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Facilitating family communication of familial hypercholesterolemia genetic risk: Assessing engagement with innovative chatbot technology from the IMPACT-FH study

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ABSTRACT

Objective: To assess use of two web-based conversational agents, the Family Sharing Chatbot (FSC) and One Month Chatbot (OMC), by individuals with familial hypercholesterolemia (FH).
Methods: FSC and OMC were sent using an opt-out methodology to a cohort of individuals receiving a FH genetic result. Data from 7/1/2021 through 5/12/2022 was obtained from the electronic health record and the chatbots' HIPAA-secure web portal.
Results: Of 175 subjects, 21 (12%) opted out of the chatbots. Older individuals were more likely to opt out. Most (91/154, 59%) preferred receiving chatbots via the patient EHR portal. Seventy-five individuals (49%) clicked the FSC link, 62 (40%) interacted, and 36 (23%) shared a chatbot about their FH result with at least one relative. Ninety-two of the subjects received OMC, 22 (23%) clicked the link and 20 (21%) interacted. Individuals who shared were majority female and younger on average than the overall cohort. Reminders tended to increase engagement.
Conclusion: Results demonstrate characteristics relevant to chatbot engagement. Individuals may be more inclined to receive chatbots if integrated within the patient EHR portal. Frequent reminders can potentially improve chatbot utilization.
Innovation: FSC and OMC employ innovative digital health technology that can facilitate family communication about hereditary conditions.

1. Introduction

Familial hypercholesterolemia (FH), a common hereditary condition characterized by lifelong elevation of low-density lipoprotein cholesterol (LDL-C), is associated with a significantly increased risk for premature cardiovascular disease [1]. When left untreated, males with FH have a 50% risk of a coronary event by 50 years of age, and females have a 30% risk by 60 years of age [2,3]. Early identification and subsequent initiation of aggressive lipid-lowering therapy are critical to improving health outcomes and reducing mortality in individuals with FH. Despite its prevalence of approximately 1:220 individuals worldwide, FH is vastly underdiagnosed and undertreated [4-6]. Recent estimates report that only 30% of cases have been identified [7]. Without diagnosis, individuals with FH may not receive the necessary medical

Abbreviations: FH, Familial hypercholesterolemia; LDL-C, Low-density lipoprotein cholesterol; FDR, First-degree relative; IMPACT-FH, Identification Methods, Patient Activation, and Cascade Testing for FH Study; FSC, Family Sharing Chatbot; Gia®, Genetic Information Assistant; CC, Cascade Chatbot; OMC, One Month Chatbot; EHR, Electronic Health Record.

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recommendations to reduce their risks of heart disease, heart attack, and stroke [4].

As FH is an autosomal dominant condition, any parent, full sibling, or child (first-degree relative, FDR) of an individual with FH has a 50% chance of also having inherited the familial variant in the *APOB*, *LDLR*, or *PCSK9* gene. A highly effective way to identify additional cases of FH is through cascade testing, a systematic approach that prioritizes screening the FDRs of the first person in a family found to have the hereditary condition of concern (proband). Subsequent testing then proceeds for the proband's more distant relatives depending on who remains at risk [5,8]. The Centers for Disease Control and Prevention designated FH as a Tier 1 Genomics Application given the potential for cascade testing to have a significant, positive impact on public health [9].

One major barrier to cascade testing is that the duty to notify at-risk relatives often falls solely on the proband, who is simultaneously trying to manage their own care related to their FH diagnosis [10]. Probands with FH have described barriers limiting their communication with relatives about the condition, such as the complexity of this type of genetic risk information and perceived insufficient authority to motivate at-risk relatives to pursue cascade testing. Furthermore, probands have expressed frustration with at-risk relatives who do not pursue screening or follow-up care, which may lead to a lack of motivation to continue broaching the subject with those relatives or notify others [11,12]. The most common strategy to support family communication and cascade testing is a standardized family letter given to the proband by a healthcare professional or advocacy organization. While probands find family letters acceptable and appropriate for this purpose, they may feel emotionally or logistically burdened by the task of sending them, particularly to more distant relatives or those with whom their relationship might not be strong [13,14]. Thus, additional strategies are needed to better facilitate family communication and cascade testing for FH.

Digital tools have been developed to fill the need for additional family communication strategies. Notable examples include secure websites that allow probands to share confidential documents [15] or personalized electronic health records [16] with, or send email templates and educational resources [17] to, at-risk relatives. Chatbots, internet-based conversational agents with which users can engage in a simulated conversation with human-like software by selecting pre-made dialogue and/or entering free-text responses, have also been developed for use in various genomic contexts. Several use cases have been described in the literature, including for hereditary cancer [18-20] and communication of secondary genomic findings [21]. Probands have qualitatively shown support for chatbot technology as an alternative or supplemental strategy to facilitate the sharing of genetic results and risk information with relatives [22]. Indeed, the technology shows promise for many aspects of genomic health, from pre-test consenting to proband education and family sharing [23,24].

