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Research and Applications

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Genomics in nephrology: identifying informatics opportunities to improve diagnosis of genetic kidney disorders using a human-centered design approach

Katrina M. Romagnoli, PhD, MS, MLIS*,[1], Zachary M. Salvati, MS[2], Darren K. Johnson, MA[2], Heather M. Ramey, MS[2], Alexander R. Chang, MD[1,3], Marc S. Williams, MD[2]

[1]Department of Population Health Sciences, Geisinger Clinic, Danville, PA 17822, United States, [2]Department of Genomic Health, Geisinger, Danville, PA 17822, United States, [3]Department of Nephrology, Geisinger, Danville, PA 17822, United States

*Corresponding author: Katrina M. Romagnoli, PhD, MS, MLIS, Department of Population Health Sciences, Geisinger Clinic, 100 N. Academy Avenue, Danville, PA 17822, United States (kmromagnoli@geisinger.edu)

Abstract

Background: Genomic kidney conditions often have a long lag between onset of symptoms and diagnosis. To design a real time genetic diagnosis process that meets the needs of nephrologists, we need to understand the current state, barriers, and facilitators nephrologists and other clinicians who treat kidney conditions experience, and identify areas of opportunity for improvement and innovation.

Methods: Qualitative in-depth interviews were conducted with nephrologists and internists from 7 health systems. Rapid analysis identified themes in the interviews. These were used to develop service blueprints and process maps depicting the current state of genetic diagnosis of kidney disease.

Results: Themes from the interviews included the importance of trustworthy resources, guidance on how to order tests, and clarity on what to do with results. Barriers included lack of knowledge, lack of access, and complexity surrounding the case and disease. Facilitators included good user experience, straightforward diagnoses, and support from colleagues.

Discussion: The current state of diagnosis of kidney diseases with genetic etiology is suboptimal, with information gaps, complexity of genetic testing processes, and heterogeneity of disease impeding efficiency and leading to poor outcomes. This study highlights opportunities for improvement and innovation to address these barriers and empower nephrologists and other clinicians who treat kidney conditions to access and use real time genetic information.

Key words: genomic medicine; nephrology; human-centered design.

Introduction

As recognition of the contribution of genetics to disease grows, improvements to equitable access to genetic testing in clinical practice are necessary.[1] The rapidly evolving field of genomic precision medicine presents significant challenges for clinicians, particularly those without formal training in genetics, as they are often first to encounter patients with genetic conditions. Genetic conditions are individually rare, though collectively common.[2] Most clinicians have not encountered them in training, which causes them not to be considered during initial differential diagnosis.

While many research studies have examined integration of genetic testing into the management of cancer,[3,4] little has been done in other areas such as chronic kidney disease (CKD), which affects 1 in 7 US adults.[5] The diagnosis of CKD may benefit from improved integration of genetic testing as a monogenic cause may affect as many as 10% of patients with CKD. Kidney Disease Improving Global Outcomes (KDIGO) 2012 guidelines recommend referral to nephrologists (physicians who specialize in diagnosing and treating kidney conditions) for those with more advanced CKD, extensive/recurrent kidney stones, or hereditary kidney disease.[6,7]

Genetic testing may help when there are monogenic subtypes in a clinical category (eg, congenital/cystic nephropathies, steroid-resistant nephrotic syndrome), positive family history, early age of onset, syndromic features, possibility of identifying a condition in which a targeted treatment may be available.[1] Genetic testing is also important for potential kidney donors with family history of kidney disease, and to inform family planning. Even when clinical diagnosis is easy, as in the case of polycystic kidney disease (PKD), genetic information (such as the differences between *PKD1* truncating, *PKD2* truncating, *PKD1/PKD2* missense variants, other genes, or negative results) can aid in predicting disease severity and prognosis.[8–12] Without a genetic diagnosis, other kidney diseases, such as Autosomal Dominant Alport Syndrome, are underdiagnosed and misdiagnosed.[13] Earlier initiation of condition-specific management based on genetic diagnosis may improve outcomes. Challenges to genetic testing include insufficient experience and knowledge among nephrologists, cost and access barriers, and lack of electronic health record integration.[14] Our systematic review

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highlighted the potential for clinical decision support (CDS) tools to improve the uptake of genetic services and the challenges in effectively implementing them, such as the reliance on alerts and reminders, lack of standards for genomic data integration, and underuse of implementation frameworks.[3] The review also demonstrated genetic CDS tools primarily focus on cancer and pharmacogenomics, indicating a knowledge gap in applying genotype and family history data for other specialties, such as nephrology. Scant attention has been paid to clinician needs and workflow, which has led to low adoption of genetic diagnosis. Use of implementation frameworks to objectively evaluate CDS systems in practice is uncommon, which may contribute to the poor uptake of genetic CDS tools in practice. Understanding nephrologists' perspectives and experience on genetic diagnosis in their clinical workflow and how genetics should be incorporated into it enables the development of tailored CDS tools addressing the specific challenges faced by nephrologists and those who treat kidney conditions. Human-centered design (HCD), also known as user-centered design, is a collection of methodologies that include the user or recipient of a service throughout the design and implementation process.[15–20] HCD methodologies include qualitative research to understand and empathize with the user's current experience, use that deep understanding of the current state (such as how genetic diagnosis is implemented in clinical care at the present time) to identify innovative solutions, and iteratively design and test increasingly sophisticated prototypes with end users engaged in every stage.

Objective

This project aimed to use qualitative and HCD research to understand the current state of genetic diagnosis in kidney disease. We addressed the following research questions:

1) What is the current state of diagnosis and treatment of genetic kidney conditions at multiple institutions?
2) What is the experience, from the perspective of nephrologists and those who treat kidney conditions, of diagnosing and treating patients with complex kidney conditions that may have a genetic cause?
3) What pain points, barriers, and facilitators exist in the process of diagnosing and treating patients with complex kidney conditions that may have a genetic cause?

Methods

Design and setting

Interview process

We used semistructured interviews to understand the experiences of nephrologists and internal medicine doctors who diagnose and treat genetic conditions in nephrology. An interview guide was developed by the study team (Supplementary material) using an experiential phenomenological approach.[21] Interview questions were informed by the literature on the barriers experienced by clinicians to conducting genetic testing. Interview topics included experience(s) with genetic kidney diagnosis and experience(s) with genetic testing in general. The interview guide included a demographic survey and open-ended questions exploring interviewee experience diagnosing and treating genetic conditions, their most complicated and most simple experiences diagnosing a genetic condition, and asking them to share what their ideal experience diagnosing genetic conditions would be. Each interview was scheduled for 45 minutes and was conducted by a single investigator (DKJ) in the presence of an experienced medical geneticist (MSW) who was available for clarification and follow-up questions.

