

Collaboration Networks of the Implementation Science Centers for Cancer Control (ISC³): A Social Network Analysis

Rebekah R Jacob (✉ rebekahjacob@wustl.edu)

Washington University in Saint Louis <https://orcid.org/0000-0003-2466-8809>

Ariella R Korn

National Cancer Institute

Grace C Huang

Westat

Douglas Easterling

Wake Forest University School of Medicine

Daniel A Gundersen

Dana-Farber Cancer Institute

Shoba Ramanadhan

Harvard University T H Chan School of Public Health

Thuy Vu

University of Washington School of Public Health

Heather Angier

Oregon Health & Science University

Ross C Brownson

Washington University in St Louis

Debra Haire-Joshu

Washington University in St Louis

April Oh

National Cancer Institute

Robert Schnoll

University of Pennsylvania

Research

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Abstract

Background: Multi-center research initiatives offer opportunities to develop and strengthen connections among researchers. These initiatives often have goals of increased scientific collaboration which can be examined using social network analysis.

Methods: The National Cancer Institute (NCI)-funded Implementation Science Centers in Cancer Control (ISC³) initiative conducted an online social network survey in its first year of funding (2020) to examine early scientific linkages among members (faculty, staff, trainees) and recognize areas for network growth. Members of the seven funded centers and NCI program staff identified collaborations in: *planning/conducting research, capacity building, product development, scientific dissemination, practice/policy dissemination*.

Results: Of the 192 invitees, 182 network members completed the survey (95%). The most prevalent roles were faculty (60%) and research staff (24%). Almost one-quarter (23%) of members reported advanced expertise in implementation science (IS), 42% intermediate, and 35% beginner. Most members were female (69%) and white (79%). Across all collaboration activities, the network had a density of 14%, suggesting high cohesion for its first year. One-third (33%) of collaboration ties were between members from different centers. Degree centralization (0.33) and betweenness centralization (0.07) measures suggest a fairly saturated network (no one or few central member(s) holding all connections). The most prevalent and densely connected collaboration network was for *planning/conducting research* (1470 ties; 8% density). *Practice/policy dissemination* had the fewest collaboration ties (284), lowest density (3%), and largest number of non-connected members (n=43). Median degree (number of collaborations) varied across member characteristics and collaboration activities. Members with advanced IS expertise were more connected than intermediate/beginner groups for most activities (e.g., advanced IS members had a median of 24 *capacity building* collaborations (range: 4-58) vs. intermediate (median 9; range 2-53) and beginner (median 7; range 1-49) members. The number of *practice/policy dissemination* collaborations were similarly low across IS expertise levels (median degree 3 for advanced, 2 intermediate, 2 beginner).

Conclusions: Results provide important directions for interventions within the ISC³ network to increase scientific collaboration and capacity, with a focus on growing cross-center collaborations and increasing engagement of under-represented groups. Findings will be used to capture infrastructure development as part of the initiative's evaluation.

Background

In the United States, an estimated 1.9 million people are diagnosed with cancer each year (1, 2). While cancer mortality rates have decreased overall from 2001 to 2018, they have done so disproportionately in magnitude across cancer types and certain racial/ethnic groups (1, 3). In 2030, it is estimated that the US will spend \$246 billion on cancer-related healthcare, a 34% increase from 2015 (4). Effective interventions exist to reduce cancer burden, but they are largely dependent on fine-tuned implementation at the policy and practice level (health care and public health settings), which often lags approximately 17 years behind the research (5, 6). Discovering the tools and methods to close this "know-do" gap is the charge of the Implementation Science (IS) field (7, 8) and is a priority in cancer research initiatives and funding.

In 2018, the National Cancer Institute (NCI) issued requests for funding to support Implementation Science Centers for Cancer Control (ISC³) (2019-2024) (9-11). Each of the seven funded ISC³ centers conducts pilot work in IS approaches and includes an "implementation laboratory" that provides important linkages with clinical and community sites. Through this infrastructure, the ISC³ aims to build scientific capacity in the field with targeted approaches for developing and testing innovative methods and measures for dissemination and implementation research and engaging scholars in a rich network of investigators (11). ISC³ has the potential to foster field-wide collaboration with multiple funded centers addressing important and timely IS research in cancer control. Collaboration among ISC³ investigators and staff within and across centers is critical and can lead to greater productivity and impact, diverse thinking, and increased opportunities for capacity building in the field (12-14). Priming the network to develop additional scientific linkages between researchers is a key focus of the ISC³, and therefore, understanding the extent of these connections is an important evaluation priority.

