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ORIGINAL RESEARCH—CLINICAL

A Systematic Assessment of the Quality of Smartphone Applications for Gastroesophageal Reflux Disease

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BACKGROUND AND AIMS: Smartphone applications aimed at patients with gastroesophageal reflux disease (GERD) have been downloaded more than 100,000 times, yet no systematic assessment of their quality has been completed. This study aimed to objectively assess the quality of GERD smartphone applications for patient education and disease management. **METHODS:** The Apple App Store and Google Play Store were systematically searched for relevant applications. Two independent reviewers performed the application screening and eligibility assessment. Included applications were graded using the validated Mobile Application Rating Scale, which encompasses 4 domains (engagement, functionality, aesthetics, and information) as well as an overall application quality score. The associations between overall application quality, user ratings and download numbers were evaluated. **RESULTS:** Of the 4816 unique applications identified, 46 met inclusion criteria (patient education = 37, disease management = 9). Mean overall application quality score was 3.02 ± 0.40 out of 5 ("acceptable"), with 61% (28/46) rated as "poor" (score 2.0–2.9). Applications scored highest for aesthetics (3.24 ± 0.48) and functionality (3.88 ± 0.37) and lowest for information (2.58 ± 0.64) and engagement (2.39 ± 0.65). Disease management applications were of significantly higher quality than education-focused applications (3.59 ± 0.38 vs 2.88 ± 0.26, $P < .001$). There was no correlation between graded quality and either user ratings or the number of downloads. **CONCLUSION:** While numerous smartphone applications exist to support patients with GERD, their quality is variable. Patient education applications are of particularly low quality. Our findings can help to inform the selection of applications by patients and guide clinicians' recommendations. This study also highlights the need for higher-quality, evidence-informed applications aimed at GERD patient education.

Keywords: Gastroesophageal Reflux; Mobile Health; Digital Technology; Patient Education; Chronic Disease Management

Introduction

Gastroesophageal reflux disease (GERD), a common condition affecting 16%–44% of the North American population, requires a combination of lifestyle, behavioral, and pharmacologic interventions for optimal management.[1–4] There is growing interest in the development of mobile health technologies to maintain or improve health behaviors, quality of life, and wellbeing for patients with chronic conditions such as GERD. Mobile smartphone applications that are designed to educate patients and aid in the management of such conditions are numerous, with over 350,000 'health apps' available across smartphone platforms.[5,6] As 85% of all American adults own a smartphone, these applications are becoming an increasingly prevalent element of people's health management, and nearly 60% of adult mobile phone users have downloaded a health application.[7,8]

Patient-facing smartphone applications for GERD have the potential to improve patient education, disease monitoring, treatment adherence, and self-management for this condition and support patient empowerment through online support networks.[9] For example, health applications can provide information on the diagnosis, pathophysiology, and treatment of GERD, and enable tracking of GERD-related symptoms, triggers, and adherence to medications and lifestyle interventions. Previous research has shown that patients with chronic medical conditions who utilize mobile health applications are more likely to take part in health-promoting behaviors.[10] GERD is a particularly amendable condition to target with a smartphone application, as there are several key lifestyle-related risk factors and interventions that patients can learn about and track.[11,12] The aim of GERD management is to provide effective long-term control of symptoms in a personalized, symptom-based, patient-centered, and evidence-based manner.[13–15] Smartphone applications could help achieve this goal as they can increase patient engagement with established treatment

Abbreviations used in this paper: **GERD, gastroesophageal reflux disease; ICC, intraclass correlation coefficients; MARS, mobile Application Rating Scale; PRISMA, preferred reporting items for systematic reviews and meta-analyses; SD, standard deviation.**

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strategies in an individualized way through functions such as personalized goal setting, custom dosing reminders, and gamification elements.[16] Mobile health applications may also help to facilitate social networking and improve patient-physician communication through features that allow patients to share symptom, trigger, and medication adherence summaries with their healthcare providers.[17]