Participant selection and sampling

We used a purposive sampling strategy to elicit diverse experiences and reactions to making genetic diagnoses. The population of interest in this study consisted of nephrologists and other clinicians with experience in diagnosing and treating kidney conditions with genetic causes. Additionally, while the study focuses on the current state of genetic diagnosis at Geisinger, we also wanted to capture the current state of genetic diagnosis in the nephrology community beyond Geisinger. This led us to recruit both academic and nonacademic clinicians, from large and small institutions to identify common characteristics that could be applied to Geisinger. Nephrologists external to Geisinger were recruited via convenience sampling at Geisinger, from non-Geisinger study team members' organizations (University of Utah) and via Twitter—a tweet inviting US nephrologists using #nephtwitter. Finally, opportunistic snowball sampling from the participants ensured a diverse and broadly representative sample. Eligible participants were contacted via email, inviting them to participate in an interview. Follow-up emails were sent to schedule the interviews. Due to low participant numbers at individual sites, interviewers were unable to reach thematic saturation within any subgroup. As a result, interviews were conducted until thematic saturation was reached across all participants, meaning new concepts were not being identified in additional interviews.

Data analysis

Interviewers completed episodic summaries for each interview within 24 hours of interview completion. The notes captured the context and summary of the interview conversation. Interviews were audio-recorded and transcribed verbatim by medical transcriptionists at Geisinger. Study data were collected and managed using a framework based on the interview guide, in an Excel spreadsheet.

Thematic analysis

Emergent themes were analyzed using a rapid, thematic approach (RADaR: Rapid Data Analysis and Reporting)[22] by 2 independent reviewers (DKJ and HMR). RADaR is a method of organizing and analyzing qualitative data in a rigorous and systematic way that is faster than other methods, and is particularly appropriate for applied qualitative research which informs the design and implementation of practical applications. It uses widely available software (any word processing and spreadsheet software) to organize, reduce, code, and summarize data iteratively into tables. RADaR does not use any form of inter-rater reliability score, rather is an iterative approach that involves reducing data into concise actionable data tables. The reviewers iteratively coded and reviewed their coding together until they reached consensus. RADaR was used to summarize and identify themes in the answers to the interview questions. Summaries and exemplar quotes were entered into the study database (Excel). Themes (barriers, facilitators, and opportunities for innovation) were summarized from the study database.

Capturing variability across different users is important as diagnostic processes evolve to incorporate genetics. To generate complementary visualizations of how genetic diagnosis is implemented, we used visualizations of qualitative data to synthesize findings and build empathy with the end user. We created service blueprints (visual diagrams representing the service being performed, mapping roles, tools, and tasks) and process maps (visual diagrams detailing the sequence of actions) to help stakeholders visualize and understand processes.

Service blueprints illustrate the overall service design and delivery inclusive of context, as no tool or resource exists in a vacuum, and identify barriers to success and opportunities for improvement and innovation. They represent the most common processes, and while they illustrate complexity and can be quite detailed, they tend to have a bird's eye view of the larger process. In contrast, workflow process mapping depicts the variability seen within heterogenous groups of users. A workflow process map details a sequence of actions to help relevant stakeholders visualize and understand processes. Historically, process maps have been applied to health services research and quality improvement studies to help visualize those steps and pinpoint sites of intervention.[23,24]

Service blueprinting

Using the rapid analysis data set, the interview data were iteratively synthesized into 2 service blueprints: one representing the process of diagnosis by primary care clinicians from the perspective of nephrologists, and one representing the process of diagnosis by nephrologists from their own perspective.[25,26] For the purposes of this study, we are focusing on the nephrology service blueprint. Information about roles, actions (front stage, or those actions conducted within the view of the subject of the service blueprint; and back stage, those actions conducted out of the view of the subject of the service blueprint) and tools or resources used to support those actions were captured and summarized. This information was used to draft an increasingly sophisticated service blueprint representing the current state of genetic diagnosis of kidney disease. To triangulate the findings, the draft maps were presented to the larger study team which included nephrologists, medical geneticists, and informaticians for their feedback, which informed updates to the maps. The maps were designed using Miro, an online visualization and collaboration tool.[27]

Process mapping

Concurrent to service-blueprinting, using data from the rapid analysis following the interviews with clinicians from 7 health care systems, ZMS listed process and contextual differences for ordering germline genetic testing and/or appropriately referring to a genetic counselor. These data were then iteratively adapted to workflow process maps, representing each pathway a nephrologist or other clinician may take to diagnose genetic kidney disease. These workflow process maps were then presented to the study team of content experts, both from within and outside the health care organizations, to communicate the current state, verify pathway validity, and update maps accordingly. This approach was adapted from the process mapping methodological approach from Salvati et al.[24]

Results

Sixteen clinicians (14 nephrologists, 2 internists) from 7 different healthcare systems were interviewed (Geisinger, Hattiesburg Clinic, University of Cincinnati, University of Utah, Johns Hopkins Medicine, Georgetown University Hospital, and Marshfield Clinic). Fifty percent of participants currently practice at Geisinger, which has a robust genomic medicine focus. One participant was in the process of relocating from one health care system to another; their responses reflected both organizations. Demographic information is included in Table 1. All completed the full interview.

More participants use genetic testing in general (12 out of 16), many of whom (10 out of 12) use a broad next-generation sequencing-based kidney disease gene panel[28] from external genetic testing vendors. Neither of the 2 internists reported used genetic testing for kidney disease.

Genetic diagnosis information needs

Nine themes in 3 categories were identified. Participants experience barriers to integrating genetics into clinical practice, including: a limited understanding of genetics and its application in clinical care; difficulty accessing genetic testing resources, and difficulty understanding individual cases and diseases. Participants reported lack of genetics training during their medical education and rely on the expertise of medical geneticists and genetic counselors to address gaps in their genetics knowledge.

Participants also shared facilitators to integration of genetics into their clinical practice. Certain commercially available genetic testing services offer online, easy-to-use portals for ordering genetic tests, which participants consider particularly helpful. Clinical scenarios with clear, diagnostic genetic test results make the experience straightforward. Participants reported that is very helpful to have access to genetics specialists or nephrology colleagues with genetic expertise to help guide them through the process.

Participants identified 3 information needs they experience related to genetic testing: trustworthy genetics resources, how

Table 1. Participant demographics.[a]

	$n = 16$	%
Gender		
Female	4	25
Male	10	62.5
Not specified	2	12.5
Health care organization		
Geisinger	9	
Georgetown University Hospital	1	
Hattiesburg Clinic	1	
Johns Hopkins Medicine	1	
University of Cincinnati	1	
University of Utah	3	
Marshfield	1	
Years in practice		
5-10	7	43.75
11-20	4	25
>20	5	31.25
Clinical practice area		
Nephrology	14	87.5
Internal medicine	2	12.5

[a] Total number of health care organizations exceed number of participants because one participant was in the process of moving from one organization to another, and their interview responses reflected their experience at their prior place of employment.

Table 2. Genetic diagnosis information needs.

