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Mobile health applications for atrial fibrillation: A readability and quality assessment

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ABSTRACT

Background: Mobile health applications may improve patient education and self-care for a complex condition such as atrial fibrillation (AF). Little is known about the accessibility of mobile health applications ("apps") and their readability. We evaluated the readability and quality of available apps for AF.
Methods: We searched the Apple and Google Play app stores with the terms "atrial fibrillation" and "afib." We downloaded English-language apps (up to $n = 100$ for each term) and categorized them by name, App store, cost, content, uploading agency (heath care associated [HCA] versus non-HCA), target audience (health care professional [HCP] versus non-HCP), scientific validity (i.e., citation of peer-reviewed or validated medical information), and user ratings. We analyzed the text of apps intended for a non-HCP target audience for readability with 10 established measures.
Results: Of the 206 downloaded apps, 50.5% were excluded as unrelated to AF, inaccessible, or non-English language. The majority of apps contained information about AF (63.2% Apple, 52.2% Google Play) and AF detection (52.6% Apple, 56.5% Google Play). A minority of non-HCP apps contained scientifically validated content (Apple, 15.8%; Google Play, 13.0%; $P = NS$). App mean readability was grade 12.1 ± 2.6.
Conclusions: Most AF apps lacked scientific validation and were written at excessively high reading-grade levels. Our results suggest caution with mobile health apps, particularly for users with limited health literacy. There is potential opportunity for a multi-disciplinary effort by regulatory agencies, healthcare organizations, and app stores to improve relevance, scientific validity, and readability of AF apps for patients with this complex and morbid disease.

1. Introduction

In the digital age, the internet is a common communication tool. Medical information is frequently searched on the Internet, as studies show 84% of Americans utilize the Internet with 80% searching for medical information [1,2]. Moreover, with 68% percent of adults owning a smartphone [3], mobile application, or "app," development for the purpose of medical care has soared in popularity. Apps have potential to help patients manage their chronic diseases and educate them about their conditions [4]. Therefore, the quality of health information disseminated on apps is relevant to high-quality patient care. However, a study of cancer apps found that only 32% of apps targeted to the general public had scientifically validated content [5].

Digital health educational materials have the potential to be misunderstood by patients and negatively impact health outcomes [6,7]. Health literacy is a robust gauge of an individual's health status [8], with reading ability playing a vital part in health literacy [9]. Readability is the reading comprehension level required by an individual to correctly understand and engage with written material [10,11]. The mean reading level in the United States is only at the 7-8th grade [12]. Multiple professional societies and medical organizations have proposed that health education materials be tailored to a 5–6th grade level to maximize their accessibility and readability [13,14].

Atrial fibrillation (AF) is a complex medical condition that is challenging for patients to understand, particularly those with limited

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health literacy [15]. AF patients with limited health literacy have worse outcomes and decreased access to care [15]. Despite this, patient education materials promoted by cardiovascular professional societies exceed national recommendations [16]. Our group previously reported that the readability of health education articles accessed via Google for common cardiovascular diseases also exceeds national recommendations [17]. For the current study, we aimed to assess the readability and quality of apps developed for AF, given the challenges of the condition and their exacerbation by limited health literacy. Specifically, we evaluated the readability, content, and quality of apps aimed at improving patient education and self-care for AF.

2. Methods

2.1. Mobile application descriptive data collection

The terms "atrial fibrillation" and "afib" were searched individually May 18–19, 2018, in the Apple App Store and Google Play Store to identify candidate apps. We selected these stores as they are, per US smartphone distribution metrics, the most frequently utilized digital application marketplaces [18]. We reviewed the app screen shot and description of the first hundred apps returned for each search term and excluded those pertaining to other medical conditions, non-English language, not medically oriented (e.g., games), or without evident relevance to AF. The remaining apps were subsequently downloaded and reviewed from May 24 to June 2, 2018. We contacted the developers of apps that were non-accessible due to software bugs or restrictions to request app access; if access was granted prior to June 2nd, 2018, the app was included for analysis.

