MoleMapper: an application for crowdsourcing mole images to advance melanoma early-detection research

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Abstract

Advancements in smartphone technologies and the use of specialized health care applications offer an exciting new era to promote melanoma awareness to the public and improve education and prevention strategies. These applications also afford an opportunity to power meaningful research aimed at improving image diagnostics and early melanoma detection. Here, we summarize our experience associated with developing and managing the implementation of MoleMapper™, a research-based application that not only provides an efficient way for users to digitally track images of moles and facilitate skin self-examinations but also provides a platform to crowd-source research participants and the curation of mole images in efforts to advance melanoma research. Obtaining electronic consent, safeguarding participant data, and employing a framework to ensure collection of meaningful data represent a few of the inherent difficulties associated with orchestrating such a wide-scale research enterprise. In this review, we discuss strategies to overcome these and other challenges leading to the implementation of MoleMapper™.

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The worldwide incidence of melanoma continues to rise. In the United States alone, new cases of melanoma have consistently increased by approximately 1.4% each year over the last 10 years.¹ In 2018, an estimated 91,270 new cases were expected, which is in stark contrast to the 34,100 new cases observed in 1995.²³ Even though mortality rates have been relatively stable, melanoma accounts for 1.5% of all cancer-related deaths.⁴

Melanoma arises through malignant transformation of a nevomelanocyte within a benign nevus (mole) or from benign melanocytes that can resemble a new mole.³ This malignant transformation is often associated with visible changes and, if diagnosed early and surgically resected, is associated with favorable outcomes. Unfortunately, melanoma is an aggressive disease that readily metastasizes beyond the primary site while still relatively small in size (eg, 1 mm in depth). Delayed diagnosis allows for disease progression and leads to a grim prognosis, with 5-year survival decreasing from 97.6% for those with melanoma of the skin (stage I-II) to 16% for those with metastastic disease (stage IV).⁴ Even with cutting-edge therapies (eg, combined immunotherapy) associated with a 4-year overall survival rate of 52%, patients with advanced disease must still face the high financial cost of therapy, as well as the greater rate of treatment-related adverse side effects.⁵⁶ This highlights the importance of implementing preventive strategies to detect cutaneous malignancies early in the tumorigenic process in order to improve patient quality of life, decrease disease-related mortality, and combat rising treatment-related costs.⁷

Strategies aimed at reducing the rising incidence of melanoma largely include primary prevention methods such as educating the public on reduced sun exposure, as well as secondary prevention strategies such as full-body visual skin examinations. To date, most preventive public health campaigns have promoted primary rather than secondary prevention. Primary prevention has the advantage of reducing development of the disease, as well as preventing all of the downstream morbidity and mortality that might have resulted. However, benefits of primary prevention are more difficult to discern because it is not easy to measure events that fail to happen or to determine conclusively the cause of the reduction, particularly in a complex, uncontrolled population setting. Broad promotion of sun protection measures in communities of diverse ethnic composition could also have unintended negative consequences.⁸⁹ For example, restriction of sun exposure in low-risk populations could reduce vitamin D levels, leading to bone disease that poses a greater risk to health than skin cancer.¹⁰ Because the latency period for melanoma development is approximately 10 to 20 years, results of a primary prevention program, such as that deployed in Australia, will not be readily observable in the near term.¹¹¹² Finally, those individuals who have already received enough ultraviolet radiation to cause melanoma and those that have a genetic predisposition for melanoma may not be able to prevent melanoma development by reduction of ultraviolet exposure.¹³¹⁴ For these individuals, a secondary prevention (ie, early detection) solution is most pragmatic.

Secondary prevention relies on removal when the lesion is in a prelethal phase. The successful implementation of any preventive strategy largely relies on gaining consistent access to the public, and though this still remains a challenge, continued advancements to smartphone technology and the Internet have revolutionized communication. The use of specialized health care applications (apps) offers an exciting new era in promoting melanoma awareness to the public. An estimated 77% of US adults own a smartphone, and a majority of these individuals use their devices for online access.¹⁵ Specialized health care apps readily allow for the dissemination of information related to signs and symptoms of melanoma and can promote strategies relating to skin protection and self-screening.¹⁶¹⁷¹⁹ In particular, the integration of a specialized health app with technological features of a smartphone device,
such as high-resolution cameras, provides an innovative platform by which to image and screen moles for early cancer detection. These apps can enable users to catalogue and track mole images over time, as well as facilitate teledermatology consultations with providers. Another growing trend in screening apps is the utilization of an automated algorithm for image analysis to discern whether a skin lesion is concerning for melanoma. However, excitement over such technology is tempered by concerns that these platforms may provide misleading or incorrect advice to users, as they often lack appropriate validation or regulatory oversight.