Despite the potential benefits of patient-facing health applications for GERD, there is currently limited information published regarding their quality and functionality. This makes it difficult for clinicians and patients to identify optimal applications for use. Importantly, due to the lack of consistent regulation across digital marketplaces, smartphone applications for various chronic health conditions have been shown to be of uncertain quality and efficacy.[9,18–20] Concerningly, health applications for gastrointestinal diseases were found to be among the lowest quality across an assessment of 20 different condition-specific health categories.[6] To address this gap, we sought to systematically identify and objectively assess the quality of publicly available, patient-facing smartphone applications for GERD using the validated Mobile Application Rating Scale (MARS), the most widely used tool for evaluating health applications.[21] This information will enable informed decisions around application use for patients with GERD and identify gaps to inform future health application development.

Methods

This study was planned, conducted, and reported, where possible, in adherence to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines for systematic reviews.[22]

Search strategy

We completed a systematic search of smartphone applications in the Canadian versions of the Apple App Store and Google Play Store from May 15, 2020, to July 25, 2020. Search terms included: "acid reflux," "reflux," "heartburn," "spit up", "spit-up", "regurgitation", "esophagus", "oesophagus", "esophagitis", "oesophagitis", "gastroesophageal", "gastro esophageal", "gastro oesophageal", "gastroesophageal reflux disease", "gastro esophageal reflux disease", "gastroesophageal reflux", "gastro-oesophageal reflux disease", "GERD", "proton pump inhibitors", "omeprazole", "Losec", "lansoprazole", "dexlansoprazole", "Prevacid", "esomeprazole", "Nexium", "rabeprazole", "Pariet", "ranitidine", "Zantac", "pantoprazole", "Tums", "indigestion", "stomach acid", "acid taste", "acid", "pH" and "endoscopy." Each search term was entered in both the Apple App Store and Google Play Store, leading to 72 total searches.

Application selection

Applications were included if they were: (1) available on either the Apple App Store or Google Play Store; (2) functional (ie, it was possible to download and open the application); (3) self-contained (ie, did not require an add-on or another type of external device to work); (4) free; (5) available in English; (6) patient-facing (ie, not intended for use primarily by medical professionals); and (7) targeted at either GERD education or management. If a health application was available in both free and paid versions, only the free version was assessed. Within free applications, components that required paid upgrades were not assessed. Applications targeting a specific product or clinic were excluded. We redownloaded nonfunctional applications and excluded them if they remained nonfunctional on the second attempt. Two authors (M. J. G. and C. L.) independently completed application selection by screening application titles and summaries and then downloading those that appeared to meet eligibility criteria for full assessment to determine inclusion. When required, a third author (C. M. W.) adjudicated any disagreements.

Data extraction

Android applications (Google Play Store) that met inclusion criteria were downloaded and tested using a BlackBerry Priv (Android version 6.0.1) and Blackberry Keyone (Android version 7.1.1). iOS applications (Apple App Store) were downloaded and tested on an iPhone 6s (iOS version 14. 4) and an iPhone 11 (iOS version 14.0.1). Health applications available on both platforms were tested on all the aforementioned devices.

Using a standardized data extraction form that was developed a priori, 2 reviewers (M. J. G. and C. L.) independently and in duplicate extracted data for each eligible application. To incorporate a diversity of perspectives, reviewers were purposefully chosen to include a gastroenterology fellow (M. J. G.) and an undergraduate science student (C. L.), providing both a content expert and lay perspective. Application characteristics abstracted included: application name, platform (Android, iOS), version number, file size, cost, developer, year of development, date of most recent update, affiliated societies/institutions, number of downloads, user-generated ratings, number of ratings, age recommendation, availability of a translation function, available languages, offline capabilities, and the ability to interact with a healthcare professional through the application. The total number of application downloads, an important metric that speaks to an application's adoption amongst patients, was only available for applications found in the Google Play Store, as the Apple App Store does not disclose this information. We also documented whether applications contained explicit end-user safety information, such as warnings about the limitations of the application's scope and reasons to contact a healthcare professional. Finally, we categorized applications as being primarily focused on either patient education or disease management, including behavior and symptom tracking.