Theme	Description	Quote
Barriers to integrating genetics in clinical practice		
Limited understanding of genetics and application in clinical care	Inadequate training and assumptions in genetics, alongside patient misunderstanding, hinder genetics integration in clinical practice	"For me, ordering genetic testing on my patients . . . is not something that I learned in my training in nephrology fellowship."—Participant 3 (nephrologist) "People that have genetic conditions that affect the kidneys . . . have usually been diagnosed before I see them."—Participant 3 (nephrologist) "A lot of people don't want the testing because they don't understand the implications which is why I refer them to genetics. They're more trained to have that conversation."—Participant 3 (nephrologist) "I don't think [patients] get any results until I get the results first . . . are we missing any patients and they don't actually know what the results are?"—Participant 1 (nephrologist)
Difficulty accessing genetic testing resources	Challenges in ordering, billing, and limited genetic specialist access hinder genetic testing integration	"Its not streamlined. Every time we're considering a diagnosis there is running down the hall and trying to ask, "how do you guys order this?" Should I send them to genetics, should I order on my own? If I just order this in the computer am I going to get a result, is [the patient] going to get a big bill because I ordered this wrong?"—Participant 3 (nephrologist) "I don't know how to order [genetic testing]. . .very often they don't send the right sample or it's not even a genetic test, it's an enzyme for a genetic test . . . I'm always worried if I order it, usually not available in [EHR] but if it is I'm worried it's not going to be sent correctly to me or the patient."—Participant 3 (nephrologist) "We lack the ability to reach out to geneticists or genetic counselors, they are extremely rare."—Participant 6 (discussing prior experience)
Difficulty understanding individual cases and diseases	Navigating inconclusive results, premature conclusions, and handling multifaceted complex cases challenge clinical genetics integration	". . . but still things don't add up, I don't know a diagnosis for them."—Participant 2 (nephrologist) "Physicians I've worked with did genetic testing and they would get some results back that it's a variant of unknown significance and oftentimes I noticed they would pretty much just jump to the conclusion that's the cause even if the evidence is not quite there."—Participant 1 (nephrologist)
Facilitators to integrating genetics in clinical practice		
Good user experience	Streamlined processes, symptoms alerts, and automated genetic counseling enhance genetics integration experience	"Put the patient on this medicine, I don't love that kind of [recommendation], but . . . an alert that captures information about symptoms . . . and tell you genetic testing is appropriate. I think you could probably capture more people with genetic conditions."—Participant 3 (nephrologist) "I'm pretty familiar, but definitely not initially for the first few years of my career. . . [outside company] streamlining the process of ordering and having an automatic genetic counseling session to follow up with the patients."—Participant 1 (nephrologist) "It's very easy and streamlined for me to order it, so I don't think of it as another hassle. . .I know it's a busy clinic for us, but still in that clinic I'm easily able to order [genetic testing] for them."—Participant 2 (nephrologist) "See, if I send the patient to Genetics. . .not being the one actually ordering the panel. . .I don't feel like I'm learning that information, right? Whereas with [ordering directly] I actually go into their website, and I figure out, 'OK, so these are the genes that are associated with nephrolithiasis. Interesting.'"—Participant 4 (nephrologist)
Straightforward diagnoses	Clear family history and identifiable kidney diseases simplify the decision for genetic testing	"Certainly if they have a family history and they have kidney disease that I don't have a good explanation for, that's pretty much a slam dunk [to order genetic testing]."—Participant 1 (nephrologist) "The simplest example would be somebody I know who has polycystic kidney disease and we have some genetic information on them as well. I just use the [renal] panel . . . and I understand all the financial parts of it. . . its an easy situation because we know what they have and I'm just giving them a molecular diagnosis."—Participant 1 (nephrologist)
Support from colleagues	Colleague collaboration aids in understanding and interpreting genetic results, bridging gaps in specialized training	"If I'm not understanding something, I always kind of ask them, "Hey, what do you think about this?" [Colleagues] are always kind of supporting me with that."—Participant 2 (nephrologist) ". . .one of the things I love about working in this system is having partners who are very active and chatty and just trading ideas all the time. . ."—Participant 5 (nephrologist) "In a way it's easier to send people to Genetics because then I don't do the testing. They do testing [and] they decide the panel they're going to test. And I think they're doing a really good job. . . they are able to disclose the information and they're counseling the patients, right? So I kind of like that."—Participant 4 (nephrologist)

(continued)

Table 2. (continued)

Theme	Description	Quote
Unmet information needs related to genetics in clinical practice		
Trustworthy genetic resources	Access to reliable genetic facilities, expert colleagues, collaborative team approaches, and vetted electronic alerts are crucial for trustworthy genetic resources	"We are fortunate enough to have an amazing facility where it's so easy to get genetic analysis."—Participant 2 (nephrologist) "My colleagues are probably the biggest thing. . .I look it up online but there's not a ton of stuff about genetics."—Participant 3 (nephrologist) "I would like to have more of a team approach with a genetic counselor. . . so they know and contribute about the workup and management of patients with genetic conditions."—Participant 3 (nephrologist) "We have these best practice alerts which pop up in [EHR]. They can be kind of annoying, I'm not sure I would trust that type of alert unless it is really really well vetted. What else could you do? . . . you can have someone still coming to see you based off the electronic algorithm saying "it looks like this person might be at risk for genetic kidney disease and somebody should consider this patient for genetic testing". Like somebody giving them a heads up, but in a non-automatic form."—Participant 1 (nephrologist)
How to order tests	Clear guidelines in EHR, indications, and patient communication aid in streamlining genetic test orders	"I use . . . a renal panel which is basically in the [EHR] system. . . They send me a report with everything written, all references and everything I need."—Participant 2 (nephrologist) "You would have something that could kind of tell you that this seems like a possible indication to order a genetic test and then it would have some way to inform the clinician on what [they] should talk to the patient about and how to order the genetic test and what type of genetic test would be important."—Participant 1 (nephrologist)
Next steps after receiving results	Coherent reporting and referrals to genetic counselors are crucial for understanding post-test steps	"I don't think [patients] get any results until I get the results first. . . are we missing any patients and they don't actually know what the results are? I think ideally the provider should get the results, yet the patient should get the results in as interpretable way as possible."—Participant 1 (nephrologist) "I know I'm going to [get a] coherent and nice report, with a call with a genetic counselor in case I need any help."—Participant 2 (nephrologist) "I think it's very important for the patient to go to genetic counseling, I would refer them to genetic counselors."—Participant 1 (nephrologist) "[Genetic counselors] decide the panel they're going to test, and I think they're doing a really good job. I think they are disclosing the information and they're counseling the patients, right? So, I kind of like that."—Participant 4 (nephrologist)

to order tests, and how to interpret results. They are unfamiliar with where to find reliable, easy to understand information to guide them. When they recognize the need for genetic testing, they are often unsure of the optimal test to order, insurance coverage, out-of-pocket patient cost, and how to place the order correctly. When they receive results, they are often unsure how to interpret results, especially variants of unknown significance, as well as the clinical implications of the genetic findings. The thematic findings are summarized with exemplar quotations in Table 2.

