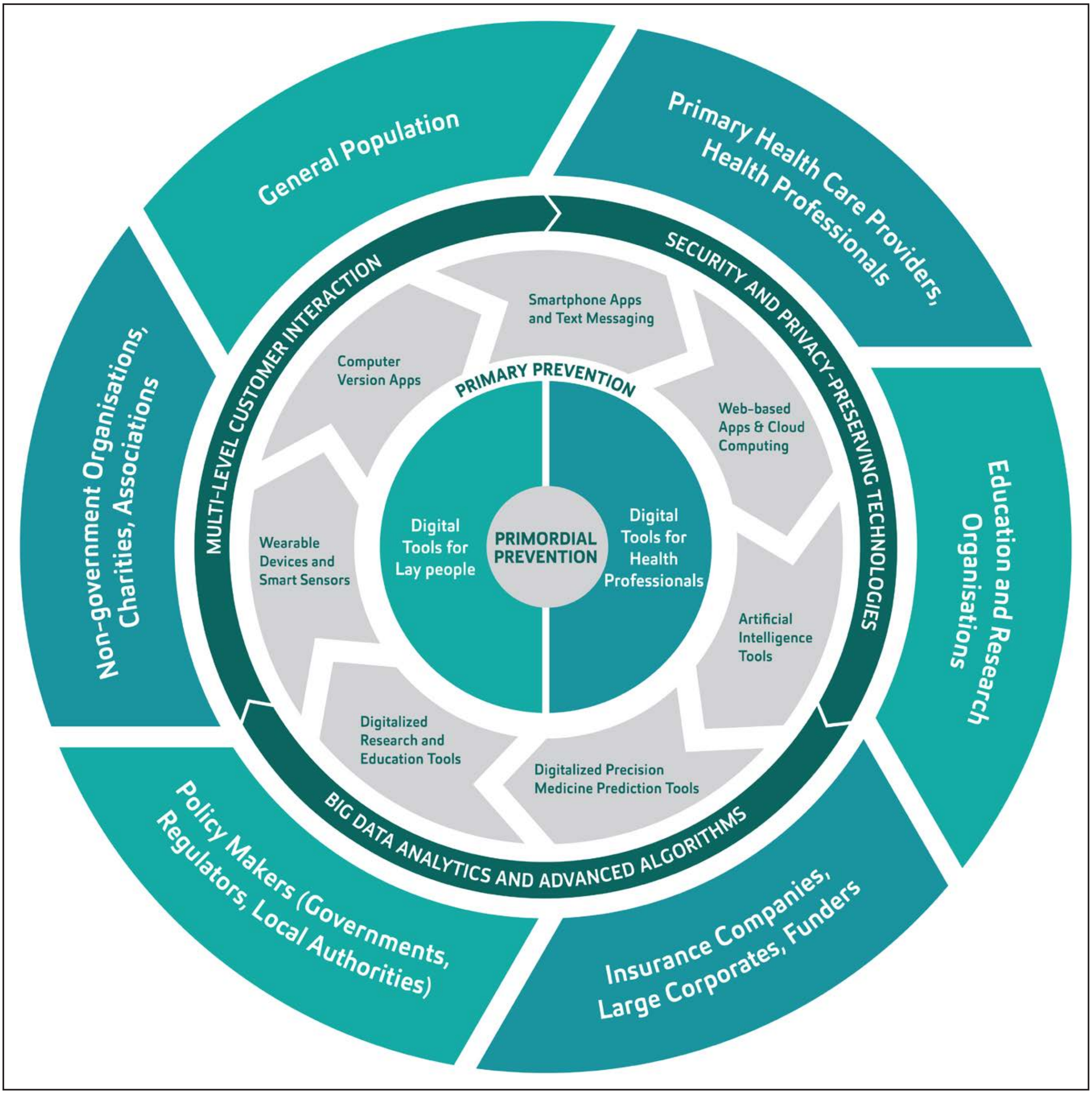

Figure 2. Digital technology ecosystem for primordial and primary stroke prevention.