We classified apps using the following criteria (summarized in Supplementary Table 1): App store (Apple, Google Play or both); cost (free or paid); content (medical information, AF detection (method), symptom journal, medication reminders, diet, activity tracking, dependence on additional device, patient support community, other); public or private health care associated [HCA] versus non-HCA); target audience (health care professional [HCP] versus non-HCP); scientific validity (i.e., citation of peer-reviewed or otherwise validated medical information); and average user ratings (ranging from 1 to 5 stars).

2.2. Readability analysis

Text from apps intended for a non-HCP Target Audience (patient-specific analysis) was collected for readability analysis if the app content: 1) contained patient-specific education material related to AF; 2) was accessible for submission to readability software; and 3) contained original content (i.e., was not copied from another source). Google Play Store apps that were not accessible were submitted to Universal Copy (Camel Corporation) [19] to extract app text. We contacted app developers directly to request access to inaccessible app text, and included here those apps for which text access was granted prior to June 2, 2018. We compiled app text into distinct Microsoft Word (Microsoft Corp, Redmond, WA) documents, excluding materials unrelated to health education (copyright notices, acknowledgments, disclaimers, web page navigational instructions, references).

We submitted app text to ten different evaluations for readability assessment using Readability Studio Professional Edition Version 2012.1 (Oleander Software, Ltd., Vandalia, OH). We included Flesch Reading Ease (FRE) [20] and nine scales to quantify scholastic grade level: Flesch-Kincaid Grade Level (FKGL) [21], New Dale-Chall (NDC) [22], FORCAST formula [23], Fry graph [24], Raygor Reading Estimate (RRE) [25], Simple Measure of Gobbledygook (SMOG) [26], Coleman-Liau Index (CLI) [27], Gunning Fog Index (GFI) [28], and New Fog Count (NFC) [21]. The FRE evaluation is rated on a 0–100 scale with lower scores indicating more challenging text and higher scores more comprehensible. FRE scores of 0–30 indicate *Very Difficult*, 30–50 *Difficult*, 50–60 *Fairly Difficult*, 60–70 *Standard*, 70–80 *Fairly Easy*, 80–90 *Easy*, and 90–100 *Very Easy*.

Institutional review board approval was not required for this project since all data were publicly available online and through public app stores.

2.3. Statistical analysis

Chi-square analyses were used to compare categorical app classifications between the two app stores. All statistical tests were two-tailed with a significance of $p < 0.05$. Apps were stratified for comparison based on Target Audience (HCP or non-HCP).

3. Results

The flow diagram for app identification, screening, and inclusion is summarized in Fig. 1. Of the 206 apps identified (93 Apple, 113 Google Play), 54 (30 Apple, 24 Google Play) were excluded as unrelated to AF based on preliminary screening. Among these apps, 17 Apple and 33 Google Play apps were determined to be either non-accessible, not in English or unrelated to AF after downloading and additional review. A total of 46 Apple and 56 Google Play apps were included in our descriptive analysis and categorized by target audience (HCP vs. non-HCP) with 19 Apple apps and 23 Google Play apps determined to be intended for a patient specific audience, i.e. non-HCP. A total of 14 apps (6 Apple and 8 Google Play) met criteria for the readability analysis. Table 1 summarizes each step of app selection.

3.1. Mobile application descriptive analysis

Of the 19 Apple apps deemed non-HCP and selected for inclusion in the patient-specific analysis, 14 (73.7%) were free to download while 5 (26.3%) required payment to download (Table 2) with an average cost of $2.19 per app. Of the 23 Google Play apps selected for inclusion in the patient specific analysis, 20 apps (87.0%) were free to download while 3 apps (13.0%) required payment to download (Table 2) with an average cost of $2.05 per app.