Chatbots may address several of the barriers to family communication described above by: (1) providing trustworthy medical information at the user's pace, (2) overcoming geographical distance by utilizing the internet, and (3) acting as a neutral third party to relay the information in cases of strained or distant relationships. However, while certainly promising, chatbots are not without limitations and disadvantages. Each chatbot requires a significant level of manual work, such as building content and workflow in collaboration with healthcare professionals and the target populations, conducting user testing, and integrating and maintaining in practice [18,22]. Additionally, while it is estimated that 85.3% of households in the United States have access to the Internet [25], there will always be the need for other, non-technologically based family sharing strategies that may also be less labor-intensive to construct. Thus, it is essential to investigate real-world utilization of chatbots to assess their potential reach and impact.

Chatbots have been deployed to facilitate proband follow-up and family sharing within the Geisinger MyCode® Community Health Initiative (MyCode), a large research biobank and precision medicine study that returns actionable genetic results from population genomic screening to patient-participants [26-29]. Evaluation of the initial MyCode chatbot use cases found that probands were willing and able to use the technology to facilitate family sharing, which led to increased uptake of cascade testing among at-risk relatives [30]. These chatbots were later optimized as part of the IMPACT-FH (Identification Methods, Patient Activation, and Cascade Testing for FH) study, which aimed to design and test new and innovative family communication strategies for FH [31]. Interviewing individuals with FH and their family members informed content and functionality enhancements, leading to the development of the Family Sharing Chatbot (FSC) and One Month Chatbot (OMC) [32,33].

The FSC is an interactive chat that probands receive soon after receiving their FH result from MyCode. Within the FSC, probands can exchange messages with the human-like virtual Genetic Information Assistant (Gia®). Gia starts by introducing herself and explains that the chat was created by experts in genetics before explaining the importance of family sharing and giving probands the option to send their at-risk relatives a link to a separate Cascade Chatbot (CC) via email, text message, Facebook messenger, or copied link (Fig. 1). If the proband responds that they are unsure about sharing, Gia tailors her approach by providing additional support and encouragement. The CC relays information directly to the at-risk relative about the proband's result and facilitates cascade testing.

Probands who have not completed a genetic counseling visit within one month of receiving their FH result are sent a link to the OMC in addition to the initial FSC. The purpose of the OMC is to follow-up with less engaged probands to remind them to discuss their result with a clinician, provide the option to schedule a genetic counseling visit, and nudge them to use the FSC to share with at-risk relatives (Fig. **2**).

IMPACT-FH launched a prospective, pragmatic trial to test the optimized chatbots in a real-world setting as one of three new family communication strategies. In the present study, we evaluate the uptake and utilization of the FSC and OMC by FH probands to assess the following research questions (RQ):

RQ1. What demographic factors may impact an FH proband's decision to opt out of receiving chatbots?

RQ2. To what extent did FH probands utilize the FSC?

RQ3. To what extent did FH probands utilize the OMC?

2. Methods

Probands are patient-participants who received an FH result from MyCode from 7/1/2021 through 3/31/2022 and were included in the IMPACT-FH trial. The trial was reviewed and approved by the Geisinger Institutional Review Board (FWA #00000063 IRB #00008345), Study #2020-0579.

During return of their FH result, probands were verbally introduced to three family communication strategies: direct contact of at-risk relatives by a genetic counselor, a packet of information to share with at-risk relatives and their healthcare professional, and the optimized chatbots. At this time, probands were asked their preferred method of digital communication for receiving chatbots (patient electronic health record (EHR) portal, email, or text message). All probands received the packet and a flyer about the direct contact program but could opt out of receiving the chatbots. Fig. 3 presents the overall workflow.

For all probands who did not opt out of receiving the chatbots, the initial FSC invite was sent upon the proband's receipt of their FH result from MyCode®; reminders were sent after two weeks and two months regardless of whether the proband started the FSC prior. Out of 175 probands included in the trial, 154 were sent the FSC. Probands were encouraged to share with relatives during subsequent touchpoints with the study team. The additional touchpoints included: (1) an optional genetic counseling visit, and (2) a 1-month follow-up call to each proband, regardless of whether a genetic counseling visit was completed, with the purpose of discussing their family sharing preferences for each at-risk relative (direct contact, packet, and/or chatbot). A total of three messages (1 initial invite plus 2 reminders) containing a hyperlink and a prompt to engage with the chatbot were sent

