American Journal of Preventive Cardiology 19 (2024) 100710

Contents lists available at ScienceDirect

American Journal of Preventive Cardiology

journal homepage: www.journals.elsevier.com/american-journal-of-preventive-cardiology

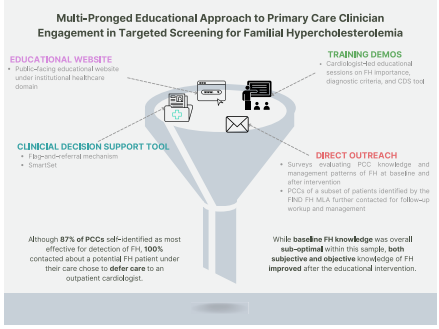
Primary care clinician engagement in implementing a machine-learning algorithm for targeted screening of familial hypercholesterolemia

Kain Kim [a,*], Samir C. Faruque [b], David Kulp [a], Shivani Lam [c], Laurence S. Sperling [d,e,f], Danny J. Eapen [g]

[a] Emory School of Medicine, Atlanta GA 30306, USA
[b] Division of General Medicine, Washington University School of Medicine, St. Louis MO 63110, USA
[c] Department of Biology, Emory University, Wayne Rollins Research Center, Atlanta GA 30306, USA
[d] Hubert Department of Global Health, Rollins School of Public Health at Emory University, Atlanta GA 30306, USA
[e] Emory Center for Heart Disease Prevention, Atlanta GA 30306, USA
[f] Emory Clinical Cardiovascular Research Institute, Atlanta GA 30306, USA
[g] Department of Medicine, Emory School of Medicine, Atlanta GA 30306, USA

GRAPHICAL ABSTRACT

Central Illustration: We developed a comprehensive, multi-pronged educational program for primary care clinicians (PCCs) on screening, diagnosis, and management of Familial Hypercholesterolemia. Our interventions included (1) launch of an educational website on our institution's domain with both patient- and provider-facing information, embedded user survey, and additional resources, (2) an internal clinical decision support (CDS) build that flagged individuals with LDL-C values concerning for FH and suggested a SmartSet of additional labs/testing/referrals, (3) live cardiologist-led demonstration of CDS use and didactic presentation on FH, and (4) direct InBasket outreach to PCCs of patients identified by the FIND FH® machine-learning algorithm to have potential FH. Pre- and post-intervention survey responses indicate suboptimal levels of baseline FH knowledge among PCCs, and that despite being motivated to take ownership of FH management, limited capacity among PCCs may benefit from use of CDS tools and interdisciplinary partnerships.



ARTICLE INFO

Keywords:
Familial hypercholesterolemia
Machine learning algorithm
Electronic health record

ABSTRACT

Objective: To assess the impact of a multi-pronged educational approach on the knowledge, attitudes, and behaviors regarding Familial Hypercholesterolemia (FH) management at a large academic medical center with the aim of empowering primary care clinicians (PCC) to diagnose and treat FH.
Methods: A comprehensive educational program for PCCs on FH management was developed and piloted from July 2022 to March 2024. Components of our intervention included: 1. Implementation of a novel clinical decision support tool in the electronic medical record for FH management, 2. Development and dissemination of an

* Corresponding author at: 2-1308 1440 Rock Springs Cir NE, Atlanta, GA 30306, USA.
E-mail address: kain.kim@emory.edu (K. Kim).

https://doi.org/10.1016/j.ajpc.2024.100710
Received 13 May 2024; Received in revised form 9 July 2024; Accepted 17 July 2024
Available online 22 July 2024

interactive educational website focused on FH and its management, 3. Delivery of virtual instructional sessions to increase awareness of the tool, provide education on its use, and obtain support from institutional leadership, and 4. Direct outreach to a pilot subset of PCCs whose patients had been detected using the validated FIND FH® machine learning algorithm. Participating clinicians were surveyed at baseline before the intervention and after the educational session.

Results: 70 PCC consented to participate in the study with a survey completion rate of 79 % ($n = 55$) and 42 % ($n = 23$) for the baseline and follow-up surveys, respectively. Objective PCC knowledge scores improved from 40 to 65 % of responders correctly responding to at least 2/3rds of survey questions. Despite the fact that 87 % identified PCC's as most effective for early detection of FH, 100 % of PCCs who received direct outreach chose to defer care to an outpatient cardiologist over pursuing workup in the primary care setting.

Conclusion: Empowering PCCs in management of FH serves as a key strategy in addressing this underdiagnosed and undertreated potentially life-threatening condition. A systems-based approach to addressing these aims may include leveraging EMR-based clinical decision support models and cross-disciplinary educational partnerships with medical specialists.