The number of apps in the Apple Store containing medication reminder functions was significantly greater than those in the Google Play Store ($P = 0.04$), with no significant differences noted among other app variables (Table 2). The majority of apps from both stores contained medical information about AF (Apple = 63.2%; Google Play = 52.2%) and a method for AF detection (Apple = 52.6%; Google Play = 56.5%) with most apps requiring an additional device for AF detection ($n = 5$; Supplemental Table 2). We further summarized the additional devices are summarized mobile health content available by app in Supplementary Table 3.

Only a minority of apps from both stores were determined to contain scientifically validated content (Apple = 15.8%; Google Play = 13.0%; Table 2), with no significant differences between stores. The uploading agencies of the apps were primarily Private HCA (Apple = 63.2%; Google Play = 91.2%; Table 2) for both Apple and Google Play apps.

Six of the 19 Apple apps with reviews had an average rating of 3.48 (out of 5.00) based on 971 reviews. Seventeen of the 23 Google Play apps were reviewed and had an average rating of 3.76 based on 342 reviews.

3.2. Mobile application readability analysis

In total, 131 articles from 14 apps that contained text intended for patient education were analyzed for readability from the Apple App Store and Google Play Store. The mean readability of all articles across grade level scales was 12.1 ± 2.6. We observed variability across readability scales with SMOG scoring the highest mean readability as 13.6 ± 2.5 and the New Fog Count scoring the articles with the lowest mean readability at 9.90 ± 3.3 (Supplemental Fig. 1). All articles were written above the recommended 5th–6th grade level. Furthermore, 49% of articles were written above the 12th grade reading level, suggesting a high school diploma and some collegiate coursework required for readability. Moreover, 7% of articles required at least a 4-year collegiate degree for readability. The non-grade level readability scale, the FRE evaluation, scored the mean readability of all articles as 44 ± 18, indicating text that is *Very Difficult* to read (Supplementary Fig. 2). By app store, the FRE scale scored the Apple App Store with a mean readability of 45 ± 14 (*Very Difficult*) while the Google Play Store scored 44 ± 19 (*Very Difficult*).

When analyzed by app store, Apple Store apps had a mean grade-level readability of 12.3 ± 2.2 while Google Play Store apps scored 12.0 ± 2.7 (Table 3). When articles were categorized by their respective app, all individual applications from the Google Play Store and Apple App Store scored a mean grade level readability above the recommended 5th–6th grade reading level (Table 3).

4. Discussion

In this study we examined the quality and readability of mobile health applications for AF available on the Apple App and Google Play