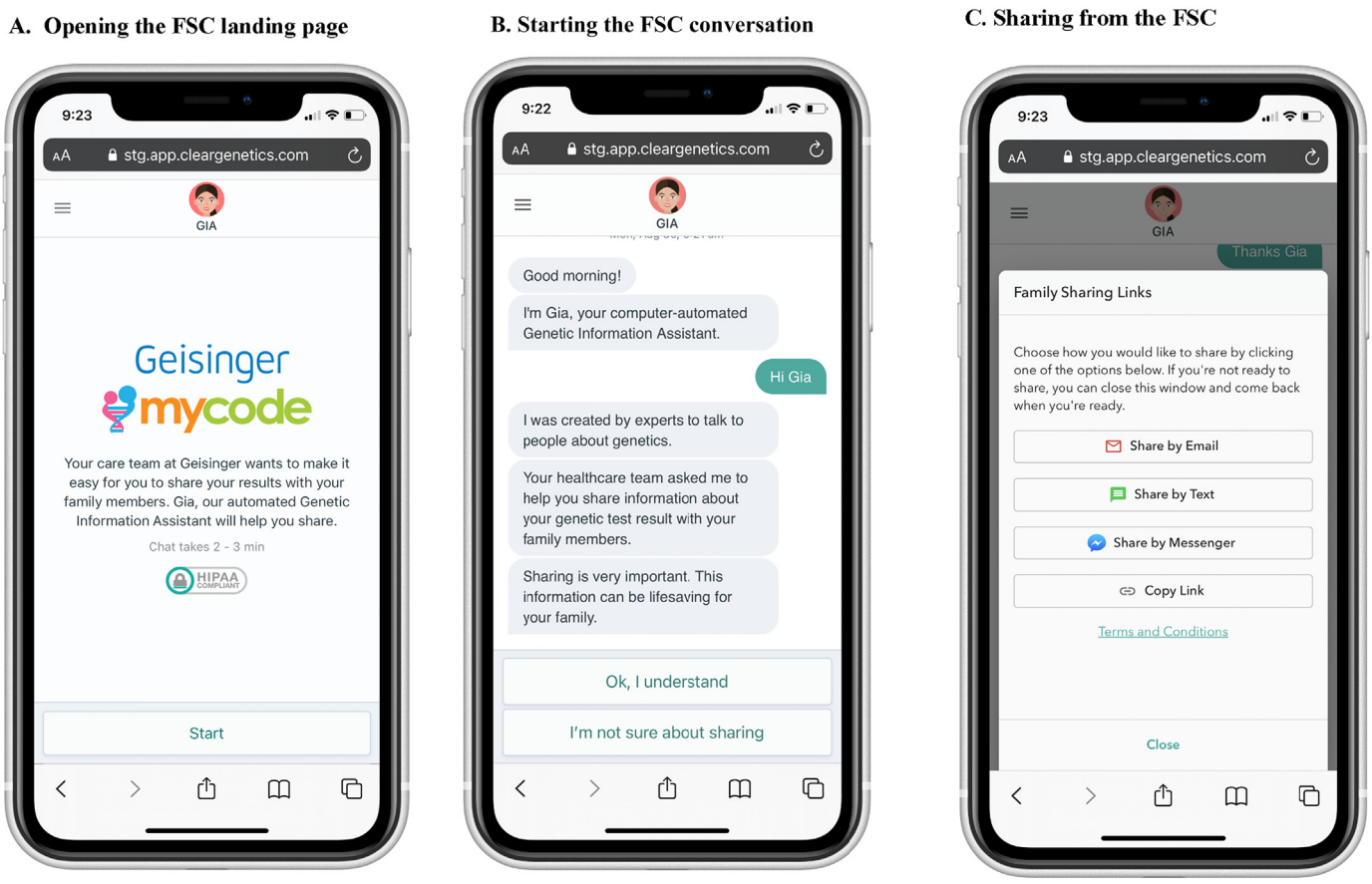

Fig. 1. Family Sharing Chatbot (FSC). A. Opening the FSC landing page CAPTION: This figure displays the first page that probands see immediately after clicking on their link to open the FSC. This page provides introductory material prior to starting the chatbot conversation. B. Starting the FSC conversation CAPTION: This figure displays the chatbot conversation that probands can engage with in the FSC. The response options at the bottom of the screen are pre-populated for probands to select. C. Sharing from the FSC CAPTION: This figure displays the sharing module at the end of the FSC that probands can utilize to send a CC link to at-risk relatives. The sharing options include email, text message, Facebook messenger, or copied link.

to the proband via their chosen digital communication preference (e.g., patient EHR portal, email, text message).