1. Introduction

Familial Hypercholesterolemia (FH) is a common genetic disorder that increases the risk of developing premature atherosclerotic cardiovascular disease (ASCVD). If left untreated, it is estimated that 85 % of men and 50 % of women will have had a coronary event by age 65 [1]. Simon-Broome diagnostic criteria state that adults with low-density lipoprotein cholesterol (LDL-C) levels exceeding 190 mg/dL and a family history of premature MI or elevated cholesterol are eligible for further screening of "possible FH" and should be referred to specialists for advanced diagnostics and management [2]. However, despite various clinical guidelines not requiring genetic screening or risk factor calculation to diagnose FH, such guidelines are under-utilized in clinical practice [3].

Primary care clinicians (PCC) are often the initial point of contact for these undiagnosed patients in the community and are also more likely to care for multiple members within affected families, which is particularly notable in conditions like FH that display an autosomal dominant pattern of inheritance. As such, PCCs occupy a pivotal position in addressing this disparity through augmenting screening, detection, and management of FH. Despite the high utilization of primary care services in the United States, however, recent surveys from the National Lipid Association found that FH remains under-recognized and under-treated despite assessment by PCCs [4,5]. When compared to cardiologists, PCCs were significantly less likely to accurately diagnose a hypothetical case of FH, refer patients to a lipid specialist, or prescribe a PCSK9 inhibitor [5,6]. Even among cardiologists, awareness of FH's prevalence, heritability, and risk remains limited [7]. Other studies reflecting a similar gap in PCC knowledge about FH have highlighted several prominent challenges in generalist FH management that may account for this care gap, including unfamiliarity with diagnostic criteria, lack of access to reliably recorded family history or physical exam findings, and systemic barriers leading to shortages in lipid specialist services or apheresis centers [8-10].

To increase PCC awareness of FH, we implemented at a multipronged approach that incorporated a novel electronic medical record (EMR)-driven Clinical Decision Support (CDS) tool, a machine learning algorithm (MLA) for targeted FH screening, and inter-departmental education initiatives at a large, academic medical center. To our knowledge, no prior studies have attempted to integrate this MLA into outpatient clinical care with the primary purpose of empowering PCCs to diagnose and treat FH. By assessing the effects of this intervention on existing PCC familiarity with FH, their attitudes, and perceived barriers to engagement, we hope to inform future quality improvement initiatives with the ultimate goal of increasing early FH identification and intervention within healthcare systems.

2. Methods

A comprehensive educational program for PCCs on FH management was developed and piloted from July 2022 to March 2024. Our intervention consisted of four main components: 1. Implementation of a novel EMR-driven CDS tool that enhances the prompt identification, management, and referral of patients with a family history and/or laboratory measures concerning for potential FH, 2. Development and dissemination of an interactive educational website on FH and its management, 3. Delivery of virtual instructional sessions to increase awareness of the tool, provide education on its use, and obtain support from institutional leadership, and 4. Direct outreach to a pilot subset of PCCs whose patients had been detected by the FIND FH® (Flag, Identify, Network, and Deliver Familial Hypercholesterolemia) machine learning algorithm. Participating PCCs were surveyed at baseline before the intervention and after the educational session.

This study was reviewed and approved by the [Redacted] Institutional Review Board (IRB#: 00003806).

2.1. Clinical decision support tool

An EMR-based workflow was designed to notify and engage PCCs whose patients met threshold LDL-C criteria for a possible diagnosis of FH. The workflow contained two primary components: a flag-and-referral mechanism that required physicians to click on an alert for further information at point-of-care, and a SmartSet CDS tool. Both components were linked to an automated EMR detection algorithm that identified patients with an LDL-C $\geq$ 190 mg/dL. The workflow was integrated across the entirety of the host institution's health system.

As the [Redacted] Healthcare system initiated the EPIC healthcare software as its primary EMR in October 2022, the first intervention included implementing a flag on LDL-C values $\geq$190 mg/dL listed under a patient's laboratory results for all patients within this [Redacted] healthcare system. The flag advised clinicians to consider an FH diagnosis once secondary causes were ruled out and included links to electronic resources clarifying the diagnostic criteria and offering guidance on referral to specialty care, as further described below. Flags were also created for triglyceride (TG) values $\geq$ 500 mg/dL and lipoprotein (a) values $\geq$ 50 mg/dL that recommended further evaluation for other lipid disorders. PCCs were made aware of this intervention through educational sessions conducted during departmental monthly service line conferences and via email listservs.