In May 2014, we launched the first phase of Oregon’s War on Melanoma (WoM), a statewide, population-based, early detection initiative aimed at combating the high incidence of melanoma and the related mortality due to the disease. The WoM initiative began by actively engaging the public and continuously recruiting a host of community volunteers who are vested in promoting education and research regarding melanoma. To this end, the WoM has established the Melanoma Community Registry as a means of expediting the typically slow progress made in research by actively building large cohorts of participants to study melanoma. This effort is largely driven with the aid of online social media campaigns, as well as through participation in the MoleMapper study, an institutional review board (IRB)-approved (approval number 16038), app-based observational study that enables the longitudinal cura-
tion of numerous images of moles from participants along with specific demographic and behavioral information.

The MoleMapper app is designed to provide an efficient way to digitally track images of moles and facilitate skin self-examinations. The size of a mole in an image and potential changes are quantified by having the user include a reference coin of known size in each photograph. The app is freely available for download (https://itunes.apple.com/us/app/id1048337814), and users are provided full app functionality regardless of whether they enroll in the corresponding MoleMapper study. Enrolled participants elect to share their data but may stop participating at any time. The goal of this crowdsourced data collection is to empower many different research groups by providing access to Health Insurance Portability and Accountability Act (HIPAA)-compliant de-identified data through appropriate data-sharing agreements. Importantly, while MoleMapper provides users with an easy way of presenting sequential images to their health care provider for further assessment of possible disease, the app is not designed or intended to provide medical advice. During the digital consent process, users are required to answer specific questions to demonstrate an understanding of this limitation to the app.

The overall ability to leverage the MoleMapper platform to crowdsource research participants affords us with an unprecedented opportunity to power meaningful research aimed at improving image diagnostics and early melanoma detection. Here, we summarize our experience associated with developing and managing the implementation of MoleMapper.

Methods

Software development and back-end infrastructure

MoleMapper was developed by Dan Webster and Oregon Health & Science University (OHSU; Portland, Oregon) in collaboration with Sage Bionetworks (Seattle, Washington) and Apple Inc. (Cupertino, California). The app was founded on 3 primary goals: (1) to provide a mole-tracking tool to individual users, (2) to facilitate health care visits for individual users, and (3) to enable research derived from mole images and other relevant participant data. To achieve these goals, the MoleMapper app captures images of lesions and surrounding skin, delivers educational information, prompts users with reminders, and allows users to share images and related data with the study team. MoleMapper was built using several frameworks and libraries, including Apple’s ResearchKit open source framework (http://researchkit.org/). While data are stored locally on the device in the app’s allocated sandboxed storage location, collection and transmission of data for individuals who enroll in the MoleMapper study requires a back-end data service to facilitate transmission of encrypted data to a central database. This was achieved using a Bridge software development kit (SDK; https://github.com/Sage-Bionetworks/Bridge-iOS-SDK) for Apple operating system (iOS) to provide integration of the front-end MoleMapper app with Sage Bionetworks’ Bridge Server (https://developer.sagebridge.org/). The server and associated software provide a means of secure collection and management of mobile health data. The Bridge server consists of a set of HIPAA-compliant web services, developed and operated by Sage Bionetworks, to facilitate the collection and management of participant data from the front-end app, including secure account creation, consent tracking, and collection of other personal information. De-identified data from participants are subsequently transferred to a separate server, Synapse (https://www.synapse.org/), which is a collaborative research platform that allows research teams to share data, track analyses, and collaborate across organizational boundaries.

Like any other app, MoleMapper has required continuous maintenance that includes routine debugging and implementation of updates to changing operating systems (OSs). Seldom are apps released with the full complement of desired features, and MoleMapper is not unique to this case, as the app has undergone various improvements made to its features based on feedback from both users and developers, as well as updates associated with the advent of new OS features that significantly improved the app’s capabilities.

The development of MoleMapper continues to require a highly skilled and diverse ensemble of software engineers and developers, informaticians, and clinical dermatologists to optimize its functionality and utility. Implicit to this are the associated costs and labor-intensive aspects of developing and maintaining MoleMapper as an ongoing research platform. Our experience points to the need for considerable planning toward resources not only for development but also for long-term maintenance, as the overall process is dynamic and not limited to a single event.