Application quality appraisal

To objectively assess application quality, each health application was rated independently by 2 reviewers (M. J. G. and C. L.) using the MARS tool.[23] The MARS is a validated multidimensional measure of application quality that has been used to assess mobile health applications for a wide variety of chronic health issues, including hypertension, chronic kidney disease, and rheumatoid arthritis.[24–26] An external validation study that evaluated the MARS's construct validity, concurrent validity, reliability, and objectivity and included an analysis of

Table 1. Description of Mobile App Rating Scale Domains

Domain	Description	Subdomains
Engagement	Degree to which application is fun, interesting, customizable, interactive and targeted to intended audience	1. Entertainment 2. Interest 3. Customization 4. Interactivity 5. Target group
Functionality	Degree to which application performs, is easy to learn, navigate and contains logical flow and gestural design	1. Performance 2. Ease of use 3. Navigation 4. Gestural design
Aesthetics	Degree of overall application visual appeal, color scheme and stylistic consistency	1. Layout 2. Graphics 3. Visual appeal
Information quality	Degree to which application description accurately describes application content and to which the application contains measurable goals and high-quality information from a credible source	1. Accuracy of application description 2. Goals 3. Quality of information 4. Quantity of information 5. Visual information 6. Credibility 7. Evidence base

ratings from 1299 mobile health applications covering 15 different health domains, found that the MARS was a suitable and valid tool.[21] The tool is also used internationally and has now been validated in several languages, including Korean, Arabic, French, German, and Japanese.[27–31] The MARS tool includes 19 objective items in 4 domains, namely engagement (5 items), functionality (4 items), aesthetics (3 items), and information quality (7 items).[23] A description of these 4 domains can be found in Table 1. Subjective quality is rated using an additional 4 items. Each of the 23 items is scored on a 5-point Likert scale: 1 = inadequate, 2 = poor, 3 = acceptable, 4 = good, and 5 = excellent. The mean of the 4 objective domains (engagement, functionality, aesthetics, and information quality) is calculated to generate an overall application quality score, and the mean of the 4 subjective items is calculated to generate a subjective application quality score (quality scores: 1.0–1.9 = inadequate, 2.0–2.9 = poor, 3.0–3.9 = acceptable, 4.0–4.9 = good, 5.0 = excellent).

Each reviewer underwent training in the use of the MARS tool, as recommended by the MARS developers, and a calibration exercise was completed on 5 test applications prior to initiating study scoring.[23] Questions pertaining to the information quality domain were completed by one reviewer with formal gastroenterology training. Prior to rating, reviewers tested each application for a minimum of 10 minutes to gain an adequate understanding of its functionality.

We also sought out any published trials evaluating the efficacy and/or effectiveness of each included application by checking the developer website, when available, and by searching Google and PubMed with the application name as the search term.

Data analysis

We used descriptive statistics to summarize application characteristics. We calculated MARS domain-specific mean scores and standard deviations for each reviewer and averaged these scores across reviewers to determine the final scores for each domain. We then calculated an overall application quality score by averaging the mean scores across the engagement, functionality, aesthetics, and information quality domains. Subjective application quality scores for each application were also calculated, and then a mean score across reviewers was determined.

Interrater reliability describes the extent to which the scores assigned by the 2 reviewers are in agreement with each other.[32] We calculated the interrater reliability of the MARS overall quality score as well as the subjective application quality score using two-way random effect intraclass correlation coefficients (ICC) with average measures.

We compared MARS domain and overall application quality scores for applications categorized as being primarily focused on patient education with those focused on disease management using an independent sample t-test. We used Pearson correlation coefficients to determine the relationship between the overall application quality score and the subjective application quality score, as well as the relationship between the overall application quality score and patient-facing metrics, including an application's user-generated rating in its respective application store(s) and the number of times it had been downloaded. We used a point-biserial correlation to calculate the relationship between MARS scores and the presence or absence of end-user safety information within an application.

Statistical significance was set to $P < .05$. Data analyses were completed using SAS® OnDemand for Academics (SAS Institute Inc., Cary, NC, USA).