diseases prevention strategies in a combined and integrated manner. The wide use of evidence-based digital technologies could improve physician-patient relationships and communication, interpersonal communication with colleagues, improve daily productivity and efficiency, and upscale the intake of preventative guidelines.[104,122] Physicians should play a central role in digitalizing health care provision, including participation in clinical trials on digital tools and evaluation of evidence of their feasibility, acceptability, or efficacy/effectiveness. Results of the recent large survey of physicians in Germany showed that education on digitalization as a means to support health care provision should be included in the medical curriculum and advanced training of physicians.[122]

Our suggested criteria for the quality of digital technologies in stroke prevention should help physicians to critically assess these technologies and deliver an active contribution to their development. Digital health technologies that do not meet basic quality criteria (not scientifically based and do not have evidence-based content) should not be used for primary stroke/CVD prevention. For example, large companies, such as Apple and Google, that host digital technologies should request evidence of scientific soundness of the apps and their content from developers submitting their health-related apps. However, to support further development and global scaling up of proven effective, scientifically robust, and highly affordable (ideally free to use) digital tools for primary stroke prevention, the World Health Organization recently suggested setting up a Global Action Plan for Digital Health Technologies.[19] Governments and nongovernment organizations should be encouraged to support the use and, if required, subsidize implementation of such tools with their subsequent integration into health systems.[17] The wider use of such digital technologies (especially in combination with other primary stroke/CVD prevention strategies) could not only significantly reduce stroke burden across the globe, save millions of lives, and support wellbeing of the people but will also reduce the burden on health service providers and enhance equitable access to health services. As recently stated by the World Heart Federation "global health justice, especially in a post-COVID world and in circulatory health, cannot be achieved without a critical understanding of digital health."[17] This position is fully shared by the World Stroke Organization.[40] Every national government needs a digital health strategy to be able to channel the power of digital technologies to tackle the human resources crisis as well as to make health care systems sustainable.[123]

FUTURE RESEARCH

Given the overall positive impact of some digital interventions on primary stroke and CVD prevention, further research (including full-scale RCTs) is needed to determine the most effective digital technologies (including their combinations and combinations with other primary stroke prevention interventions) in various populations. Further research is needed to determine the most effective strategies to be incorporated into digital tools to motivate people to follow healthy lifestyle and behavior across the lifespan. Conclusive evidence from various populations in the format of full-scale RCTs with follow-ups sufficient to determine effectiveness (including cost-effectiveness) of digital tools for primordial and primary stroke prevention is urgently needed. Future research is also required on digital technologies for primary stroke prevention in elderly people, people with low education attainments, ethnic and racial minorities or various disabilities, and on how to enhance the privacy and security of user information collected by the digital tools. A promising area of digital technologies in primary stroke prevention that warrants further research is the integration of artificial intelligence techniques with wearable monitoring devices, mobile apps, and smartphones for individualized prediction (precision medicine) of stroke occurrence and primary stroke prevention interventions. Finally, as the conduct of clinical trials, including those in the area of primordial and primary stroke prevention, has been discouraged and compromised by increasing rules, regulations, bureaucracy, governance, complexity and costs, opportunities to improve the quality, and efficiency of RCTs include accessing established registries and electronic health care records to recruit a broad range of patients rapidly and implementing interactive electronic case report forms and digital technologies (eg, smartphones, telehealth) to facilitate real-time monitoring and improve protocol adherence, completeness of follow-up, and trial quality.[124,125]

ARTICLE INFORMATION

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Disclosures

Dr Feigin declares that PreventS-MD Web app and free Stroke Riskometer app are owned and copyrighted by Auckland University of Technology, New Zealand. Drs Feigin and Hankey have contributed video commentaries to the Stroke Riskometer app. The other authors report no conflicts.

Supplemental Material

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