Data collection and sharing

To achieve the goal of crowdsourcing research, data must be robustly and securely transmitted and stored in a platform that readily allows access to research collaborators. The encrypted data captured using MoleMapper that are sent to the Bridge server are parsed into identifiable and nonidentifiable information. Identifi-
able information required to create a record of consent includes first name, last name, date of birth, and email address and is stored separately. Nonidentifiable study data include, among other, mole measurements and demographics. De-identified study data comprising survey responses and image data are subsequently exported to Synapse.

As part of the hosting agreement with Sage Bionetworks, data curated using MoleMapper will be made available to the research community as controlled (or minimally restricted) data. In order to gain access to the data, individuals must first establish their validity as researchers with Sage Bionetworks by becoming a Certified User with a validated profile. This is required to ensure that users of the data are aware of the Common Data User Procedures and pledge to treat the data ethically and according to the expected standards set by Sage Bionetworks. The second step requires researchers to sign a data-sharing agreement with OHSU. These conditions of use allow for the curated data to be made available to research teams without the requirement of IRB approval for each individual user. This mechanism also permits scientists and analysts, without the capability of developing and maintaining an IRB, to participate in the project. Our aim is to rapidly advance melanoma research by providing access to MoleMapper study data for secondary research, as well as engage the interest of multiple research disciplines in both computer science and medicine.

Data security
The ability for MoleMapper to work efficiently as a research platform requires that local data collected from the participants’ smartphones be transmitted to a central server. It is critical that data derived from the MoleMapper study be kept secure, private, and confidential in order to comply with guidelines of the IRB-approved protocol and federal regulations (eg, HIPAA rules). Malicious cyberattacks pose significant concerns over data breaches resulting in loss of participant privacy and increased institutional liability.26,27 Several layers of security have been implemented in order to reduce or mitigate these concerns. Our approach fundamentally includes repeated design and testing at each system level to ensure data security; however, we ultimately rely on the platform’s inherent security and the user’s own appropriate safeguards with respect to passwords and device security. Another security feature inherent to the app’s design is the use of sandboxed, app-specific data that do not use the iOS photo storage capabilities but instead allow for only the MoleMapper app to access images and data it captured itself. This security layer is especially important given that iOS allows for photos stored in a user’s library to be readily shared with other devices, including the screen saver of an Apple TV device and sharing in iCloud™. Photos taken during the use of MoleMapper are unable to be stored or shared in this way to prevent unintentional distribution of data.

Another threat to data security involves the external transmission of data from participants’ devices to an outside Bridge server. It was our experience that the research institution, while capable of protecting data that are already behind secure firewalls, is ill-equipped to protect the transfer of data across device boundaries. The solution would then reside with either establishing our own in-house monitoring system or outsourcing the service. Using economies of scale, our consideration for establishing an in-house system to provide constant monitoring was not found to be cost-effective because it required a highly skilled team of security and data professionals. Instead, we partnered with Sage Bionetworks, a leading provider of scientific data repository services that has significant experience with ResearchKit and ResearchStack. Sage Bionetworks is able to provide state of the art capabilities in a cost-sharing fashion to reduce the burden on such an academic research endeavor. If a user has joined the study, an account is created on Sage Bionetworks’ Bridge server, and the credentials are securely stored only on the phone. These credentials are used to create a secure connection with the server, and then MoleMapper encrypts the data prior to sending it to the server. Once the data are on the server, the back end decrypts the data and performs the first de-identification pass that binds the data to a random healthcode generated for the user at account creation time. The de-identified data are then transferred behind Sage’s firewalls to a separate Synapse server accessible only by the OHSU study team. These data are further de-identified using an IRB-approved curation process to ensure that images made available to external researchers do not contain any reasonably identifiable markings. As an additional safeguard, the code behind MoleMapper is analyzed by a third-party static analysis tool to identify possible security risks that must be mitigated before we release the app.

Protection of participant privacy
One significant way that MoleMapper differs from other mole-tracking apps is that our platform is intended to support melanoma research and is therefore subject to local and federal regulations pertaining to the protection of human subjects. The MoleMapper study is currently collecting data only within the United States and must conform with Regulations for the Protection of Human Participants of Research codified in 45 Code of Federal Regulations (CFR) Part 46, 21 CFR Part 50, and 21 CFR Part 56. International expansion of the MoleMapper study will require additional adherence to other country-specific regulations, such as Europe’s General Data Protection Regulation (https://eurjdpr.org). (For a review of various country requirements, refer to Parker et al28).