Results

We identified a total of 7764 potentially relevant applications through searches of the Apple App Store (n = 1326) and Google Play Store (n = 6438). We removed 2948 duplicate applications and excluded 4741 applications through a review of application titles and summaries. We

downloaded 75 applications for further evaluation and excluded 29 applications because they did not meet inclusion criteria (n = 25) or they were subsequently deleted from their respective application store(s) (n = 4). We provide a preferred reporting items for systematic reviews and meta-analyses study flow diagram in Figure 1.

Included applications

We included 46 applications, 6 (13.0%) of which were available in the Apple App Store, 37 (80.4%) in the Google Play Store, and 3 (6.5%) in both. A summary of application characteristics can be found in Table 2 and a comprehensive list of applications for GERD, with their respective properties, can be found in Appendix 1. Thirty-seven (80.4%) applications focused on patient education, and 9 (19.6%) focused on disease management. User-generated ratings were available for 16 applications (34.8%), with a mean rating of 3.58 ± 0.81 out of 5. Of the applications available in the Google Play Store, 13 (32.5%) had been downloaded more than 1000 times. We identified 5 applications (10.9%) that allowed users to export their data from the application to share with their healthcare provider. Applications were most recently updated between 2016 and 2020, with a median update year of 2019. We identified 3 applications (6.5%) that were developed in affiliation with an academic institution or non-governmental organization and 4 that were developed in partnership with a pharmaceutical company (Appendix 1).

Application quality

Across all applications, the MARS overall quality score was 3.02 ± 0.40 ("acceptable"), with 61% (28/46) being