In addition to understanding the science generated and disseminated among network members (publications, presentations, funding), social network methods can be utilized to establish a baseline assessment of collaboration among investigators and identify where efforts should be allocated to achieve goals. Multi-organization initiatives and research networks have demonstrated the utility of social network measures for evaluation and for midway planning to enhance network cohesion (15-21). For example, the Translational Research Network conducted longitudinal surveys over four years that highlighted new researcher-clinician linkages that occurred due to the network as well as projects not directly funded by the Translational Research Network but attributed to network membership (20). In addition, Vacca et al. used social network analysis to identify and match researchers with funding collaborations across various research communities (16, 22). Understanding linkages within networks informs areas where growth or additional relationship types are desired and carried out through purposefully designed network interventions (23, 24). This is especially important at the beginning of an initiative given the time to implement and measure outcomes resulting from the creation of new collaborations or other changes to linkages (24). Likewise, these measures are key evaluation pieces for initiatives that seek to understand how efforts have impacted network functions and how collaboration aided productivity and created potentially durable infrastructure for further action.

The purpose of this study is to understand the scientific collaborations and early linkages within the ISC³ network during the initiative's first year. We examined collaboration patterns overall and by distinct activities: *planning or conducting research, capacity building, product development, scientific dissemination, and practice/policy dissemination*. In addition to serving as baseline, year 1 data will be used to inform additional network reassessments planned for years 3 and 5. This research is expected to inform ISC³'s efforts to strengthen ties and support the development of new IS collaborations to bridge specific areas of IS and cancer control research.

Methods

Center descriptions

The seven funded centers that make up the ISC³ are:

1. The Implementation Science Center for Cancer Control Equity (ISCCE) (Harvard T.H. Chan School of Public Health),
2. Building Research in Implementation and Dissemination to close Gaps and achieve Equity in Cancer Control (BRIDGE-C2) Center (Oregon Health & Science University),
3. Colorado ISC³ (University of Colorado School of Medicine),
4. Optimizing Implementation in Cancer Control: OPTICC (University of Washington),
5. iDAPT: Implementation and Informatics—Developing Adaptable Processes and Technologies for Cancer Control (Wake Forest School of Medicine and University of Massachusetts Medical School),
6. Washington University ISC³ (WU-ISC³) (Washington University in St. Louis), and
7. Penn Implementation Science Center in Cancer Control (Penn ISC³) (University of Pennsylvania).

All centers were funded starting in October 2019 except for Penn ISC³ who entered as a new center in October 2020. Additional information on each center can be found at <https://cancercontrol.cancer.gov/is/initiatives/isc3>.

Cross-Center Evaluation Work Group

In the fall of 2019, a work group formed to develop cross-center evaluation measures with representation from each of the centers, NCI program staff, and by the initiative's contracted evaluator, Westat. The Cross-Center Evaluation work group developed a survey tool to assess both intra- and inter-center research collaborations that were of interest to the ISC³ evaluation. The work group continues to meet monthly and is facilitated by center members.

Participants

Each center's leadership team assembled and provided a list of key researchers- faculty, staff, trainees, and others who were critical to their scope of work. The Cross-Center Evaluation work group developed inclusion criteria to assist centers in developing their

network survey participant list. Inclusion criteria for ISC³ network membership were: faculty members supported directly by ISC³ funds and/or directly involved in ISC³ activities; staff members supported by ISC³ funds whose main role was research (research staff); and doctoral and post-doctoral trainees supported directly through ISC³ funds and/or who were involved in the center's research. NCI ISC³ program staff and leadership were also included as invitees because of their role in many of the network activities, including product development and capacity building. Across the seven ISC³ centers and NCI, a total of 192 individuals were invited to participate (range 11-51 invitees per center).