Additional oversight is also required from the local IRB of each participating research institute. Unlike traditional app development, this additional level of scrutiny requires that all aspects of the consent process, as well as intended use of data, must be clearly described. This is especially important given that traditional medical research consent processes, using a paper form with a clinical coordinator physically present to answer questions, is not practical or cost-effective; the app-based research approach utilizes an electronic (e)-consent process that is conducted on the user’s smartphone. While the Apple ResearchKit™ provides the general framework for an e-consent platform, details specific to MoleMapper require additional customization to address our study’s needs. Experience with our institutional IRB has been a multistep process of ensuring clear communication and providing education regarding the unique aspects to the app-based research approach. This has included providing the IRB with a clear understanding of how information obtained from consenting participants is transmitted, stored, and shared with collaborators in order to comply with ap-
Inherent to the MoleMapper research platform is the continuous need to securely transmit encrypted data from the phone to a back-end server. The transmission of data containing any identifying information is subject to export compliance controls. Because users of apps are considered consumers, these digital platforms fall under the FTC’s jurisdiction to protect consumers, which includes oversight of advertising and evaluation of the truthfulness and substantiation of marketing claims about the app. This emphasizes the careful planning required for the development of a mole-tracking app and requires that developers be cognizant of both regulatory agency requirements. If not, then the process of app development can become harder to manage and increasingly costly. Likewise, careful consideration is also required if marketing the app internationally. Although currently only available in the United States, possible global expansion of the MoleMapper app will require shipping the product in multiple languages. This costly prospect is cumbersome, and efforts are needed to streamline evaluation of curated images. In particular, image quality poses a challenge for an app such as MoleMapper that is intended to curate clinical quality images. Although invalid images only account for 10% of total images submitted, we have observed image blur, specular reflections, and lighting variation in our samples. How these artifacts will affect the accuracy of classification algorithms is unclear. Addressing these artifacts has been challenging and is a large reason why many researchers rely on dermoscopy images, in which such artifacts are greatly reduced.29 Requiring users of MoleMapper, however, to subsequently purchase a dermatoscope is costly and would further hinder the ability to crowdsource research data. Consequently, we have begun to evaluate the functionality of deep learning algorithms to facilitate the identification and quantification of these artifacts.30,31

Results
The initial MoleMapper iOS app was launched in October 2015 and continues to be updated, with the most recent version 3.1.1 released in October 2018. As of August 15, 2018, MoleMapper has been downloaded 25,530 times, of which 4,615 (18%) of users have consented to participate in the MoleMapper study. To date, only 30 participants have withdrawn from the study. The median age of individuals participating in the MoleMapper study is 37 years (range 18-91 years), with participants geographically dispersed across the United States (Figure 1).

Since the start of the study, more than 13,356 mole images have been submitted by participants, of which 2,129 are repeated images at different time points. Mole images have been captured across all 59 body zones that are defined by the app, the majority of which are thus far predominately localized to the face and forearms (Figure 2). Compared with females, males appear to have a higher frequency of images measured at these sites (Figure 2). A preliminary assessment of mole distribution relative to prior history of melanoma suggests that, while a lesser number of moles are measured on the back, individuals with a prior history of melanoma tend to measure their back more than their front (Figure 3). In contrast, individuals with a prior history of any cancer other than melanoma collectively have fewer images than those with a history of melanoma (Figure 4). To date, 106 participants have reported clinical removal of an imaged mole and provided details of the associated diagnosis.

Challenges and future directions
The need for improvements to the MoleMapper platform is continuously driven by advancing smartphone technologies, an ever-evolving health care arena, and our own data-driven findings. Several challenges exist that we are currently addressing, and these are described below.