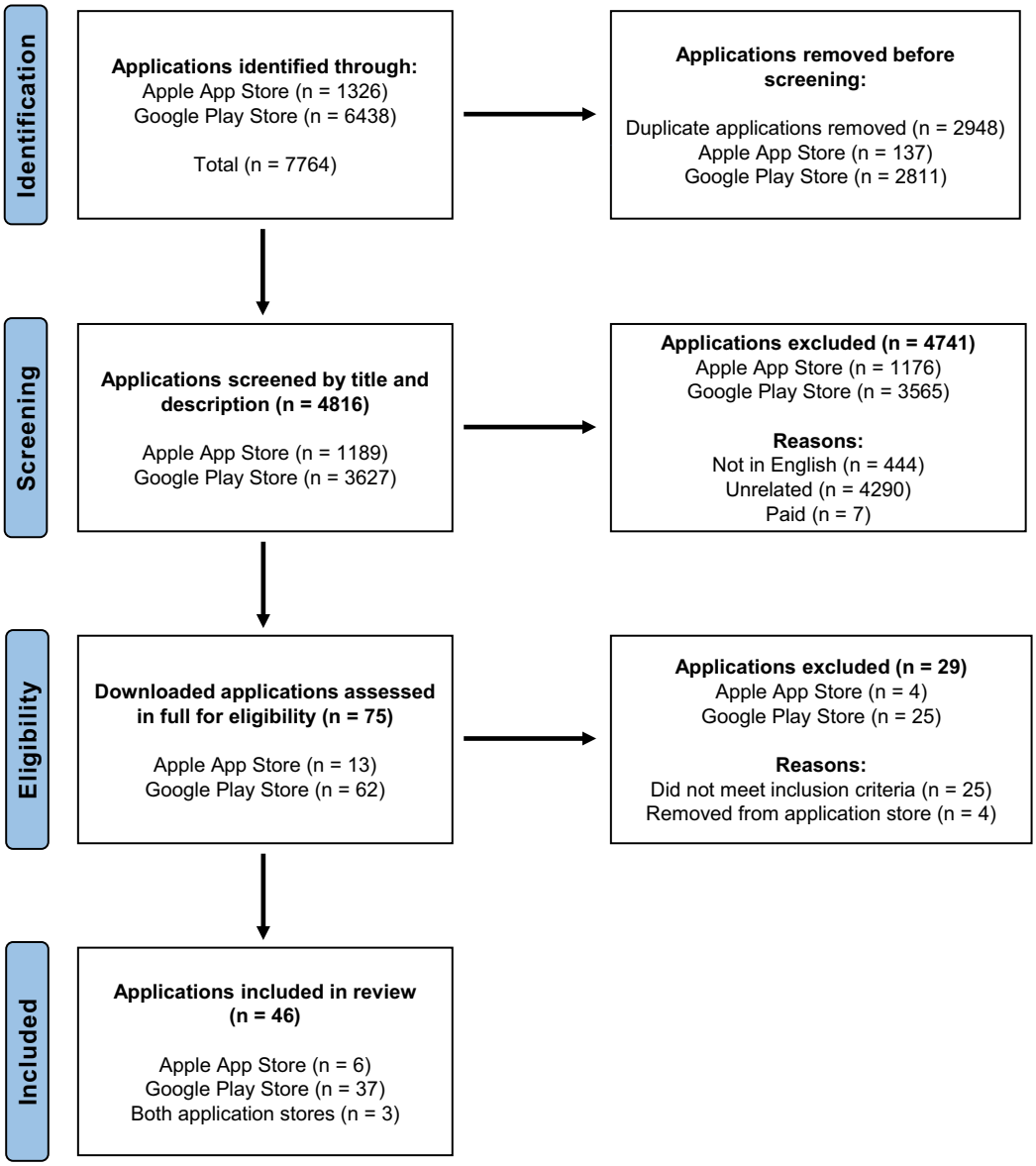

Figure 1. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram for application selection.

Table 2. Summary of Mobile Applications Meeting Inclusion Criteria

Application store	Number of applications identified	Number of downloads	User-generated rating (mean ± SD)	Age recommendation (y)	Inapplication purchases	Offline capability
Apple app store	6	Not stated: 6	3.75 ± 0.68 (n = 4)	≥4: 2 ≥12: 4	Yes = 3 No = 3	Yes = 4 No = 2
Google play store	37	0–49: 4 50–99: 3 100–499: 14 500–999: 6 1000–9999: 9 >10,000: 1	3.78 ± 0.87 (n = 10)	All ages: 37	Yes = 2 No = 35	Yes = 32 No = 5
Both	3	1000–9999: 2 >10,000: 1	3.16 ± 0.62 (n = 3)	≥4: 1 ≥12: 1 All ages: 1	Yes = 1 No = 2	Yes = 1 No = 2

n, number of applications with a rating; SD, standard deviation.

rated as "poor" (score 2.0–2.9). Only one application was given an overall quality mean score ≥ 4 ("good" or "excellent"), *My GiHealth GI Symptom Tracker*. Applications scored highest for functionality (3.88 ± 0.37; "acceptable") and aesthetics (3.24 ± 0.48; "acceptable") and lowest for information (2.58 ± 0.64; "poor") and engagement (2.39 ± 0.65; "poor"). The mean subjective application quality score was 2.13 ± 0.86 ("poor") and was highly correlated with the overall quality mean score (r = 0.85, $P < .001$). A summary of domain and overall application quality scores can be found in Appendix 2. The interrater reliability for the MARS overall application quality score indicated moderate agreement (ICC 0.61; 95% CI: 0.39, 0.76), as did the ICC for the subjective application quality score (ICC 0.57, 95% CI: 0.34, 0.74).

Disease management applications were of significantly higher quality than education-focused applications, with MARS overall quality scores of 3.59 ± 0.38 ("acceptable") and 2.88 ± 0.26 ("poor"), respectively ($P < .001$). This was also true across each of the MARS domains, aside from functionality (Table 3). Only 41% (19/46) of applications included end-user safety information. There was a significant correlation between the presence of end-user safety information and overall application quality scores (r = 0.50, $P < .001$). We found no correlation between the MARS overall quality score and the number of times an application had been downloaded (r = 0.26, $P = .12$) or its user-generated application ratings (r = −0.08, $P = .77$). We did not find any published randomized controlled trials or other studies evaluating the effectiveness of any of the applications included in this review.