Probands who received the FSC and did not complete a genetic counseling visit within a month after receiving their FH result were also sent the OMC. The initial invite for the OMC was sent to 92 probands at the 1-month time point, followed by two reminders over the next five days unless they completed the OMC.

This analysis was conducted after all included probands had their FH result for at least 1 month and 5 days. Data on chatbot use from 7/1/2021 through 5/12/2022 was obtained from the EHR and the chatbot's HIPAA-secure web portal. Statistical analyses were conducted using SPSS version 26. To address RQ1, we performed a chi-square test to test for associations between proband sex and whether they opted out of receiving any chatbots. Further, we conducted two separate binomial logistic regressions to examine the effects of age (independent variable) and the number of FDRs (independent variable) on whether probands opted out of receiving chatbots (dependent variable). For RQs 2-3, we report descriptive statistics and frequencies on the level of utilization of the chatbots from the pragmatic trial.

3. Results

3.1. Decision to opt out

RQ1: The demographic characteristics of all 175 probands included in the pragmatic trial are presented in Table 1. On average, each proband had 4.53 living FDRs. In total, 21 (12%) probands opted out of receiving chatbots.

A chi-square test was performed to examine the relation between sex and whether a proband opted out of receiving any chatbots. The relation between these variables was not significant (χ^2 (1, N = 175) = 0.60, p = 0.438). A logistic regression was performed to examine the effects of age on the likelihood that probands would opt out of receiving any chatbots, which was statistically significant (χ^2 (7, 154) = 10.35, p < 0.001). Older probands were more likely to opt out than younger probands [Exp(B) = 0.942, (0.909, 0.977)]. A second logistic regression was run to examine the effects of the number of FDRs on the likelihood that probands would opt out of receiving any chatbots, which was not significant (p = 0.926).

3.2. Family Sharing Chatbot (FSC)

The demographic characteristics of the 154 probands who received the FSC are presented in Table 1. Those who shared a CC link from the FSC were younger than the overall sample (M = 52 years), married (n = 23, 64%), female (n = 24, 67%), and reported an average of 4.94 FDRs each. Fig. 4 presents the FSC utilization level by digital communication preference.

RQ2: Digital communication preferences varied among the probands who received the FSC (n = 154), with the majority (n = 91, 59%) choosing to receive chatbots via the patient EHR portal, followed by email (n = 40, 26%), text message (n = 21, 14%) and multiple methods (n = 2, 1.3%). For those who received the FSC via the patient EHR portal, probands who read all three invites showed the highest levels of utilization of the FSC,