A second intervention was built and implemented in Fall 2023 in the form of a SmartSet that was recommended to PCCs for patients within this [Redacted] healthcare system with an LDL-C of $\geq$ 190 mg/dL (Supplementary Materials Appendix 1). The SmartSet was designed to integrate into the existing outpatient workflow utilized by PCCs during the creation of their assessment and plan within the EMR. One of the

primary aims of this build was to create an actionable, visible practice recommendation that would not rely on disruptive Best Practice Alerts (BPAs), which are commonly ignored, over-ridden, and contribute to alert fatigue [11,12]. Rather, our multi-component SmartSet provided a streamlined workflow that allowed PCCs to: 1. add appropriate visit diagnoses, including a diagnosis of FH, hyperlipidemia, or a family history of FH; 2. rule out key secondary causes of elevated cholesterol with additional laboratory testing such as urine microalbumin/creatinine ratio, TSH, and a comprehensive metabolic panel; 3. further evaluate for lipid disorders with laboratory testing with additional pre- and post-treatment lipid panels and lipoprotein (a) testing; 4. initiate optional medical therapy with high-intensity statins and/or other lipid-lowering agents, including ezetimibe and PCSK-9 inhibitors; and 5. refer to specialty care to lipid specialists within the division of cardiology for further evaluation and management.

2.2. Website and resources

A public-facing educational website was created under this [Redacted] healthcare system domain to provide patients and clinicians with comprehensive information regarding FH and its clinical significance. On the patient-centered page, information about the diagnosis, heritability, symptoms, and treatment of FH were detailed in layperson's terms. On the clinician-centered page, the underdiagnosis of FH was emphasized and followed by the clinical criteria for its diagnosis. Additionally, different pharmaceutical therapies and lifestyle modifications were described along with target post-treatment LDL-C levels. The website link was embedded within the flag tool in EPIC to facilitate access to educational materials.

A survey was also embedded into the website and queried various aspects of user experience and background, including the user's role (patient, physician, registered nurse, or physician assistant), the mode through which the website was found, and the effectiveness of the website as an educational tool. Google Analytics data was utilized to determine site statistics and form submissions during the study timeframe.

2.3. Educational session

The workflow was presented at a monthly departmental group meeting in January of 2024 to 77 [Redacted] PCCs. The session was led by a preventive cardiologist on the study team and lasted 30 min. Covered content included an educational session on FH case identification and assessment using recommended criteria and a demonstration of the EMR flag and SmartSet CDS tool.

2.4. Primary care clinician outreach

The corresponding PCCs of a small pilot subset of patients identified by the FIND FH® MLA were contacted to provide further information and resources on the diagnosis of FH, as well as inquire how PCCs would like to proceed in future management. The FIND FH® MLA is a random forest algorithm that has already been deployed at several medical centers to identify individuals without an FH diagnosis based on EMR data [13-15]. De-identified encounter data was extracted from this healthcare system's [Redacted] CDW (Clinical Data Warehouse) and analyzed by the MLA. Individuals selected by the algorithm as potential FH candidates were then manually chart-reviewed for baseline characteristics, medical history, laboratory values, medications, and family history. Patients were classified as eligible for "phenotypic FH diagnosis" if they had a recorded LDL-C $\geq$ 190 mg/dL (while on no lipid-lowering therapies) or $\geq$125 mg/dL (while currently treated with lipid-lowering therapies) with a family history of ASCVD or a lipid disorder.

PCCs for all patients meeting these criteria were contacted by a team member via an in-basket letter in the EMR. The letter followed a templated format explaining the FIND FH® algorithm, outlining [Redacted] healthcare system's initiative in improving timely diagnosis and early treatment of FH, and that the PCC's patient (specifically mentioned by name and MRN) had been identified as deserving further assessment for FH. All contacted PCCs were then given the option of either conducting their own workup for FH in the primary care setting or deferring to the care of a preventive cardiology lipid specialist within the division of cardiology. The letter requested that PCCs confirm their decision through a return in-basket message. Any medical decisions regarding further diagnostic or therapeutic measurements were left to the discretion of the contacted physician.

2.5. PCC survey

All PCCs were contacted to conduct a baseline survey before the intervention and after workflow implementation, demonstration, and outreach. The surveys aimed to evaluate baseline PCC knowledge and awareness of FH and to gain early insights into the intervention's effectiveness.

The authors conducted purposive sampling with the inclusion criteria that participants: 1. Be current staff physicians within [Redacted] Healthcare in Atlanta, Georgia, and 2. Practice within primary care departments, including internal medicine and family medicine. Physicians were contacted by the [Redacted] FIND FH research team through templated recruitment emails containing a brief description of the study, risks and benefits of participation, details on confidentiality and the voluntary nature of the study, and a web-based survey link administered through RedCap.