Top 3 applications

The 3 top-rated applications identified were: (1) *My GiHealth GI Symptom Tracker* (available in the Apple App Store); (2) *Reflux Tracker* (available in both the Apple App Store and Google Play Store); and (3) *mySymptoms Food Diary & Symptom Tracker Lite* (available exclusively from the Google Play Store), with MARS overall quality scores of 4.09 ("good"), 3.96 ("acceptable"), and 3.91 ("acceptable"), respectively. Of note, all 3 of these applications are focused on disease management. The highest scoring patient education application was *Acid Reflux Diet Helper* by the developer Appstronaut (available in both the Apple App Store and Google Play Store) with an overall application quality score of 3.82 ("acceptable"). Tables 4 and 5 outline the characteristics of the top scoring applications focused on disease management and patient education, respectively. As illustrated in Table 5, even among the top-scoring patient education applications, nearly all educational information provided was not compliant with the 2022 American College of Gastroenterology Guidelines. This included information about the pathophysiology, diagnosis, and management of GERD.

Discussion

While many patient-facing smartphone applications exist for GERD, we determined that their quality is variable and is often inadequate. Of the 46 applications we assessed, 61% had a "poor" overall application mean quality. When looking at specific quality domains, while most applications had at least "acceptable" functionality and aesthetics, we found that many applications scored in the "poor" range for information quality and user engagement, with only 2 applications having a "good" or "excellent" information quality score. Applications aimed at patient education were of particularly low quality.

This is the first study to systematically assess the quality and usability of freely available smartphone applications for GERD in North American application stores, and the first to assess these applications using a tool validated for the assessment of application quality (the MARS tool). The low overall quality scores determined by our review are similar

Table 3. MARS Domain Specific and Overall Application Quality Scores Based on Primary Application Focus

	Education applications	Disease management applications	*P*-value
Engagement	2.13 (0.39)	3.41 (0.42)	<.001
Functionality	3.91 (0.36)	3.78 (0.41)	.36
Aesthetics	3.12 (0.45)	3.70 (0.33)	<.001
Information	2.34 (0.41)	3.45 (0.62)	<.001
MARS overall quality score	2.88 (0.26)	3.59 (0.38)	<.001

to those reported for applications targeting other chronic medical conditions, including type 2 diabetes, chronic lower back pain, and heart failure.[18,33,34] Previous research evaluating the readability of 9 patient-facing smartphone applications for GERD found that none of the applications assessed met the readability standards for patient education materials set out by the National Institutes of Health (all exceeding the suggested reading grade-level).[35] Although this group evaluated application readability and not application quality, in concert with our findings, this further supports the idea that current smartphone applications for patients with GERD are insufficient.

Table 4. Characteristics of the 3 Highest Quality Applications Focused on Disease Management (Based on MARS Overall Quality Score)

	My GiHealth GI symptom tracker	Reflux tracker	mySymptoms food diary & symptom tracker lite
MARS overall quality score	4.09	3.96	3.91
Symptom tracking	✓	✓	✓
Medication compliance tracking		✓	✓
Diet tracking		✓	✓
Activity tracking	✓		✓
Bowel habit tracking			✓
Quality of life tracking	✓		✓
Tracking reminders	✓	✓	✓
Medication reminders			
Appointment reminders			
Goal setting			
Goal tracking			
Exportable reports	✓	✓	✓
Community/ social networking features			
Interaction with a healthcare professional			
Patient education component	✓	✓	

Patients with gastroenterological diseases are willing to use smartphone applications and perceive them to be useful.[36] Despite this, applications have not been widely integrated into routine healthcare.[37,38] Previous research has also shown that gastroenterology patients value provider input in directing them to trustworthy electronic health information.[39] However, many practitioners are likely unfamiliar with the currently available patient-directed smartphone applications for GERD and ill-equipped to address patient questions about them. This study provides important information to help inform clinicians about which applications are of higher quality and could be recommended to patients (of which there are few) and which applications are of such poor quality that they cannot be safely suggested.