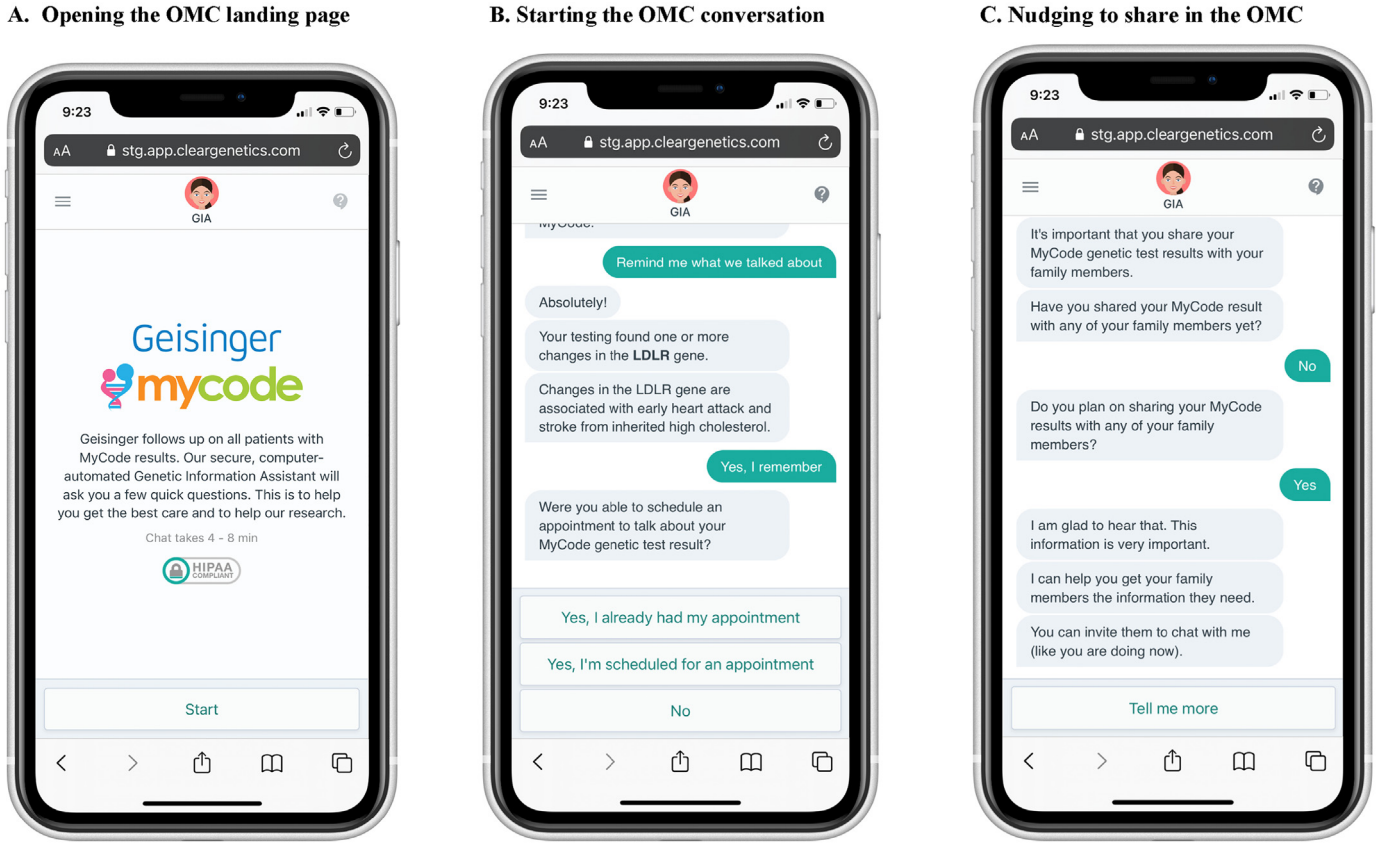

Fig. 2. One Month Chatbot (OMC). A. Opening the OMC landing page CAPTION: This figure displays the first page that probands see immediately after clicking on their link to open the OMC. This page provides introductory material prior to starting the chatbot conversation. B. Starting the OMC conversation CAPTION: This figure displays the chatbot conversation that probands can engage with in the OMC. The response options at the bottom of the screen are pre-populated for probands to select. C. Nudging to share in the OMC CAPTION: This figure displays the messaging at the end of the OMC that encourages probands to send a CC link to at-risk relatives.