Image quality
The collection of images using the MoleMapper platform still requires assessment by two independent curators of the study team to verify whether any image contains identifiable features (eg, >50% of the face [including mouth and nose], a full ear, tattoos, etc.) or are otherwise invalid because of poor image quality. This process is cumbersome, and efforts are needed to streamline evaluation of curated images. In particular, image quality poses a challenge for an app such as MoleMapper that is intended to curate clinical quality images. Although invalid images only account for 10% of total images submitted, we have observed image blur, specular reflections, and lighting variation in our samples. How these artifacts will affect the accuracy of classification algorithms is unclear. Addressing these artifacts has been challenging and is a large reason why many researchers rely on dermoscopy images, in which such artifacts are greatly reduced.29 Requiring users of MoleMapper, however, to subsequently purchase a dermatoscope is costly and would further hinder the ability to crowdsource research data. Consequently, we have begun to evaluate the functionality of deep learning algorithms to facilitate the identification and quantification of these artifacts.30,31

Federal regulations and oversight
As already stated, MoleMapper does not provide medical advice to users, but a desired goal of implementing crowdsourced research using the MoleMapper study is to create a platform that can be used as a first-line proxy for suspicious lesion screening. While the impact of an app capable of recognizing early stage melanoma would be transformative, the realization of this prospect requires careful consideration as to the federal oversight required of such a health app, notably, the US Food and Drug Administration (FDA) and Federal Trade Commission (FTC).

The FDA regulates the manufacture and distribution of products intended to be utilized for the diagnosis, treatment, and cure or prevention of disease or other conditions. Particularly relevant is the FDA’s recently issued draft guidance, establishing a Digital Health Innovation Action Plan (https://www.fda.gov/medicaldevices/digitalhealth) that delineates the agency’s role in regulating health apps. If a mole-tracking app is to provide recommendations regarding a mole image, then the FDA may consider the app as a medical device and subject to its oversight. As advancements to image processing using artificial intelligence and machine learning continue to improve early melanoma detection, the design, development, and deployment of a mole-tracking app for such purposes require careful consideration as to FDA requirements for ensuring that the health app is an accurate and reliable tool for both patients and health care providers.

Incorporation of the MoleMapper research platform is the continuous need to securely transmit encrypted data from the phone to a back-end server. The transmission of data containing any identifying information is subject to export compliance controls. Because users of apps are considered consumers, these digital platforms fall under the FTC’s jurisdiction to protect consumers, which includes oversight of advertising and evaluation of the truthfulness and substantiation of marketing claims about the app. This emphasizes the careful planning required for the development of a mole-tracking app and requires that developers be cognizant of both regulatory agency requirements. If not, then the process of app development can become harder to manage and increasingly costly. Likewise, careful consideration is also required if marketing the app internationally. Although currently only available in the United States, possible global expansion of the MoleMapper app will require shipping the product in multiple languages. This costly prospect is not trivial, as creating new language versions of platform requires multiple levels of design verification, including the need to validate the consent process across different languages and cultures. Moreover, shipping of an app in different countries requires careful understanding of those countries’ regulatory rules regarding human data collection.28 In some cases, identifiable data are not allowed to be exported outside the country of origin, which impacts the app’s back-end solution.
User retention
Across all industries, the average mobile app retention rate is about 20% after 90 days (http://info.localytics.com/blog/mobile-apps-whats-a-good-retention-rate). This poses a significant challenge for any app developer and can severely undermine the intentions of MoleMapper to serve as a research platform. Creating reminders using push notifications and in-app messages can increase how often the user interacts with the app. Similarly, the use of incentives can also improve retention; however, for MoleMapper and other research-based apps, this approach can potentially skew the data that are collected or even encourage behavior that has unintended consequences if not thought through carefully and tested. For example, incentivizing participants to record the clinical removal of their mole may result in individuals being inappropriately motivated to remove the mole for the purpose of gaining a reward. This can result in untoward harm to a participant as they risk complications of a potentially unnecessary clinical procedure as well as create an unintended consequence of capturing meaningless data. It is important to address incentivizing methods with the IRB because they are helpful in verifying the wording and mechanisms meant to encourage consistent app use.

Addressing an ever-expanding study registry
After only 3 years since implementation, MoleMapper has enrolled thousands of research participants and collected tens of thousands of associated mole images. As the number of study participants increases, managing both participant and associated image data also increases in complexity. It is therefore important to have established processes to handle the multitude of study participants, including updating participants on how their data are being used for research, allowing for easy study withdrawal, preventing multiple same-person registrations, and curating an increasing volume of participant and image data. Study participants can use the MoleMapper app to withdraw consent any time during the study. This withdrawal of consent still allows the users full utilization of the MoleMapper app but prohibits the collection of their images for research purposes (starting from the time of study withdrawal). Notably, if an individual chooses to rejoin the study, they can use their same registration information and provide reconsent, and the system will resume the collection of their data for research. A challenge to this, and general user account management, is implementing effective strategies that prevent or reduce the creation of multiple different accounts by a single user. These multiple accounts, if not linked to one another, can create potential systematic errors, as well as reduce the ability for successful longitudinal tracking of an individual’s mole images.