The baseline (pre-intervention) period was defined as the July 2022 to October 2022 timeframe during which surveys were disseminated. The survey consisted of twenty-six closed-ended items (see Supplementary Materials Appendix 2 and 3). PCCs were queried about their knowledge and confidence in reporting current FH screening practices, barriers to identification, demographics, diagnostic workup, and treatment. Immediately after the educational demonstration on the use of the CDS workflow, participants were sent a personalized Redcap link to the post-intervention survey, which was identical to the pre-survey.

Survey responses corresponding to questions targeting objective knowledge were scored to calculate a numerical percentage of correct responses for each respondent. Descriptive data, including demographic factors and frequency of responses, were also summarized.

The study was approved by the institutional review board at [Redacted] University. All survey respondents provided electronic informed consent at the time of enrollment.

3. Results

All descriptive statistics of PCC demographic data are shown in Table 1. 74 PCCs were initially invited to participate in the study. 70 consented to the baseline survey with a 79 % ($n = 55$) completion rate. After the clinician education session, integration of the EMR clinical decision tool, and launching of the [Redacted] FIND FH website, a post-intervention survey was distributed with a 42 % ($n = 23$) completion

Table 1
Demographics of surveyed primary care clinicians.

Variable	Pre-Survey ($n = 55$)	Post-Survey ($n = 23$)
Patients under care currently formally diagnosed with FH	2.855 ± 4.548	4.826 ± 10.834
Years in practice since finishing medical school	18.963 ± 17.296	19.912 ± 11.329
Type of practice area	n (%)	n (%)
Metropolitan GP	33 (60.0)	16 (69.6)
Outer metropolitan GP	19 (34.5)	4 (17.4)
Other	3 (5.5)	3 (13.0)
Awareness of lipid specialist services	29 (52.7)	16 (69.6)
Female gender	35 (63.6)	12 (52.2)

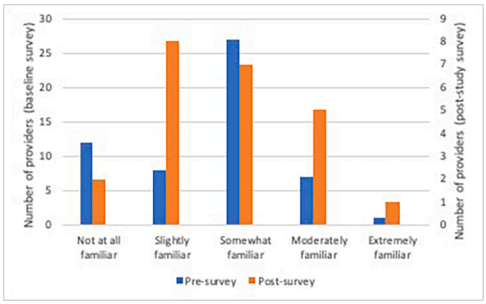


Fig. 1. Primary care clinician ratings of familiarity with guidelines on diagnosis and management of Familial Hypercholesterolemia.

Table 2
Cumulative scoring of objective FH knowledge from surveyed primary care clinicians.

Score (# correct of 9)	Pre-Survey Total, n (%)	Post-Survey Total, n (%)
11 % (1)	0 (0)	0 (0)
22 % (2)	1 (1.8)	1 (4.3)
33 % (3)	5 (9.1)	1 (4.3)
44 % (4)	13 (23.6)	3 (13.0)
56 % (5)	14 (25.5)	3 (13.0)
67 % (6)	7 (12.7)	5 (21.7)
78 % (7)	11 (20.0)	7 (30.4)
89 % (8)	3 (5.5)	1 (4.3)
100 % (9)	1 (1.8)	2 (8.7)

rate. In the initial baseline survey, PCCs reported a mean of 2.85 patients (SD=4.55) under their care currently diagnosed with FH, but only 40 % of all surveyed PCCs recommended routine screening of children and first-degree relatives. 53 % were aware of the existence of preventive cardiology and lipid specialist services at their institution. Although 87 % of PCCs identified themselves as having the greatest responsibility for early detection of FH, nearly half (47 %) had low-to-average scores on assessments of objective FH knowledge (Fig. 1). In the post-survey, the number of patients under PCC care currently diagnosed with FH had increased to 4.83 patients (SD=10.87), and 70 % reported awareness of preventive cardiology and lipid specialist services.

FH Clinician Knowledge Score. The results of survey questions assessing PCCs' objective FH knowledge are shown in Table 2, with discrete question responses listed in Supplementary Appendix 2 (correct responses bolded for comparison). Amongst pre-survey responses, 34.5 % ($n = 19$) scored lower than 50 % (<5 out of 9 questions correct). Only 7.3 % ($n = 4$) of responses achieved a pre-intervention score of at least 89 % (≥8 questions correct). In contrast, responders to the post-intervention survey had only 21.6 % ($n = 5$) score lower than 50 %. 43.4 % ($n = 10$) responded with at least 78 % question accuracy, correctly identifying 7 of 9 key competencies of FH management (Fig. 2).