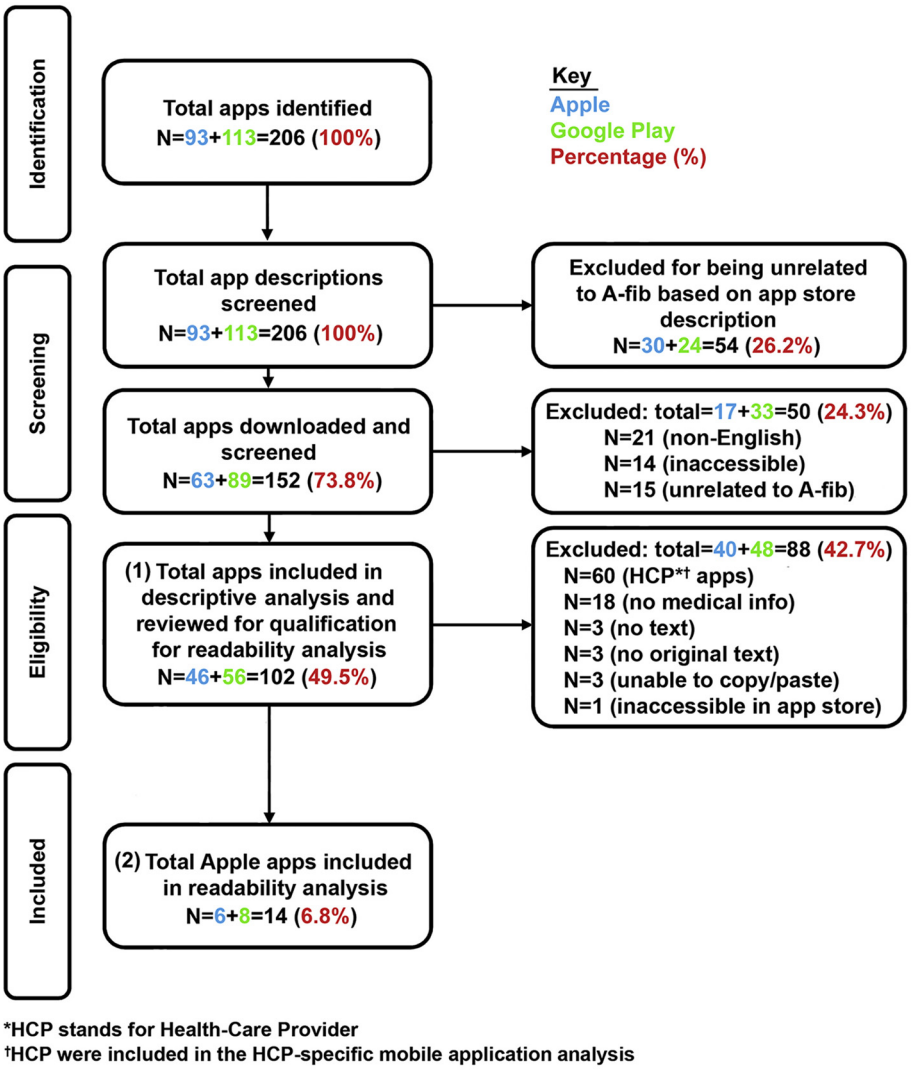

Fig. 1. Flow diagram summarizing exclusion process for all applications included in [1] descriptive and [2] readability analysis.

Stores. Mobile health apps are increasingly used, and our study is innovative in its concurrent analysis of descriptive app metrics and app readability analysis to gauge their content and accessibility for patient use.

Table 1
Summary of applications (apps) included in analyses, total and by app store (Apple, Google Play).

	N (%)
Number of apps identified	206
Apple	93 (45.1)
Google Play	113 (54.9)
App descriptions screened	206
Apple	93 (45.1)
Google Play	113 (54.9)
Excluded for no relation to AF based on app store description	54 (26.2)
Apple	30 (14.6)
Google Play	
Total number of apps downloaded	152 (73.8)
Apple	63 (30.6)
Google Play	89 (43.2)
Total number of apps included in categorical analysis	102 (49.5)
Apple	46 (22.3)
Google Play	56 (27.2)
Total number of apps included in readability analysis	14 (6.8)
Apple	6 (2.9)
Google Play	8 (3.9)

AF indicates atrial fibrillation.

Importantly, we found that the majority of mobile apps lacked scientific validation and were inaccessible because of their high reading-grade level. Most apps required a reading-grade level beyond high school education, well over the recommendations for health-related material. Our findings indicate fundamental challenges in mobile health apps for individuals with AF and suggest prominent obstacles for those with limited general or health literacy.

We further note that over half of the 206 apps identified by our search were excluded from our analysis. Excluded apps lacked content related to AF, had software issues that precluded assessment for analysis (i.e. crashed when opened, restricted access by developer), or were not English language. The paucity of apps included for final analysis suggests to us that there is insufficient oversight to monitor the relevance and functionality of apps by app vendors [29,30], in addition to the foremost readability obstacles identified here. Our finding that only 14.4% of AF apps for patients were scientifically validated is consistent with a study of cancer apps [5]. The absence of scientific validity for app content further suggests absence of oversight regarding medical and scientific quality of the information provided by mobile health apps.