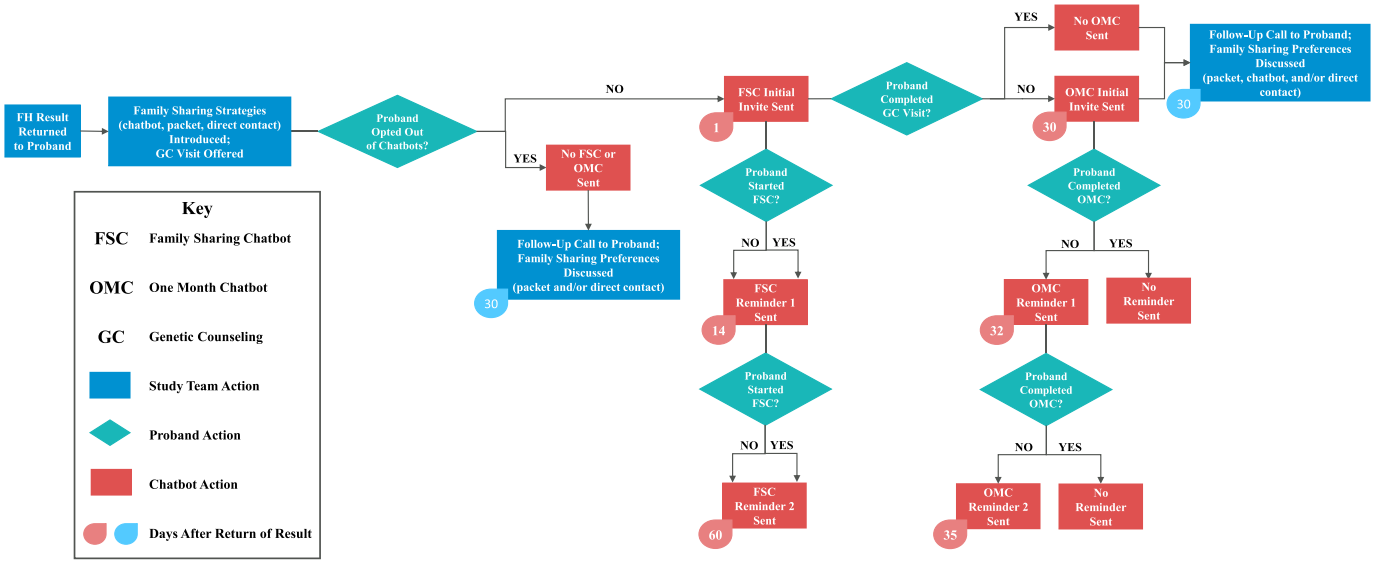

Fig. 3. Workflow diagram. CAPTION: This figure displays chatbot workflow for the IMPACT-FH study. All probands were offered a genetic counseling visit and verbally introduced to the family sharing strategies, including the chatbots, during return of their FH result. Probands who did not opt out of receiving chatbots were sent an initial FSC invite and two reminders, regardless of whether or not they started the FSC. Probands who did not opt out of receiving chatbots and did not complete a genetic counseling visit received an initial OMC invite and up to two reminders. Separately, the study team attempted to follow up with each proband one month after return of their FH result for the purpose of discussing their family sharing preferences.

Table 1
Proband Demographics for Family Sharing Chatbot (FSC).

	Overall (n = 175)	Received FSC (n = 154)	Opted Out (n = 21)
Age at Result Receipt, years			
Mean	57	55	69
Minimum	21	21	21
Maximum	88	88	85
Biological Sex			
Female	103	89	14
Male	72	65	7
Race			
White or Caucasian	170	149	21
Black or African American	2	2	0
Asian	1	1	0
Other	1	1	0
Declined to Provide	1	1	0
Hispanic or Latino Origin			
Yes	1	1	0
No	171	150	21
Declined to Provide	3	3	0
Marital Status			
Single	37	33	4
Married	111	97	14
Separated or Divorced	22	20	2
Significant Other	1	1	0
Widowed	4	3	1
FH Gene			
LDLR	112	97	15
APOB	63	57	6
PCSK9	0	0	0
Patient EHR Portal Access			
Yes	146	136	10
No	29	18	11

EHR: Electronic Health Record.
FSC: Family Sharing Chatbot.

Table 2
Proband demographics for One Month Chatbot (OMC).

	Received OMC (n = 92)	No OMC (n = 62)
Age at Result Receipt, years		
Mean	57	53
Minimum	21	21
Maximum	88	86
Biological Sex		
Female	52	37
Male	40	25
Race		
White or Caucasian	88	61
Black or African American	2	0
Asian	0	1
Other	1	0
Declined to Provide	1	0
Hispanic or Latino Origin		
Yes	1	0
No	88	62
Declined to Provide	3	0
Marital Status		
Single	19	14
Married	57	40
Separated or Divorced	13	7
Significant Other	0	7
Widowed	3	0
FH Gene		
LDLR	35	40
APOB	57	22
PCSK9	0	0
Patient EHR Portal Access		
Yes	80	56
No	12	6

EHR: Electronic Health Record
OMC: One Month Chatbot

with 23 (56%) starting the chat and 14 (34%) sharing a CC link, compared to 17 (34%) and 7 (14%) who read fewer invites, respectively.

Of those who received the FSC, 75 (49%) clicked on the link to open the chat (Fig. 1A), 62 (40%) started the chat (i.e., began to interact with the chatbot by proceeding past the landing page) (Fig. 1B), and 36 (23%) shared a CC link with at least one relative (Fig. 1C).

3.3. One Month Chatbot (OMC)

The demographic characteristics of the 92 probands who received the OMC are presented in **Table 2**. On average, each proband reported having 4.58 living FDRs. The subset of probands who started the OMC was about the same age (M = 56.3 years) as the overall population that received it.

RQ3: Based on the 92 probands' previously documented digital communication preferences, most (n = 54, 59%) OMC were sent via the patient EHR portal, followed by email (n = 27, 29%), and text message (n = 11, 12%). Of those who received the OMC, 26 (28%) clicked on the link to open the chat (Fig. 2A) and 20 (22%) started the chat (i.e., began to interact with the chatbot by proceeding past the landing page) (Fig. 2B). As a result of interacting with the OMC, 2 (2.2%) probands requested to schedule and subsequently completed a genetic counseling visit.

Table 3 presents the OMC utilization level by digital communication preference. For those who received the OMC via the patient EHR portal, probands who read all three invites showed the highest levels of engagement with the FSC, with eight (8.3%) starting the chat compared to one (1.0%) who read fewer invites.