Data collection

Westat evaluators invited participants by email to complete a 10-25 minute web-based network survey in September 2020. The Cross-Center Evaluation work group provided input on the email invitation text and center leadership were asked to send an introductory email to precede the invitation. NCI leadership presented information about the annual ISC³ meeting in September 2020 and encouraged center members to participate. The online module included a feature for participants to save their survey progress and then return to finish at a later time. Automated reminder emails were delivered two times. In addition, center leaders were supplied weekly with their center's list of non-respondents. The survey remained open for six weeks. This study was deemed nonhuman subjects' research by the National Cancer Institute Office of Human Subjects Research Protections (20-NCI-000084) and the Westat Institutional Review Board (No. 00005551).

Measures

The survey asked participants to identify those with whom they had direct contact within the past 12 months across a roster of all 192 invited individuals. The full survey is provided in **Additional File 1**. Examples of direct contact included meetings, work groups, phone calls, and emails (participants were asked not to count contact based solely upon listservs or mass emails). We measured contact in three categories: 1) "I do not know this person"; 2) "I know who this person is, but we have had no contact"; and 3) "I have had contact with this person at least once in the last 12 months."

A set of follow-up questions asked about five potential collaborative activities for individuals with whom the participant had contact in the past 12 months: 1) "Planned or conducted research (e.g., grant writing, study design or execution)" (hereafter referred to as *planning/conducting research*); 2) "Engaged in capacity building (e.g., trainings, learning communities, mentoring)" (hereafter referred to as *capacity building*); 3) "Developed products in cross-center work group or committee (e.g., measures database, survey instrument)" (hereafter referred to as *product development*); 4) "Disseminated research to a science audience (e.g., scholarly publication, conference presentation)" (hereafter referred to as *scientific dissemination*); and 5) "Disseminated research to a non-science audience (e.g., evaluation report, policy brief)" (hereafter referred to as *practice/policy dissemination*).

The survey also assessed various participant characteristics. Participants identified their scientific discipline (public health, medicine, psychology, social work, other), length of years worked in their field (less than 5 years, 5 to 9 years, 10-15 years, more than 15 years), role within the ISC³ initiative (doctoral student, post-doc, staff, faculty, NCI staff, other), gender identity (male, female, transgender, gender non-conforming, other), and racial and ethnic background (American Indian or Alaska Native, Asian, Black or African American, Hispanic or Latino, Native Hawaiian or Pacific Islander, white, other). Participants also identified their level of expertise in IS (beginner, intermediate, advanced).

Data Analysis

Network data were cleaned and analyzed using R with the igraph package for network analysis (25). Ties were symmetrized for undirected analysis, a common approach for networks where relational direction is not a major focus and collaboration is assumed from either direction (18, 26). Therefore, in our network, a nomination indicates a collaboration activity exists between two nodes and is undirected (if A nominates B, then A/B are connected whether or not B reciprocates the nomination). We explored the network structure visually (graphs) and descriptively across the five separate activity networks and the network of all activities combined. Quantitative descriptive measures include density, degree centralization, betweenness centralization, transitivity, number of isolates, and proportion of collaborations within and across centers.

Density is a network measure that represents the overall connectivity or degree of cohesion within a network. It is calculated as the ratio of the number of ties to the total number of possible ties in the network, ranges from 0 to 1 and can be expressed as a proportion (27). *Centralization* measures hierarchy in networks or the extent that connections in the network are dependent on a select few most central nodes in the network (0 to 1). *Degree centralization* is calculated based on the number of connections where a higher degree centralization represents more hierarchy in the network or that one or more nodes hold most of the connections in the network (0 to 1). *Betweenness centralization* is calculated based on geodesic, or shortest paths, between nodes and is used to measure the extent to which networks contain bridge or gatekeepers where higher betweenness centralization would signify that one or a few nodes are responsible for holding the network together (0 to 1) (28). *Transitivity* is a measure of probability of triangles within a network or how likely ties are to form between nodes that share a common collaborator (0 to 1). For example, if A and B are connected, and B and C are connected, transitivity represents the probability that A and C are also connected (28). *Isolates*, or those nodes without any network connections, identify where opportunities for collaboration exist. We examined isolates for node-attribute level patterns. To measure the amount of collaboration happening between the different centers and NCI, we looked at percentage of all ties that were between members from separate centers.