An unfortunate finding of our study was that no apps contained medical information that met the recommended reading grade-level standard as articulated by the national health and medical organizations [8,31]. The study of the readability of mobile health applications remains limited. A study of mobile apps for gastroesophageal reflux also identified an excessively high reading level for app content, likewise

Table 2
Comparison of selected mobile apps for atrial fibrillation from the Apple ($n = 19$) and Google Play ($n = 23$) stores.

Criterion	Apple	Google Play	Chi-squared	*P*-value for χ^2
Medical information about disease/treatment	12 (63.2)	12 (52.2)	0.513	0.47
AF detection (method)	10 (52.6)	13 (56.5)	0.064	0.80
Symptom journal	4 (21.1)	4 (17.4)	0.091	0.76
Medication reminders	5 (26.3)	1 (4.4)	4.101	0.04
Diet (weight loss)	0 (0)	2 (8.7)	n/a	n/a
Activity tracker	2 (10.5)	1 (4.4)	0.600	0.44
Dependent on additional device (list device)	5 (26.3)	6 (26.1)	0.0003	0.99
Patient support community	1 (5.3)	0 (0)	n/a	n/a
Other (list)	8 (42.1)	9 (39.1)	0.038	0.85
Free	14 (73.7)	20 (87.0)	n/a	n/a
Paid	5 (26.3)	3 (13.0)		
Freemium	0 (0)	1 (4.4)		
Audience HCP	1 (5.3)	0 (0)	n/a	n/a
Audience non-HCP	19 (100)	23 (100)		
Scientific validity: Yes	3 (15.8)	3 (13.0)	0.064	0.80
Scientific validity: No	16 (84.2)	20 (87.0)		
Public HCA	0 (0)	0 (0)	n/a	n/a
Private HCA	12 (63.2)	21 (91.3)		
Non-HCA	1 (5.3)	0 (0)		
Other**	6 (31.6)	2 (8.7)		

HCP indicates health care provider; HCA, health care association.

surpassing national recommendations [32]. We and others have demonstrated the health literacy challenges in Internet-based content intended for patient education [15,33,34]. The adversity associated with limited health literacy and cardiovascular diseases such as AF is well described [35]. Limited health literacy is associated with decreased access to preventive services, challenges to adherence to medical advice, increased health care-related costs, and worse health outcomes [36–38]. The promise of mobile health is to make health education and health-related resources accessible regardless of health literacy. Our findings indicate that mobile health applications for AF have not met such essential metrics.

An important challenge for mobile health is that health apps are largely not regulated or monitored for scientific validity or veracity of app information [39]. The Food and Drug Administration is presently seeking to expand oversight into the app market through the 21st Century Cures Act but the scope of regulation remains limited [40]. In 2017, the non-profit organization Xcertia® (Austin, TX) was formed as a patient-centered working group to design and review health apps and ensure their review for quality, accuracy, readability and appropriateness as patient-centered mobile health tools as well as endorsement from professional organizations such as the American Heart Association and American Medical Association [41]. The FDA has also proffered *The Mobile Medical Applications Guidance for Industry and Food and Drug Administration Staff* as a guide medically rigorous health app development [39]. The institution of standards for content and health literacy would greatly improve the accessibility and quality of the mobile health apps for AF included in our analysis.

At present we propose that the current guidelines and regulatory environment of mobile applications for AF patients is insufficient. It is apparent that high-quality mobile applications are under development and may even currently be available to patients [42,43]; however, they are not accessible to most patients using the app store searches that we employed. Given the market share of the vendors we queried and the ubiquity of smartphones in society [3], other methods to

Table 3
Summary of application by app store, readability, scientific validity, and fundamental characteristics.