Service blueprints

A service blueprint depicting the current state of genetic diagnosis of kidney disease by nephrologists was drafted and iteratively updated with feedback from the larger research group, including nephrologists (Figure 1). While the left side of the service blueprints, depicting usual practice, shows a streamlined process with minimal confusion or barriers, the right side (Figure 2), depicting the genetic diagnosis portion of the journey, is rife with complexity and barriers (red diamonds). The genetic test experience facilitated by external genetic testing vendors offers a smoother experience (yellow stars).

Workflow process maps

Ten workflow process maps were created and synthesized to represent 3 primary processes of the current state, using nephrologists' perspectives of ordering genetic testing across 7 different health care organizations. Two organizations were found to have multiple processes nephrologists used to identify and care for patients with genetic conditions. However, it was noted from provider-stakeholder interviews these were not formal processes; rather, these steps were stakeholder-dependent due to a lack of process standardization. The primary processes to identify and care for patients with suspected genetic conditions, found from stakeholder interviews, are represented by 3 workflow process maps from Organization 1 (Figure 3). Organization 2 had 2 workflow process maps and Organizations 3 through 7 all had a single map representing each site. These workflows were slight variants of the 3 primary processes which can be viewed in Supplementary Material.

All 3 workflow process maps showed similar approaches to why a nephrologist might order or refer a patient to receive genetic testing and how a patient who receives said testing typically presents in clinic. Genetic testing was thought to be an option for suspected rare conditions, syndromic

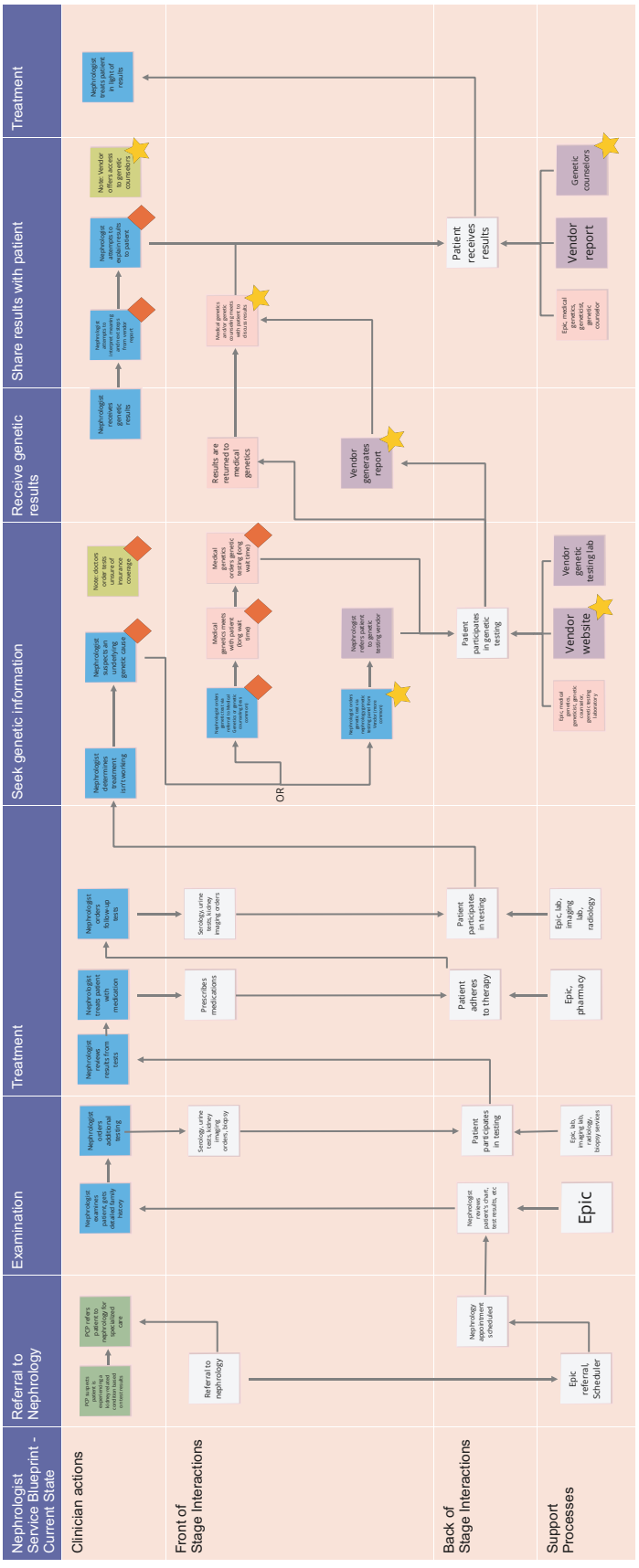

Figure 1. Current state of genetic diagnosis of kidney disease by nephrologists. Yellow stars indicate facilitators to process of genetic diagnosis. Red diamonds indicate barriers to the process of genetic diagnosis.