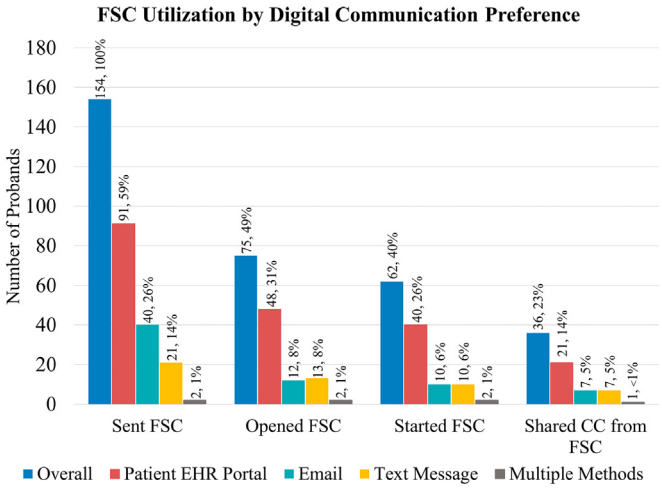

Fig. 4. Frequencies of Family Sharing Chatbot (FSC) Utilization by Digital Communication Preference EHR: Electronic Health Record FSC: Family Sharing Chatbot CC: Cascade Chatbot.

Table 3
Frequencies of One Month Chatbot (OMC) Utilization by Digital Communication Preference.

	Overall (n = 92)	Patient EHR Portal (n = 54)	Email (n = 27)	Text Message (n = 11)	Multiple (n = 0)
Sent OMC	92 (100%)	54 (100%)	27 (100%)	11 (100%)	0 (0%)
Opened OMC	26 (28%)	15 (28%)	6 (22%)	5 (45%)	0 (0%)
Started OMC	20 (22%)	9 (17%)	6 (22%)	5 (45%)	0 (0%)
Shared CC from OMC	2 (2.1%)	1 (1.9%)	1 (3.7%)	0 (0%)	0 (0%)

EHR: Electronic Health Record.
OMC: One Month Chatbot.
CC: Cascade Chatbot.

4. Discussion and conclusion

4.1. Discussion

The purpose of this study was to assess the uptake and utilization of the FSC and OMC by FH probands to identify key factors that may impact their engagement and utilization of the chatbots to share the CC with at-risk relatives. These findings highlight important considerations for improving the current chatbot use cases as well as broader implementation of the digital health technology.

With regard to RQ1, age was found to be a significant predictor of probands opting-out of the chatbot technology in this cohort of FH probands. Similarly, prior evaluation of the chatbots within the broader MyCode population found that older probands were more likely to decline to consent to receive the chatbots [30]. Based on frequency data, probands who shared via the FSC were also younger than the overall sample, which further supports that age may be a key limitation to chatbot utilization for family sharing. While messaging was added in an attempt to dissuade probands from assuming this, those messages were sent within the FSC, which meant probands had to not opt out of receiving the chatbots, open the FSC and interact with it enough to reach that section of the chat. Thus, this type of messaging may be needed when the chatbot is first offered to probands and in follow-up messages to overcome ageist assumptions that younger individuals are more comfortable with using technology and therefore more likely to engage with the chatbots. Further, other strategies, such as family letters, should be offered as an alternative or supplement to the chatbots to facilitate family sharing.

Overall uptake of the OMC was less than the FSC. Since the OMC is sent only to probands who have not chosen to complete a genetic counseling visit, they may be less engaged and motivated by their FH result and therefore less likely to interact with the chatbot in general.

With regard to RQ2 and RQ3, the highest levels of utilization for both the FSC and OMC were seen in probands who read more of the reminders sent via the patient EHR portal and those who completed more touchpoints with the study team. These results may suggest that chatbots can be most successful when they are integrated in a workflow with multiple touchpoints, including nudges to prompt follow-up. Nudges, especially those using innovative digital tools, can work alongside healthcare professionals to improve patient engagement and health outcomes by providing reminders, more information, and resources [34-37]. While the FSC and OMC have demonstrated the potential for chatbot technology to assist with care coordination by prompting FH probands to share their result with at-risk relatives and schedule a follow-up visit for their own care, respectively, this workflow with additional touchpoints incurs additional staffing and cost that may not be possible in standard practice outside of a research context. The timing and content of these reminders and touchpoints likely also has an impact, as probands may feel too overwhelmed at first by the implications of the FH result for their own health to consider sharing with at-risk relatives immediately. Thus, additional investigation is needed to determine the optimal cadence of and messaging within these touchpoints and reminders outside of a research context.

Despite the multiple touchpoints and reminders, the majority of probands neither utilized the FSC to share a CC link with relatives nor completed the OMC. This may be due, in part, to the overall goal of the IMPACT-FH study setting, which gave probands choice in using a family sharing strategy or combination of strategies for each of their relatives. During additional touchpoints, it was emphasized that probands should choose strategies based on what they are most comfortable with and would work best for each of their relatives, understanding that their choices would not always include the chatbot. While MyCode participants have expressed interest in and willingness to use chatbots [22,30], FH probands may have preferred the other strategies that were provided in IMPACT-FH. Uptake and engagement may have been impacted by the probands' comfort and skill levels with technology and ability to access to the Internet, or concern that their at-risk relatives could not or would not prefer to receive this information via a chatbot.