In selecting which applications to download, consumers typically rely on available user-facing metrics, including user ratings and download numbers.[40] We demonstrated that these metrics did not correlate with objective, overall application quality scores and, therefore, did not provide useful information for clinicians and patients alike. Previous studies have corroborated this finding and shown that user star ratings do not correlate with application quality, clinical utility, or usability of health-related applications.[24,41]

It is also important for clinicians to note that the efficacy of any currently available patient-directed smartphone application for GERD has not been formally evaluated. This lack of objective evidence of effectiveness is not unique to GERD-focused applications.[9] A systematic review of mobile health smartphone applications identified only 22 applications across medical disciplines that had been evaluated in a randomized controlled trial.[18] Although an estimated 250 new health-related applications are added to the market daily, our findings highlight a persistent need for the development of high quality, evidence-informed smartphone applications for patients with GERD that undergo formal evaluation to demonstrate benefit. Achieving this will likely require increased engagement of clinicians in this rapidly growing space.[5,6] In the interim, clinicians should temper any claims about the benefit of smartphone application use for GERD when discussing this topic with patients.

Patient education is a primary pillar of GERD management, which can help improve adherence to treatment; however, evidence has demonstrated that current methods of patient education are largely inadequate.[3,17,42–44] Smartphone applications are a potentially powerful way to provide patient education and promote behavioral change.[10,45] We noted that an area that was particularly deficient in the mobile application space for GERD was high-quality patient education applications. We also noted a concerning trend across smartphone applications targeted at patients with GERD. Many of the applications we assessed, especially those aimed at patient education, appeared to contain identical text content copied from one application to

Table 5. Characteristics of 3 Highest Quality Patient Education Applications (Based on MARS Overall Quality Score)

	Acid reflux diet helper (Appstronaut)		Acid reflux diet plan (RK Unit)		Home remedies for acidity (Adwillz India)	
MARS overall quality score	3.82		3.14		3.12	
Educational topic	Information included	Compliant with 2022 ACG guideline	Information included	Compliant with 2022 ACG guideline	Information included	Compliant with 2022 ACG guideline
Pathophysiology	X	——	✓	X	✓	X
Symptoms	X	——	✓	✓	✓	X
Diagnosis	X	——	X	——	✓	X
Diet and lifestyle interventions	✓	X	✓	X	✓	X
Pharmacotherapy	X	——	✓	X	X	——
Surgical interventions	X	——	X	——	X	——

ACG, American College of Gastroenterology.

another (Figure 2). In many cases, this information was inaccurate and conflicting with current best practices and evidence-based guidelines.[3,4,15] This raises the possibility that some application developers are not verifying the accuracy of the health information contained within their applications, which could potentially pose safety ramifications for patients.

The issue of poor information quality is not unique to applications for GERD. A recent systematic review identified that incorrect, incomplete, or inconsistent information is the most common safety issue across mobile health applications.[46] This lack of accurate information within applications is felt to stem from a paucity of evidence-informed application development.[46] Across the mobile health field, it has been shown repeatedly that application content is often not evidence-based, adequately referenced, or up-to-date, and there is a lack of expert involvement in application development.[46,47] One prior study sought to systematically assess the information quality of smartphone applications for GERD available in the United Kingdom; however, the study did not utilize a validated tool for the assessment of smartphone application quality.[48] Despite this, similar to what was observed across the applications we assessed, the authors identified that only a small proportion of applications for GERD involved healthcare professionals in their development (2.7%).[48] Our findings, along with the existing literature around application information quality, highlight the need for healthcare professionals, regulatory bodies, and gastroenterology societies to become involved in application development and certification.[46]

This study has several limitations. We restricted our review to applications available in the Canadian Apple App Store, and Google Play Store as it is not possible to search all international application stores from a single country. Most applications, however, are not country-specific, as Apple's iOS and Google's Android operating systems are used by over 99% of the global mobile phone market.[49] We also excluded paid applications (of which there were few); however, studies from other health domains have found that paid applications are not of higher quality and do not include more evidence-based information compared with free applications.[24,50] A further limitation stems from the choice of reviewers. While an attempt was made to incorporate different perspectives through the use of both a context expert and a lay reviewer, the absence of the patient perspective was noted. Therefore, future work evaluating patient assessments of applications for GERD and the relationship between these applications and clinically relevant outcomes would be an important next step.