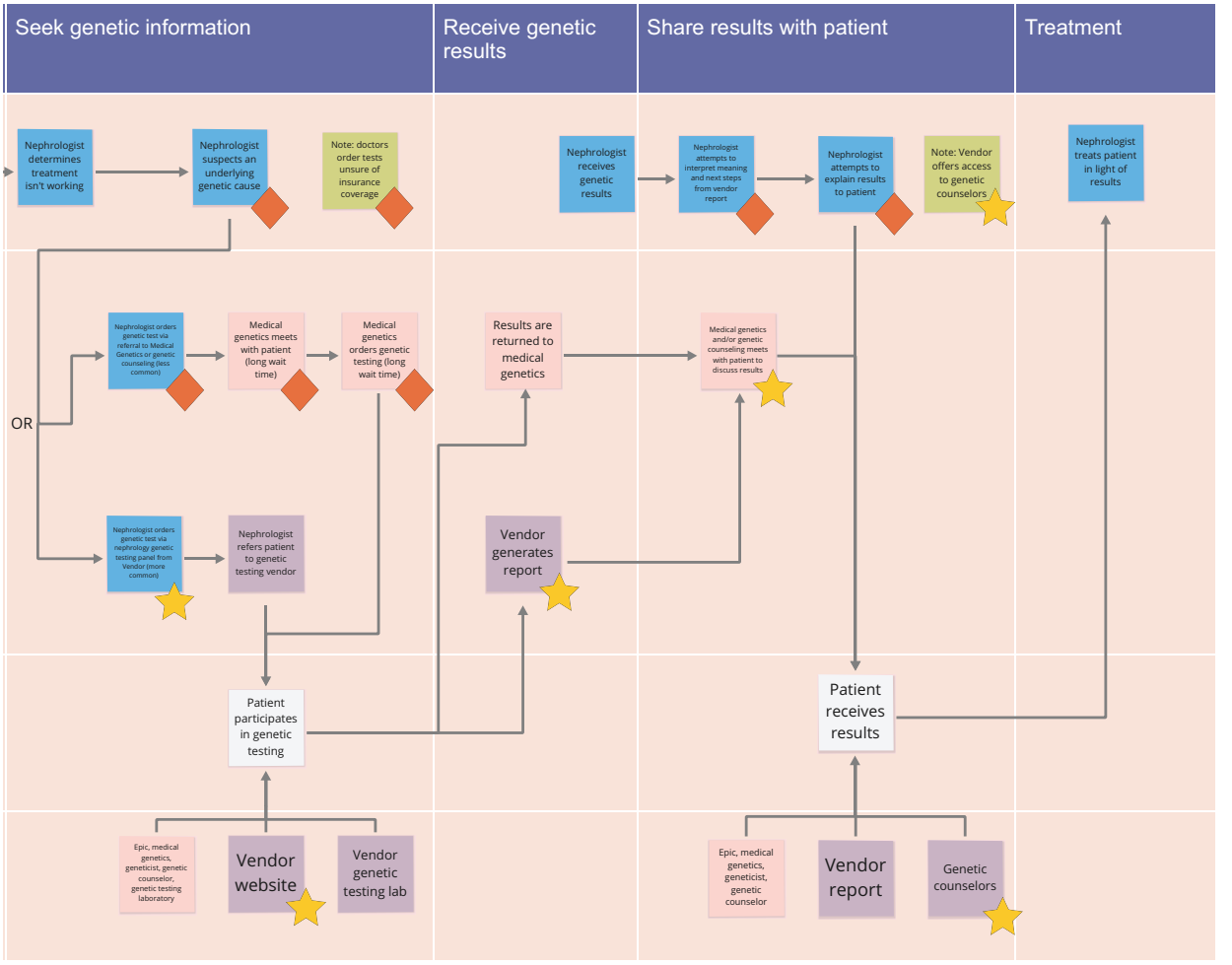

Figure 2. Detailed/zoomed in on genetic diagnosis section of current state of the diagnostic process of genomic kidney disorders.

phenotypes, genotyping PKD to inform prognosis, unexplained kidney disease, or in specific situations such as establishing a cause of kidney disease in potential kidney transplant recipients with CKD of unknown cause and for risk assessment of potential kidney donors. These patients will often be referred to Adult Nephrology for evaluation of CKD of unknown cause or when transitioning from pediatric to adult care.

The workflows deviate with the process leading up to ordering genetic testing. One workflow is described by nephrologists prioritizing a clinical diagnosis, then ordering genetic testing if necessary. This can be characterized by taking a complete medical history and family history, conducting a biopsy, imaging procedures, and/or serology. Subsequent genetic testing is warranted if a clinical diagnosis has not been made, but one nephrologist described a patient care barrier involving the return of results:

The second primary workflow process map shows taking the medical and family history first and referring to a genetic counselor if the nephrologist suspects a genetic condition. If no genetic condition is suspected, then the typical workup of biopsy, imaging procedures, and/or serology are conducted to identify a clinical diagnosis. Patient care barriers were identified related to ordering genetic testing,

The last process involved ordering genetic testing themselves or referring to genetic counselors internally. However, this process was variable. Multiple nephrologists endorsed referring to genetic counselors internally, but others had positive experiences ordering genetic testing directly without referring to a genetic counselor first.

Discussion

To understand the current state of genetic diagnosis of complex conditions in nephrology, we conducted qualitative interviews with nephrologists and internal medicine doctors who diagnose and treat kidney genetic conditions. We identified barriers (lack of knowledge, lack of access, and complexity surrounding the case and disease) and facilitators (good user experience, straightforward diagnoses, and support from colleagues) to timely diagnosis of genetic conditions in nephrology. Similar barriers have been identified by other research exploring why genetic testing for other medical conditions has been poorly implemented, such as minimal genetics knowledge among clinicians, cost and access barriers, and lack of electronic health record integration causing poor user experience.[29,30] Notably, participants in our study emphasized their lack of knowledge about what costs *might* be for their patients—they assume there would be costs, but do not know what they would be because do not know what any individual's insurance plan covers. This is an interesting facet to the well-known cost barriers surrounding genetic

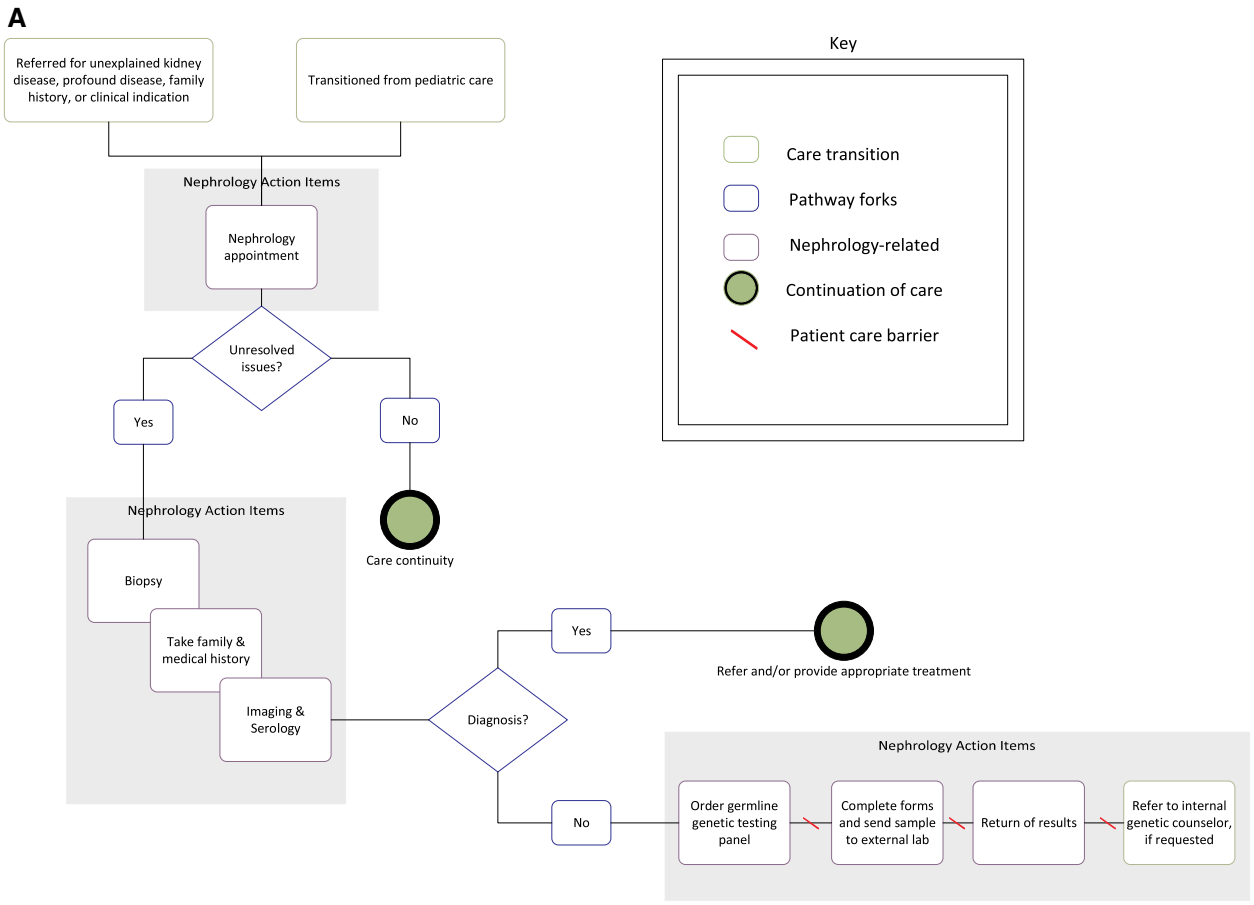

Figure 3. (A) Current state workflow process map prioritizing diagnosis then genetic testing. (B) Current state workflow process map referring to a genetic counselor. (C) Current state workflow process map with inconsistent referrals or genetic testing.