Clinician Preference Questions. In addition to an objective score gauging clinician knowledge of FH epidemiology and treatment guidelines, subjective clinician preferences were also assessed for 1) best practices in the detection and evaluation of FH and premature CAD; 2) familiarity with referral management and local preventive cardiology lipid specialist availability; and 3) pharmaceutical management (see Supplementary Materials Appendix 3). The majority of PCCs surveyed agreed that PCCs are central to initiating FH screening in first-degree relatives, both in pre-survey data (87.3 %) and post-survey data (91.3 %). Evaluation of patients with premature CAD varied amongst clinicians with different strategies noted for symptom assessment. All clinicians surveyed noted preferring a statin for initial hypercholesterolemia treatment. Of note, before the intervention, nearly half of PCCs surveyed (47.3 %) reported lack of knowledge of specialist services for patients with lipid disorders.

FIND FH MLA and Outreach. 25 PCCs whose patients had been flagged by the FIND FH® MLA were contacted iteratively through an EMR in-basket message with a 56 % cumulative response rate. Of those who responded, 100 % chose to defer care to an outpatient preventive cardiology lipid specialist within the division of cardiology over pursuing workup in the primary care setting.

Website Results. All respondents of the website user survey were patients ($n = 6$). 33 % of respondents found the website link through the flag tool in EPIC. 83 % found the website helpful and expressed interest in attending a webinar about FH. During the study timeframe (10/24/22–2/7/24), the website received 1328 unique pageviews with approximately 30 % of visitors returning to the resource. Visitors were highly engaged with the website, with a 21.5 % bounce rate and an average of 133 s spent on a page. These results are indicative of above-average engagement, as the benchmark for site engagement is 52 s internet-wide and a good bounce rate is considered 40 % or lower.

4. Discussion

We surveyed PCCs at a large academic institution to explore current FH knowledge, preventive screening practices, and potential barriers to screening. This was then used to develop and implement an internal EMR CDS tool, deliver educational teaching and web-based resources about the tool and its role in FH diagnostics and management, and pilot a targeted MLA for the detection of FH in the EMR. Our findings demonstrate that while baseline FH knowledge was overall sub-optimal within this sample, both subjective and objective knowledge of FH improved after the educational intervention. These findings highlight the critical, yet currently underutilized, role of education and guidance for PCCs in the appropriate management of FH. PCCs also largely endorsed feeling that the responsibility of screening for and diagnosing FH fell within the realm of primary care, but all those who were contacted about a patient under their care with MLA-identified potential FH opted to defer further workup to an outside specialist. This discordance

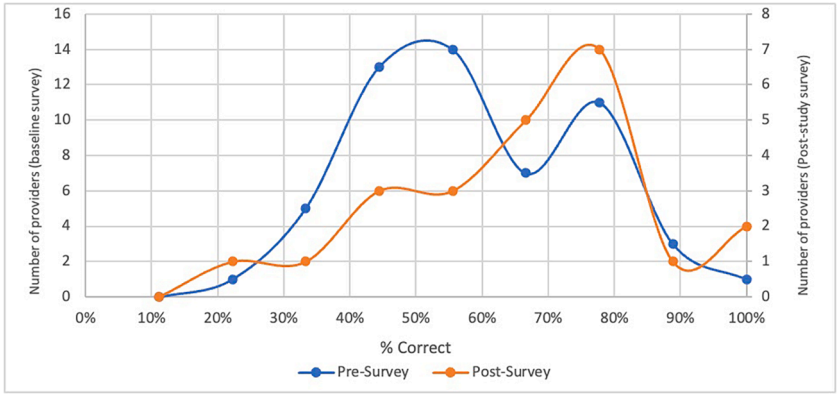


Fig. 2. Distribution of scores measuring objective FH knowledge from surveyed primary care clinicians.

in results foregrounds the possibility that PCCs may be overwhelmed to take appropriate steps even when provided education and guidance, likely due to time and workflow pressures limiting capacity to take ownership of further management.

While the PCCs surveyed at baseline had only 3 FH patients under their care on average, only 40 % of PCCs recommended routine cascade screening for children and relatives. This finding is further supported by the low-to-average scores on objective FH awareness measures, despite 87 % self-identifying PCCs as crucial for early detection. Results in the post-study survey demonstrated improvement across various measures of FH awareness, with the proportion of PCCs able to correctly identify diagnostic criteria increasing from 75.9 to 100 %. Those who believed PCSK9 inhibitors were the most important mode of therapy for FH increased from 27.3 to 43.5 %. However, nearly 60 % of PCCs continued to struggle with identifying core competencies of FH epidemiology, diagnosis, and management, receiving a score of less than 7/9 at follow-up.