Another challenge related to research at this scale resides in the curation of images. Image curation, including the removal of protected health information and assessing image quality, is currently being manually performed by two independent informaticians.
Increasing the number of images to the hundreds of thousands will require careful planning, as a linear increase in the number of informaticians and data managers is likely too costly and not practical. Rather, an alternative strategy may consider triaging images for curation using a hypothesis-generating approach, whereby images are prioritized based on research-specific questions. This approach will require maximal engagement by the research community to identify pertinent research questions that are designed to select the most informative image data sets and relevant features that require curation.

**Android and demographic issues**

The current version of MoleMapper is only available to users with iPhones, though a prior version is available on Android. This limits the overall number of users who would benefit from the app and greatly reduces the pool of potential study participants. The primary reason for limiting MoleMapper availability to iOS stems from growing concerns over the fragmentation of the alternative Android OS. Specifically, Apple operates under a closed environment in which the company controls both the hardware (ie, iPhone device) and OS (ie, iOS), thus allowing for an efficient approach to implementing system updates and a limited number of hardware configurations to support. In contrast, other smartphone manufacturers utilize an Android OS in an open environment and do not have a cohesive way of adopting upgrades or changes to the OS. This ultimately results in unwanted inconsistencies among Android OS versioning between individual devices, with as many as 42% of devices being over 2 years out of date.33 This Android OS fragmentation not only increases the difficulty of deploying the MoleMapper app but also introduces security concerns that may increase the risk of breaches to participant confidentiality. While large efforts are being put forth to solve this problem, current versioning of MoleMapper is limited to an iOS platform.

Another challenge resides with MoleMapper reliance on the smartphone camera, with the quality of images highly dependent on the quality of the camera. Even with the self-imposed limitation of MoleMapper to iOS, older devices are equipped with cameras, which may not necessarily produce the image quality needed. This challenge becomes further apparent when considering adapting MoleMapper to an Android OS platform as camera hardware varies across Android devices. This limits the potential pool of participants using MoleMapper to those who can afford newer devices and may inadvertently bias the population enrolled in this study.

**Future goals**

Since launching MoleMapper, we have already seen significant advances in smartphone capabilities and deep learning network architectures.30,31,34 Apple has also introduced wide-gamut color capture, TrueDepth cameras, Optical Image Stabilization, and Core ML for hardware-accelerated machine learning algorithms. As we move forward, we will begin to explore these advancing technologies to optimize image capture and begin to apply deep learning
convolutional neural networks\textsuperscript{30} and other new architectures (eg, U-Net and recurrent neural networks)\textsuperscript{35} to facilitate segmentation of moles based on a variety of features.\textsuperscript{31,36} While we are still collecting a sufficient number of labelled images to empower research that will enable us to distinguish benign lesions from melanoma, we have amassed enough images to begin understanding the real-world issues that users have when imaging their moles. To enhance both the users’ experience and the quality of the data collected, we intend to add machine learning capabilities to the app to improve blur detection and correction, compensate for lighting variation, and semi-automate lesion segmentation.

In addition to the above efforts to build richer data sets for lesion classification, MoleMapper is also enabling studies examining measurement behaviors by body region, gender, and age. Participants providing multiple mole measurements are helping us to understand patterns of new phenotypes and associated risk of melanoma. Of particular interest is the collective comparison between cohorts with homogenous and heterogeneous families of moles.

It is our hope that, with the advent of new technologies, app-based research platforms such as MoleMapper will continue to improve public education and advance research into melanoma early detection. Our experiences have thus far enabled a user-friendly way of having the public collect images for research. Overall, MoleMapper is providing a platform in which we are producing large, rich data sets that can be used by researchers to advance the science of early detection and characterization of melanoma.

\begin{figure}
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\caption{Relative distribution of measurements by history of cancer other than melanoma. Yellow = history of other cancer; red = no history; circle size is held constant. Note the smaller number of people using the app with a history of other cancer than melanoma. Of particular interest is the collective comparison between patients providing multiple mole measurements are helping us to understand patterns of new phenotypes and associated risk of melanoma. Of particular interest is the collective comparison between patients with a history of melanoma in Figure 3.}
\end{figure}

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MoleMapper: an application for crowdsourcing mole images to advance melanoma early-detection research