testing: the clinician's lack of insight into what the cost might be in the first place.

To identify areas of opportunity to improve genetic diagnosis, we created a suite of visual artifacts depicting the current state of genetic diagnosis of kidney conditions by nephrologists, which capture both the interaction with the larger context of healthcare and the overall service design of genetic diagnosis (service blueprints) as well as the variability of processes across different nephrologists and healthcare systems (process maps).

More participants than expected indicated they have ordered and used genetic information in their practice. This may be because nephrologists interested in genetic testing and diagnosis self-selected to participate in a qualitative research study about genetic diagnosis in nephrology at a higher rate than nephrologists who were less interested in genetic kidney disease. The nephrology field may be more developed in including genomics in their practice compared to other clinical areas, though this work cannot be generalized to all nephrologists. Additionally, Geisinger Clinic has a robust research interest in genomic medicine, increasing the likelihood of recruiting participants here who share that interest.

Some external testing vendors have developed nephrology-specific genetic testing products, marketing them to nephrologists directly.[28] These services include support for ordering and result interpretation, which addresses some of the barriers identified in this work. However, external standalone services do not address other important aspects of real time genetic diagnosis design identified by participants, such as support from colleagues and management of complexity in individual cases. The large number of genes on the panel, while intending to be helpful by providing more information, were difficult for participants to interpret due to receiving results which seem to be unrelated or having unknown significance to the indication for testing. Furthermore, genetic testing results from external services must be manually added to the patients' health record, limiting the ability to use informational resources in the EHR which could be triggered by structured data in reports. Having to use external, commercial products introduces other impediments to successful use of genetic information, even as it solves some problems.

A systematic review of clinicians' genetic testing practices found most studies focused on clinicians' knowledge, attitudes, or beliefs about genetic testing, and none evaluated the experience or process of obtaining or receiving a genetic diagnosis.[30] Within nephrology, recent articles review the current state of evidence for the genetic diagnosis of diseases,[31] and review the indications for pursuing genetic testing.[32] However, these do not include information on the current experience of clinicians in conducting genetic testing within any clinical area, nor specifically nephrology. The results of this study offer opportunities to address the unmet information

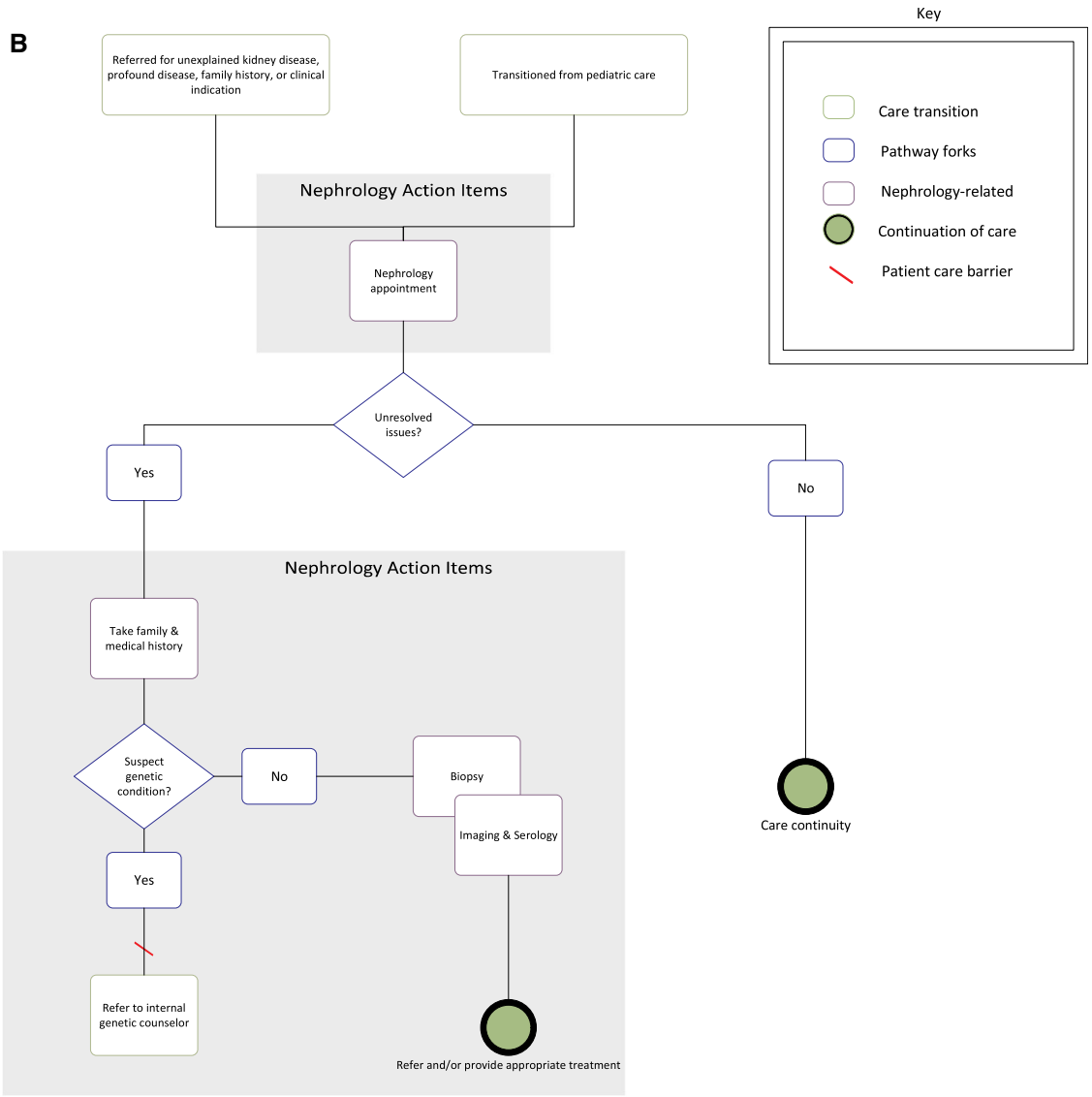

Figure 3. Continued.

needs and barriers experienced in implementing genetic diagnosis in clinical care, which have previously not been addressed in the literature.