The FIND FH® MLA demonstrated potential for identifying likely cases of FH in a pilot subset of patients. However, the 56 % PCC response rate to in-basket outreach messages suggests a need for further refinement of notification strategies. Notably, all responding PCCs elected to defer care to specialists despite earlier responses in the pre-survey suggesting otherwise, emphasizing a potential lack of actionable confidence or perceived capacity for managing FH within primary care. However, failure to adequately engage PCCs in the initial patient outreach effort may increase fragmentation and/or discontinuity of care. In fact, studies in populations with FH have shown that patients prefer direct communication from their PCCs to receive information about their diagnosis and that more active methods of direct communication by PCCs in comparison to passive letters result in a higher rate of new relatives with FH identified per proband [16,17]. Our study suggests that comprehensive support and educational opportunities for PCCs may aid in increasing awareness of FH, potentially leading to behavior activation in taking greater ownership over outpatient FH management.

While there are currently no randomized controlled trials studying systematic approaches to FH identification in primary care, several observational studies have attempted strategies ranging from direct patient outreach by specialists [18,19] to targeted chart reviews [20-22]. Less common still are studies evaluating the utility of clinical decision support (CDS) systems in facilitating these approaches, despite there being a general desire among PCCs for such user-friendly case--finding tools in FH management [23,24]. CDS systems draw specifically from existing diagnostic criteria to identify high-risk patients and prompt further assessment and can be further enhanced through the use of trained machine-learning algorithms. One Canadian study found that while EMR reminders to follow guideline recommendations on lipid management significantly increased the proportion of patients achieving optimal LDL-C levels, this increase was less exaggerated among those with diagnosed FH [25]. In 2019, the Mayo Clinic deployed an EMR best practice alert (BPA) and asynchronous in-basket alert as part of a wider implementation study [26]. Findings showed that although PCCs generally agree that they should be responsible alongside specialists for diagnosing FH [23,26], they are less confident in taking charge of subsequent treatment, which is consistent with our current findings.

Although PCCs tended to positively view the assistance of CDS tools in clarifying this role, there was a consensus that an increasing influx of EMR alerts was likely contributing to attention fatigue and information overload, thus limiting CDS utilization. These findings align with the wider literature suggesting that the demands of EMR-related tasks can reduce professional satisfaction, disrupt workflow, and increase burnout [27,28]. Proposed solutions have included creating a built-in option to refer potential FH patients to specialists, which may promote CDS adoption and reduce cognitive burden. However, these solutions fail to account for the critical role PCCs may play in educating patients, engaging close relatives in cascade screening, and providing overall improved continuity of care. Our study attempted to address these gaps by increasing foundational PCC awareness of FH management, providing EMR-incorporated CDS tools to guide management and training on their use, minimizing alert fatigue through avoidance of BPAs, and incorporating a direct-to-provider outreach component for MLA-identified patients.

Although our high patient volume provided ample opportunity for identifying potential cases, this magnitude was incommensurate with the significant current knowledge gap among PCCs regarding FH. This gap translates to missed diagnoses, insufficient patient referrals, and ultimately, a missed opportunity to prevent CVD within affected families. Previous studies have found that poor documentation of family history or physical exam findings in primary care encounters is one of the most cited barriers to conducting thorough risk assessments for FH. As such, despite broad advancements in digital CDS-guided management and MLA case identification, these tools are severely limited in efficacy if we fail to sufficiently educate PCCs on the pertinent symptoms and risk factors of FH patients. Our findings echo this need for improved educational tools and strategies to support FH management both in primary care and more specialized cardiology clinics, as well as the need for well-designed, targeted CDS interventions that can minimize clinician burden while providing clear and actionable guidance.

There were several relevant limitations to this study. First, measures of FH awareness and knowledge were self-reported and lacked further detailed information such as histories of prior FH diagnoses, referral rates to cardiologists or lipid specialists, or specific barriers to FH screening. Second, survey responses were limited, and any post-survey changes therefore might not entirely reflect intervention effects on PCC awareness of FH. As we were only reporting descriptive results without any paired tests of comparison, we refrained from excluding those participants who did not complete both the pre- and post-intervention surveys. As such, we recognize that this study is underpowered to detect any effects reliably, and that any outcomes should be interpreted as summary statistics. However, as suggested by the reported trends in responses favoring PCC ownership of FH and the unanimous preference for outpatient follow-up, we believe these surveys provide valuable insight into the competing motivations versus realistic capacity of PCCs to close the gap in FH knowledge and management. The limited response rate suggests the need for optimizing communication strategies to facilitate PCC involvement in FH screening beyond InBasket messages or email alerts. Moreover, this initial study did not include qualitative metrics, such as a focus group or interviews with PCCs and patients, to gauge perspective and supplement findings.