Conclusion

While patient demand for smartphone applications to support GERD-related education and disease self-management is high, very few applications are of sufficient quality, particularly those aimed at patient education, and none have been evaluated systematically. Additionally, application quality was not correlated with metrics patients and clinicians consider when deciding which application(s) to use, including download number or user-generated ratings. With this information in mind, most GERD-focused applications cannot be safely recommended for patient use, especially those directed at education. Overall, our results highlight the need for additional high-quality applications targeted at patients with GERD, the importance of involving medical experts in the development and evaluation of these applications to ensure they provide evidence-informed information, and the potential requirement for

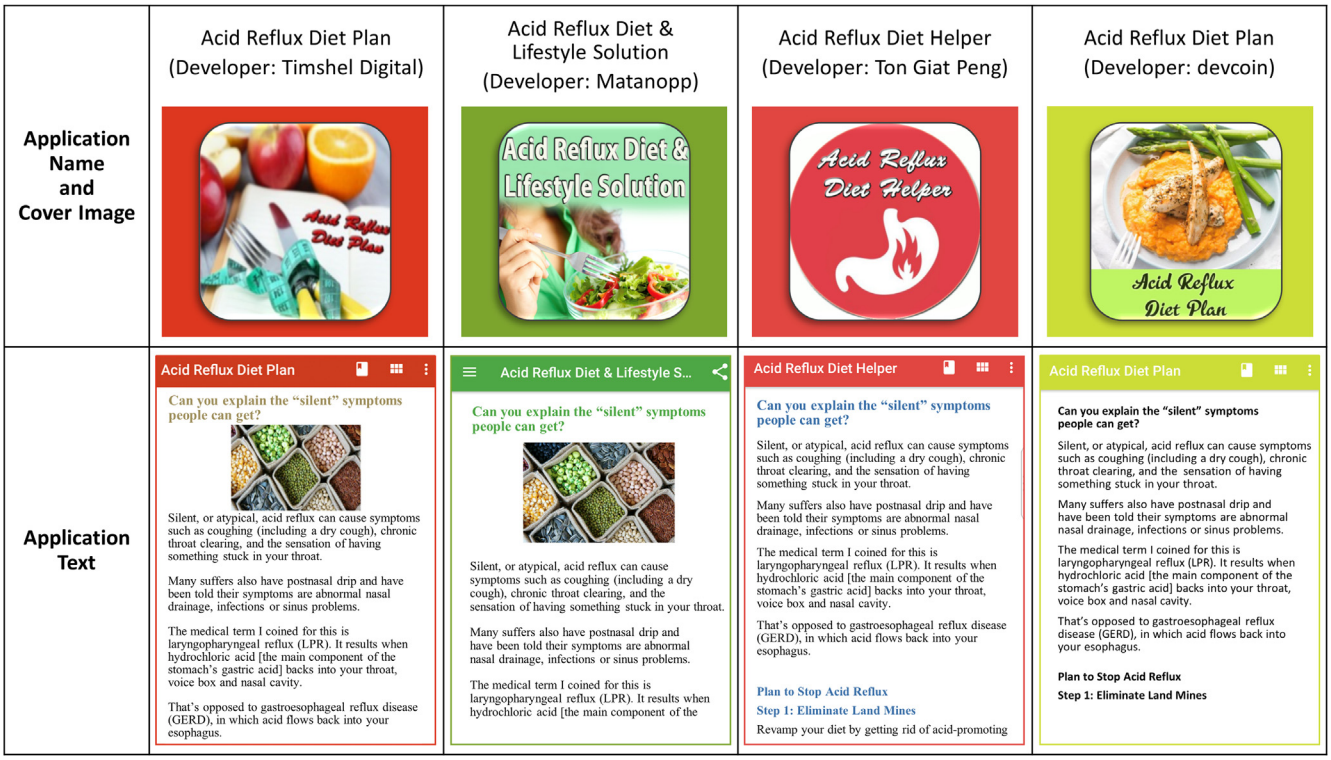

Figure 2. Example of identical text elements across several applications.

more advanced regulation of gastroenterology-related smartphone applications moving forward.

Supplementary materials

Material associated with this article can be found in the online version at https://doi.org/10.1016/j.gastha.2023.03.001.

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