In an area where no guidelines or standard practices exist, we expected to see substantial variability in the steps participants take when diagnosing genetic conditions, and this was confirmed. We also wanted to identify when and where participants experience roadblocks to achieving their goals, because those are opportunities for improvement and innovation. Neither service blueprints nor process workflow maps accomplish those goals alone—by pairing them in the analysis and synthesis of the qualitative data, we illustrate the experience with both a low-power view and a high-power view, akin to the options on a microscope. The low power view, process workflow maps, has a wider field of vision with multiple distinct experiences, less detail, and more information about variation. The high-power view, service blueprints, has a narrower field of vision, more detail, and more information about the context and structures in which the experience of obtaining a genetic diagnosis exists. Using the same data but generated independently, these visualizations provide different perspectives and information that neither would provide alone. The service blueprints and workflow process maps developed in this work offer a novel, complementary, and visual approach to communicating qualitative findings in a compelling, actionable way. Together they allow the HCD researcher to explore both the variability and the problems—and identify opportunities for improvement in genetic diagnosis in nephrology.

Limitations

This study had limitations related to sampling and data collection. First, data collection was limited to participants from 7 healthcare organizations, and participant sampling ranged from 1 to 6 stakeholder perspectives representing each site. Ultimately, a cross-case comparison by site would not have achieved thematic saturation. Rather, thematic saturation was achieved by looking at all stakeholder perspectives, with Organization 1 representing the 3 primary processes for ordering germline genetic testing in Nephrology. Future studies are needed to further characterize processes across multiple institutions to ensure all possible processes are accounted for.

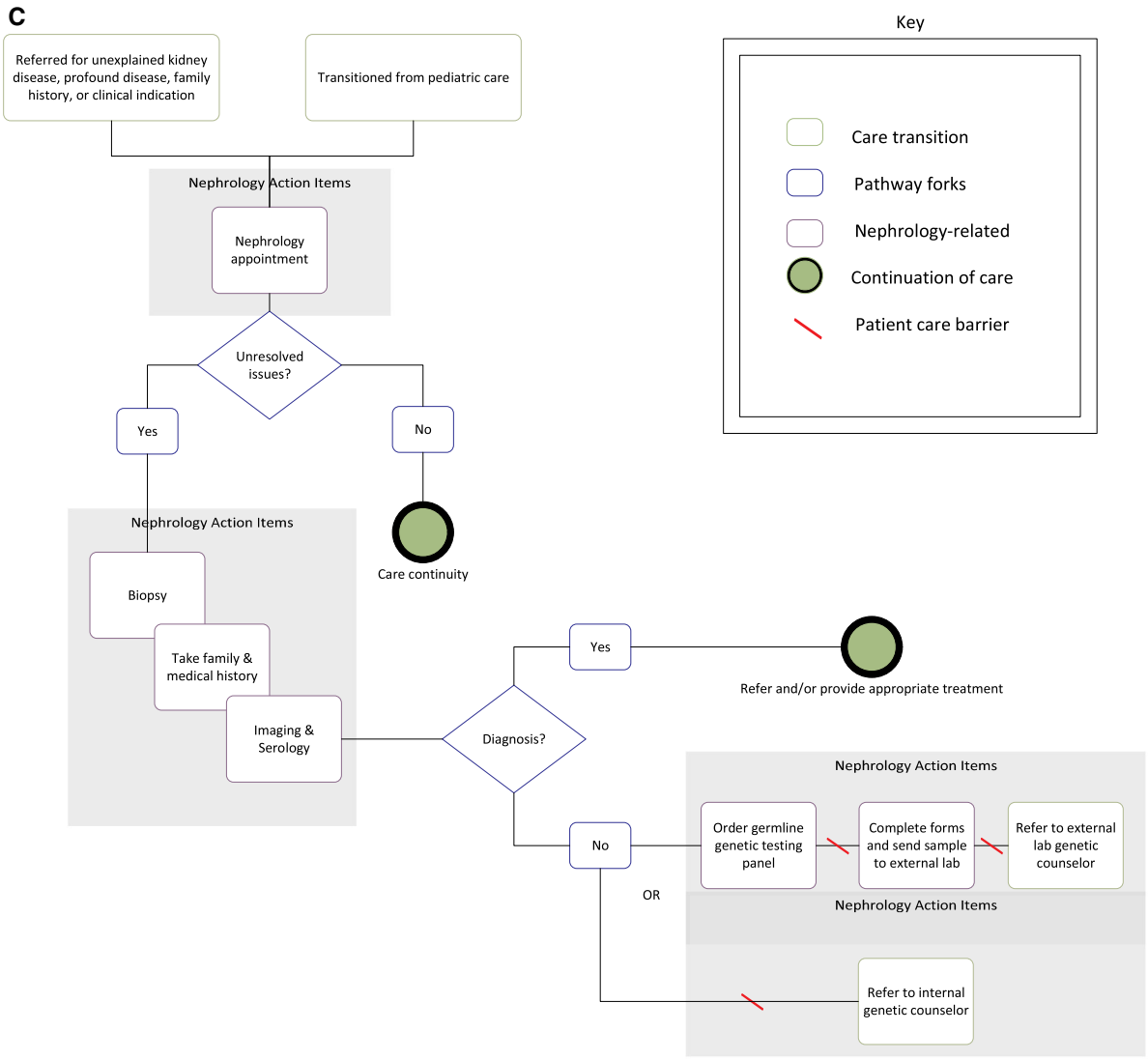

Figure 3. Continued.

While participant recruitment included healthcare systems outside our own local institutions, common themes at multiple institutions likely represent generalizable knowledge which will be important to address as real time genetic diagnosis systems are built, even as differences are identified.

Future work

Future work includes conducting a design thinking workshop with nephrologists, medical geneticists, informaticians, and other experts. The workshop will use the findings from the qualitative work, including the data visualizations, to build empathy and shared understanding of the current state of genetic diagnosis in nephrology among the participants. The output of the workshop will be a first draft prototype of the future state of genetic diagnosis in nephrology, using real-time genetic diagnosis innovations. Testing of such a prototype across a diverse group of nephrologists can facilitate the need to characterize processes as noted in the limitations.

Conclusion

The current state of genetic diagnosis in nephrology is suboptimal for timely diagnosis of kidney diseases with genetic etiology. We have identified opportunities to improve and innovate this experience with the HCD of a real-time genetic diagnosis tool.

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Author contributions

KMR, DKJ, and ZMS contributed to the conception of work, acquiring, analysis, and interpretation of data, drafting of the manuscript, critical review, revision, and final approval of the manuscript. HMR contributed to the acquiring, analysis and interpretation of data, drafting of the manuscript, critical review, revision, and final approval of the manuscript. ARC contributed to the conception of work, critical review, revision, and final approval of the manuscript. MSW contributed to the conception of work, acquiring of data, critical review, revision, and final approval of the manuscript.