In terms of the criteria that patients must exceed LDL-C levels of 190 mg/dL for triggering the flag-and-referral build within the EMR, we recognize that this is a relatively non-specific cut-off and does not incorporate consideration of other physical exam findings or family history. However, we believe these criteria are nevertheless justified as the purpose of these automated approaches was not to make a formal FH diagnosis, but to screen large populations of individuals with risk factors meriting further clinical workup for FH. With regards to online visibility, the high website user engagement suggests the patient education website was a valuable resource. However, while the tracked unique pageviews were high, the limited sample size of survey respondents requires further investigation into patient reach and impact. Finally, although the metropolitan Atlanta area provides a diverse set of PCCs for scope of study, our survey was conducted within a single academic medical system, potentially limiting generalizability.

Future Directions & Conclusions. Future research should explore the effectiveness of our proposed implementation framework in a broader healthcare setting and in the context of long-term patient outcomes. As this study focused on clinician awareness and perceived barriers, longitudinal studies are needed to evaluate the impact on both clinician behavior and patient health metrics such as LDL-C levels and CVD events. Additionally, future studies could investigate the optimal design of CDS alerts and EMR SmartTools for FH management, focusing on minimizing alert fatigue while ensuring optimal delivery of critical

information and management needs.

Ultimately, this study underscores the crucial role PCCs can play in improving FH identification and management. By developing and implementing strategies that address clinician knowledge gaps, information overload, and workflow disruptions, we can empower primary care to be the cornerstone of early FH detection and intervention.

CRediT authorship contribution statement

Kain Kim: Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Samir C. Faruque:** Writing – review & editing, Data curation, Conceptualization. **David Kulp:** Writing – review & editing, Formal analysis, Data curation. **Shivani Lam:** Writing – review & editing, Formal analysis, Data curation. **Laurence S. Sperling:** Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Danny J. Eapen:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Danny J Eapen reports financial support was provided by Emory Department of Medicine FAME (Fostering the Academic Mission in the Emory DOM) grant. Danny J Eapen reports financial support was provided by the Abraham J. and Phyllis Katz Foundation. Danny J Eapen reports financial support was provided by Family Heart Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

Supported by Emory Department of Medicine FAME (Fostering the Academic Mission in the Emory DOM) grant, the Abraham J. and Phyllis Katz Foundation, and the Family Heart Foundation.

Acknowledgements

This study was supported by The Family Heart Foundation that developed the FIND FH® machine learning algorithm. We would like to thank Chad Robichaux, Nita Deshpande, and Michael Proctor with the Emory Data Analytics Team, as well as Denise Davis with Emory's Marketing Technology and Operations Team, for their assistance in assembling the information used in this study.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ajpc.2024.100710.

References

[1] Nordestgaard BG, Chapman MJ, Humphries SE, Ginsberg HN, Masana L, Descamps OS, et al. Familial hypercholesterolaemia is underdiagnosed and undertreated in the general population: guidance for clinicians to prevent coronary heart disease: consensus statement of the European Atherosclerosis Society. Eur Heart J 2013;34(45):3478–90.

[2] Hopkins PN, Toth PP, Ballantyne CM, Rader DJ. Familial hypercholesterolemias: prevalence, genetics, diagnosis and screening recommendations from the National Lipid Association expert panel on familial hypercholesterolemia. J Clin Lipidol 2011;5(3 Suppl):S9–17.

[3] Ahmad ZS, Andersen RL, Andersen LH, O'Brien EC, Kindt I, Shrader P, et al. US physician practices for diagnosing familial hypercholesterolemia: data from the CASCADE-FH registry. J Clin Lipidol 2016;10(5):1223–9.

[4] Hemphill L, Goldberg A, Hovingh K, Cohen J, Karalis DG. Recognition and treatment of homozygous familial hypercholesterolemia by primary care physicians: a survey from the National Lipid Association. J Gen Intern Med 2020;35(7):2225–7.

[5] Block RC, Bang M, Peterson A, Wong ND, Karalis DG. Awareness, diagnosis and treatment of heterozygous familial hypercholesterolemia (HeFH) – Results of a US national survey. J Clin Lipidol 2021;15(5):682–9.

[6] Wong ND, Bang M, Block RC, Peterson ALH, Karalis DG. Perceptions and barriers on the use of proprotein subtilisin/kexin type 9 inhibitors in heterozygous familial hypercholesterolemia (from a survey of primary care physicians and cardiologists). Am J Cardiol 2021;152:57–62.

[7] Foody JM. Familial hypercholesterolemia: an under-recognized but significant concern in cardiology practice. Clin Cardiol 2014;37(2):119–25.

[8] Abdul-Hamid H, Kai J, Safura RA. Primary care physicians' perspectives on identifying familial hypercholesterolaemia in primary care: a qualitative study. Ann Family Med 2023;21(s1):1544–709. Print.

[9] Kwok S, Pang J, Adam S, Watts GF, Soran H. An online questionnaire survey of UK general practitioners' knowledge and management of familial hypercholesterolaemia. BMJ Open 2016;6(11):e012691.