	Average readability[a,b]	Range[c]	Cost ($)	Scientific validity	Uploading agency	Rating[d]	# of reviews[e]
Apple App Store application name							
Photo AFib Detector (Free) (n = 1)	11.5 ± 1.89	–	0		Lai Man Po	2.4	9
Photo Afib Detector (n = 1)	11.5 ± 1.89	–	1.99		Lai Man Po	1.6	10
Atrial Fibrillation: Patient Decision Tool (n = 1)	13.6 ± 2.61	–	0.99		Leo Lai	–	–
Heart Care & Diseases ($n = 8$)	10.9 ± 1.89	7.09–13.4	0		Dimple Shah	–	–
LifeCourse Affinity ($n = 16$)	12.9 ± 2.17	9.32–15.4	0	√	PInCH Medical Systems Ltd.	–	–
Kardia ($n = 3$)	12.8 ± 2.58	10.7–15.7	0	√	AliveCor, Inc.	4.7	4913
Total Apple App store articles ($n = 30$)	**12.3 ± 2.15**						
Google Play Store application name							
Photo AFib Detector (Free) ($n = 1$)	11.5 ± 1.89	–	0		Lai Man Po	2.4	9
Photo AFib Detector (n = 1)	11.5 ± 1.89	–	1.99		Lai Man Po	1.6	10
Afib Companion (n = 1)	10.5 ± 0.97	–	0		Pawel Kuklik	–	–
Heart Inform ECG recorder (n = 2)	13.1 ± 2.14	11.6–14.6	0		Metaresearch	3.0	2
Atlas of Atrial Fibrillation ($n = 22$)	15.0 ± 1.89	10.3–17.4	0		Focus Medica India Pvt. Ltd	4.3	10
Kardia (n = 1)	15.7 ± 2.08	–	0	√	AliveCor, Inc.	4.7	4913
AfibAlert Mobile App (n = 5)	11.7 ± 2.59	8.68–15.3	0		Lohman Technologies	1.0	3
Stroke Prevent. Helicon Guide ($n = 61$)	10.9 ± 2.23	6.39–16.8	0		Coracle Online	–	–
Total Google Play App store articles ($n = 94$)	**12.0 ± 2.72**						

[a] Mean ± standard deviation.
[b] Average readability was calculated by taking the average article readability of each application. Article readability was estimated by utilizing the mean of the nine validated readability scales for each article.
[c] Absence of range values indicates only one article was collected for the application.
[d] Absence of rating values indicates application was not rated in the app store.
[e] Absence of values for number of reviews indicates that the application did not obtain any reviews in the app store.

popularize high-quality mobile applications, such as clinical recommendation, may fall short. Our findings point to the need for professional societies to provide clear guidelines to platform app stores and app developers regarding the development of apps aiming to enhance mobile health with education and self-care tools. Furthermore, it is imperative that metrics of readability and health literacy assessments be included in studies reporting results of mobile apps as well as future iterations of professional society statements on mobile health [44]. Furthermore, we suggest there is potential benefit of regulation of medically-related mobile application. Given the ubiquity of smartphones in society, expedient growth in app quality will only be achieved with cooperation of app vendors.

We acknowledge that this study has several limitations. An important limitation is that level of readability of an article alone does not necessarily imply comprehension by the individual. First, measures specific to patient education may provide a more thorough assessment of material, in contrast to our assessments of readability. Second, we selected only the first 100 apps identified with our queries. While we may have limited the number of apps included, we consider it unlikely that users would select apps below the top 100 responses to searches specific to AF. Third, our design selected only English-language apps. While generalizability of our findings to non-English language apps may be limited, our perception is that the majority of apps marketed by app stores are developed for English speakers.

In conclusion, we identified and analyzed widely available mobile health apps for AF. We determined that the majority of apps lack scientific validation for helping patients manage their AF and are written at reading-grade levels that exceed national recommendations. Our findings indicate the challenges for evidence-based medical-care using apps and fundamental obstacles to individuals with limited health literacy. We suggest there is opportunity for a multi-disciplinary effort by app stores, professional societies, and regulatory agencies to ensure quality and readability of mobile health apps.

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Declaration of Competing Interest

None reported.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcard.2019.07.026.

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