Finally, there was a strong preference for receiving the chatbots via the patient EHR portal, but utilization was proportionally higher for those who received the chatbots via text message. This suggests that probands may be more inclined to consent to chatbot technology when it can be received via a mechanism that they are familiar with using for their healthcare and may also enhance their credibility as they appear that they are coming directly from a known entity. However, probands must take additional steps to log-in to the patient EHR portal and navigate to the message containing the chatbot link, which is likely a less familiar process than receiving a text message and may create a higher barrier to entry. Nonetheless, healthcare systems must acknowledge the preference to receive this technology via the patient EHR portal and work to integrate and support it, which requires continued oversight and monitoring should any issues arise. This underlines the need for institutional support and funding for this technology and its integration.

4.2. Innovation

Chatbots are an innovative strategy for assisting probands in understanding their genetic result and sharing important health information with at-risk relatives. Additionally, chatbots can provide standardized medical information to probands and at-risk relatives, which can not only motivate family sharing but also facilitate follow-up with less engaged probands. The standardized medical information designed by clinicians and researchers can reduce the burden on probands attempting to share this information by reducing the amount they need to correctly recall and share with their relatives.

It has been reported in the literature that probands struggle to effectively communicate complex genetic risk information with at-risk relatives to prompt cascade testing [38]. A common point of confusion and reason for which at-risk relatives forgo taking action is because they misunderstand the difference between FH and secondary causes of hypercholesterolemia [38,39]. The innovative, patient-centered approach taken to optimize the FSC and OMC may help overcome literacy barriers and ambivalence around FH. Interviews and surveys were conducted with FH probands and their families who gave their feedback for improving the chatbot and crafting messages that would motivate at-risk relatives to follow up and pursue cascade testing. Their suggestions were directly applied to the messages within and overall design of the FSC and OMC. Engaging the target users during this process led to changes that may not have otherwise been made, such as including visual and audio multimedia for those who may have different learning styles [32,33].

Unlike typical proband-mediated strategies, such as family letters, chatbots are well-situated to share information in an interactive way that may help to overcome the physical barriers that some probands face when communicating with at-risk relatives [40,41]. Rather than having to gather addresses and mail physical letters, chatbots can be received practically instantaneously by at-risk relatives. Additionally, chatbots can be tracked and monitored more precisely than most other non-digital strategies cannot to better understand engagement with the technology. The availability of uptake and usage data is especially helpful from an implementation standpoint and can provide insight for continuous improvement. Further, lessons from this study can be applied to chatbots designed for other hereditary conditions to facilitate family sharing and cascade testing. Future research should examine what optimizations may need to be made to the FSC and OMC when they are deployed in other hereditary health contexts.

4.3. Conclusion

Chatbots are an innovative digital health technology that can facilitate family communication about hereditary conditions. While some FH probands in this study chose to utilize the chatbots, our findings suggest that other strategies should also be offered to encourage further dissemination of this important health information with at-risk relatives

The present study was limited by the fact that the FSC and OMC remain accessible by probands should they wish to engage at a later time point after data collection; therefore, the actual uptake of the chatbots may be higher. Probands were also offered other family sharing strategies as part of the IMPACT-FH trial, which may have lowered the number of probands who would have otherwise utilized the chatbots. Additionally, while probands who chose to receive the chatbots via email or text message received the same number of invites and reminders as those who received the chatbot via the patient EHR portal, data on which emails and text messages were read by the proband could not be obtained. This limited the analyses that could be conducted with regard to the impact of these messages on proband engagement. The ability to statistically analyze the utilization of the OMC was limited by the smaller sample size for the subset that received the OMC, which was only sent to FH probands who did not complete a genetic counseling session. Further, the FH probands included in this study were mostly white, middle-aged females from a rural population which reduces the generalizability of the findings. Thus, more research is needed to evaluate chatbot technology within other demographics. Additionally, a majority of the FH probands reported being married, which limited comparisons on the effects of marital status on opting out of receiving chatbots. Future directions include examining the uptake of and engagement with the CC by at-risk relatives, expanding the technology beyond FH and the healthcare system (e.g., for use by advocacy organizations), and continuing to iterate upon the current use cases to increase proband engagement.

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Disclosures

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Declaration of Competing Interest

The following authors have conflicts of interest to report:

Tara J. Schmidlen and Sarah K. Savage are employees and shareholders of Invitae.

Amy C. Sturm is an employee and shareholder of 23andMe.

Laney K. Jones is a consultant for Novartis.

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