[10] Gonzalez Santos LE, Underberg J. Electronic chart review of a multispecialty internal medicine practice evaluating appropriate identification of patients with familial hyperlipidemia*. J Clin Lipidol 2011;5(3):229.

[11] Ancker JS, Edwards A, Nosal S, Hauser D, Mauer E, Kaushal R. Effects of workload, work complexity, and repeated alerts on alert fatigue in a clinical decision support system. BMC Med Inform Decis Mak 2017;17(1):36.

[12] van der Sijs H, Aarts J, Vulto A, Berg M. Overriding of drug safety alerts in computerized physician order entry. J Am Med Inform Assoc 2006;13(2):138–47.

[13] Myers KD, Knowles JW, Staszak D, Shapiro MD, Howard W, Yadava M, et al. Precision screening for familial hypercholesterolaemia: a machine learning study applied to electronic health encounter data. Lancet Digit Health 2019;1(8):e393–402.

[14] Banda JM, Sarraju A, Abbasi F, Parizo J, Pariani M, Ison H, et al. Finding missed cases of familial hypercholesterolemia in health systems using machine learning. NPJ Digit Med 2019;2:23.

[15] Hesse R, Raal FJ, Blom DJ, George JA. Familial hypercholesterolemia identification by machine learning using lipid profile data performs as well as clinical diagnostic criteria. Circ Genom Precis Med 2022;15(5):e003324.

[16] Jones LK, Walters N, Brangan A, Ahmed CD, Wilemon KA, Campbell-Salome G, et al. Patient experiences align with the familial hypercholesterolemia global call to action. Am J Prev Cardiol 2022;10:100344.

[17] Campbell-Salome G, Jones LK, Walters NL, Morgan KM, Brangan A, Ladd IG, et al. Optimizing communication strategies and designing a comprehensive program to facilitate cascade testing for familial hypercholesterolemia. BMC Health Serv Res 2023;23(1):340.

[18] Bell DA, Hooper AJ, Edwards G, Southwell L, Pang J, van Bockxmeer FM, et al. Detecting familial hypercholesterolaemia in the community: impact of a telephone call from a chemical pathologist to the requesting general practitioner. Atherosclerosis 2014;234(2):469–72.

[19] Bender R, Edwards G, McMahon J, Hooper AJ, Watts GF, Burnett JR, et al. Interpretative comments specifically suggesting specialist referral increase the detection of familial hypercholesterolaemia. Pathology 2016;48(5):463–6.

[20] Gray J, Jaiyeola A, Whiting M, Modell M, Wierzbicki AS. Identifying patients with familial hypercholesterolaemia in primary care: an informatics-based approach in one primary care centre. Heart 2008;94(6):754–8.

[21] Kirke AB, Barbour RA, Burrows S, Bell DA, Vickery AW, Emery J, et al. Systematic detection of familial hypercholesterolaemia in primary health care: a community based prospective study of three methods. Heart Lung Circ 2015;24(3):250–6.

[22] Troeung L, Arnold-Reed D, Chan She Ping-Delfos W, Watts GF, Pang J, Lugonja M, et al. A new electronic screening tool for identifying risk of familial hypercholesterolaemia in general practice. Heart 2016;102(11):855–61.

[23] Zimmerman J, Duprez D, Veach PM, Zierhut HA. Barriers to the identification of familial hypercholesterolemia among primary care providers. J Community Genet 2019;10(2):229–36.

[24] Fath F, Bengeser A, Barresi M, Binner P, Schwab S, Ray KK, et al. FH ALERT: efficacy of a novel approach to identify patients with familial hypercholesterolemia. Sci Rep 2021;11(1):20421.

[25] Langer A, Mancini GBJ, Tan M, Goodman SG, Ahooja V, Grégoire J, et al. Treatment inertia in patients with familial hypercholesterolemia. J Am Heart Assoc 2021;10(14):e020126.

[26] Bangash H, Pencille L, Gundelach JH, Makkawy A, Sutton J, Makkawy L, et al. An implementation science framework to develop a clinical decision support tool for familial hypercholesterolemia. J Pers Med 2020;10(3).

[27] Arndt BG, Beasley JW, Watkinson MD, Temte JL, Tuan WJ, Sinsky CA, et al. Tethered to the EHR: primary care physician workload assessment using EHR event log data and time-motion observations. Ann Fam Med 2017;15(5):419–26.

[28] Sinsky C, Colligan L, Li L, Prgomet M, Reynolds S, Goeders L, et al. Allocation of physician time in ambulatory practice: a time and motion study in 4 specialties. Ann Intern Med 2016;165(11):753–60.