Supplementary material

Supplementary material is available at *Journal of the American Medical Informatics Association* online.

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Conflicts of interest

None declared.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

References

1. Köttgen A, Cornec-Le Gall E, Halbritter J, et al. Genetics in chronic kidney disease: conclusions from a Kidney Disease: Improving Global Outcomes (KDIGO) Controversies Conference. *Kidney Int*. 2022;101(6):1126-1141.
2. Ferreira CR. The burden of rare diseases. *Am J Med Genet A*. 2019;179(6):885-892.
3. Johnson D, Del Fiol G, Kawamoto K, et al. Genetically guided precision medicine clinical decision support tools: a systematic review. *J Am Med Inform Assoc*. 2024. https://doi.org/10.1093/jamia/ocae033
4. O'Shea R, Taylor N, Crook A, et al. Health system interventions to integrate genetic testing in routine oncology services: a systematic review. *PLoS One*. 2021;16(5):e0250379. https://doi.org/10.1371/JOURNAL.PONE.0250379
5. Xu F, Pavkov ME, Koyama A, et al. Kidney Disease Surveillance System. Centers for Disease Control and Prevention. Accessed December 21, 2023. https://nccd.cdc.gov/CKD/default.aspx
6. Groopman EE, Marasa M, Cameron-Christie S, et al. Diagnostic utility of exome sequencing for kidney disease. *N Engl J Med*. 2019;380(2):142-151.
7. Stevens PE, Levin A; Kidney Disease: Improving Global Outcomes Chronic Kidney Disease Guideline Development Work Group Members. Evaluation and management of chronic kidney disease: synopsis of the kidney disease: improving global outcomes 2012 clinical practice guideline. *Ann Intern Med*. 2013;158(11):825-830.
8. Apple B, Sartori G, Moore B, et al. Individuals heterozygous for ALG8 protein-truncating variants are at increased risk of a mild cystic kidney disease. *Kidney Int*. 2023;103(3):607-615.
9. Chang AR, Moore BS, Luo JZ, et al. Exome sequencing of a clinical population for autosomal dominant polycystic kidney disease. *JAMA*. 2022;328(24):2412-2421.
10. Lanktree MB, Haghighi A, Di Bari I, et al. Insights into autosomal dominant polycystic kidney disease from genetic studies. *Clin J Am Soc Nephrol*. 2021;16(5):790-799.
11. Gansevoort RT, Arici M, Benzing T, et al. Recommendations for the use of tolvaptan in autosomal dominant polycystic kidney disease: a position statement on behalf of the ERA-EDTA Working Groups on Inherited Kidney Disorders and European Renal Best Practice. *Nephrol Dial Transplant*. 2016;31(3):337-348.
12. Gall ECL, Audrézet MP, Rousseau A, et al. The PROPKD score: a new algorithm to predict renal survival in autosomal dominant polycystic kidney disease. *J Am Soc Nephrol*. 2016;27(3):942-951.
13. Bonebrake L. An Alport syndrome journey: from powerless to empowered—a patient perspective. *Glomerular Dis*. 2023;3(1):42-46.
14. Jayasinghe K, Quinlan C, Mallett AJ, et al. Attitudes and practices of Australian nephrologists toward implementation of clinical genomics. *Kidney Int Rep*. 2020;6(2):272-283.
15. Harte R, Glynn L, Rodríguez-Molinero A, et al. A human-centered design methodology to enhance the usability, human factors, and user experience of connected health systems: a three-phase methodology. *JMIR Hum Factors*. 2017;4(1):e8. https://doi.org/10.2196/HUMANFACTORS.5443
16. Göttgens I, Oertelt-Prigione S. The application of human-centered design approaches in health research and innovation: a narrative review of current practices. *JMIR Mhealth Uhealth*. 2021;9(12):e28102. https://doi.org/10.2196/28102
17. Norman D, Draper S. *User Centered System Design: New Perspectives on Human-Computer Interaction*. CRC Press; 1986.
18. Kim S, Myers C, Allen L. *Health Care Providers Can Use Design Thinking to Improve Patient Experiences*. Harvard Business Review; 2017.
19. Altman M, Huang TTK, Breland JY. Design thinking in health care. *Prev Chronic Dis*. 2018;15:E117. https://doi.org/10.5888/PCD15.180128
20. Silva HM, Gonzaga do Nascimento MM, de Morais Neves C, et al. Service blueprint of comprehensive medication management: a mapping for outpatient clinics. *Res Social Adm Pharm*. 2021;17(10):1727-1736.
21. Patton MQ. *Qualitative Research and Evaluation Methods: Theory and Practice*. 4th ed. SAGE Publications, Inc; 2015:832.
22. Watkins DC. Rapid and rigorous qualitative data analysis: the "RADaR" technique for applied research. *Int J Qual Methods*. 2017;16(1):1-9. https://doi.org/10.1177/1609406917712131
23. Antonacci G, Lennox L, Barlow J, et al. Process mapping in healthcare: a systematic review. *BMC Health Serv Res*. 2021;21(1):342. https://doi.org/10.1186/S12913-021-06254-1
24. Salvati ZM, Rahm AK, Williams MS, et al. A picture is worth a thousand words: advancing the use of visualization tools in implementation science through process mapping and matrix heat mapping. *Implement Sci Commun*. 2023;4(1):43.
25. Martin B, Hanington BM. *Universal Methods of Design Expanded and Revised: 125 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions*. 1st ed. Rockport Publishers; 2019.
26. Bitner MJ, Ostrom AL, Morgan FN. Service blueprinting: a practical technique for service innovation. *Calif Manage Rev*. 2008;50(3):66-94.
27. Miro. *Miro online whiteboard* (no version provided). RealTimeBoard, Inc; 2023. Accessed August 3, 2023. https://miro.com/
28. Bleyer AJ, Westemeyer M, Xie J, et al. Genetic etiologies for chronic kidney disease revealed through next-generation renal gene panel. *Am J Nephrol*. 2022;53(4):297-306. https://doi.org/10.1159/000522226
29. Raspa M, Moultrie R, Toth D, et al. Barriers and facilitators to genetic service delivery models: scoping review. *Interact J Med Res*. 2021;10(1):e23523.
30. Paul JL, Leslie H, Trainer AH, et al. A theory-informed systematic review of clinicians' genetic testing practices. *Eur J Hum Genet*. 2018;26(10):1401-1416.
31. Knoers N, Antignac C, Bergmann C, et al. Genetic testing in the diagnosis of chronic kidney disease: recommendations for clinical practice. *Nephrol Dial Transplant*. 2022;37(2):239-254.
32. Groopman EE, Gharavi AG. Expanding opportunities and emerging challenges: broadening the scope of genetic testing in nephrology. *Kidney Int*. 2019;95(4):743-746.