For the number of nominations for each node, we examined median degree and range of ties. We used Kruskal-Wallis chi-square tests (non-parametric alternative to one-way ANOVA) to determine rank order differences in number of connections across categories of participant characteristics.

We conducted a sensitivity analysis to explore the influence of extreme outdegree levels on our findings (i.e., accounting for respondents who nominated many collaborators). To do so, we replicated all analyses using a reduced dataset that removed outgoing unreciprocated ties from “outlier” respondents. Outliers were defined as those with an outdegree more than 1.5 times the interquartile range above the third quartile ($Q3+1.5*IQR$) for each type of collaboration. We used the STROBE cross-sectional reporting guidelines detailed in **Additional File 2** (29).

Results

A total of 182 participants completed the survey (95% response rate) ranging from 91% to 100% across centers. In network analysis, survey non-respondents are still considered as members in the full network because respondents are still able to nominate non-respondents. Therefore, our total network contained 192 members. Characteristics of ISC³ network members are reported in **Table 1**. Non-respondents (n=10) were excluded from counts/totals where participant characteristic information is necessary. Most participants reported their primary discipline as public health (54.4%) or medicine (24.2%). More than two-thirds (69.8%) of network members reported ten or more years of experience in their field. The most prevalent network roles were faculty (60.4%) and center staff (23.6%). The largest proportion of network members reported intermediate expertise in IS (41.8%), followed by beginner (35.2%) and advanced (23.1%) expertise. Most members identified as female (68.7%) and white (78.7%).

Network Characteristics

With *all collaboration activities* combined, the ISC³ network included 192 members with a total of 2480 collaboration ties, of which members had a median 22 connections (**Table 2**). **Figure 1** shows the network for *all collaboration activities* combined and **Figure 2** displays the network for each separate collaboration activity. The greatest number of ties were reported in *planning/conducting research* (1470 ties; median 15 ties/member) and the fewest ties were reported in *practice/policy dissemination* (284 ties; median 2 ties/member). The ISC³ density for *all collaboration activities* was 13.5%. Across the different collaboration types, the most and least densely connected network activities were *planning/conducting research* (8.2%) and *practice/policy dissemination* (2.6%), respectively. The *practice/policy dissemination* network was the smallest network with just 143 of the 192 ISC³ network members represented whereas the other networks ranged from 173-190 members.

The overall ISC³ network was fairly decentralized (degree centralization=0.33 and betweenness centralization=0.07; **Table 2**) consistent with **Figure 1**’s basic linked local networks shape (no strong central node or group of nodes). For separate activities, *capacity building* and *product development* had the highest degree centralization (0.23 and 0.21, respectively) compared to other collaboration activities, which ranged from 0.12 to 0.17, suggesting influential positions for some members in these networks (“hub and spoke” network structure). *Scientific dissemination* and *practice/policy dissemination* networks had the highest

betweenness centralization (0.23 and 0.20, respectively), suggesting some members may be closer to each other and/or are more easily connected or reached. As more connections “pass” through these central members, their removal would result in high number of isolates.

Overall, the ISC³’s transitivity (0.47) suggests heightened probability of triangles in the network, though variation exists across collaboration types. *Planning/conducting research* had the highest transitivity measure (0.56) compared to all other collaboration networks (transitivity range: 0.33 to 0.37), suggesting that two investigators that are collaborating with the same investigator are likely to also be collaborating with each other.

One-third of all collaboration ties (33.0%) occurred between members from different centers. For specific collaboration activities, we observed the largest portion of cross-center collaboration in *product development* (48.1%), which includes involvement with cross-center work groups. Collaborating on *practice/policy dissemination* and *planning/conducting research* mostly occurred within members’ respective centers (6.0% and 11.7% cross-center ties, respectively). Network members had a median 17 connections within their own center and 7 connections from other centers across all activities.

There were no isolates for the *all collaboration activities* network because our overall network was derived from having at least one collaboration activity reported. Notably, *practice/policy dissemination* and *product development* were the two activity networks with the largest number of isolates, 22% and 10% of the total number of network members (n=43 and n=19, respectively).

Descriptive analysis on isolates from these two activity networks showed that half of ISC³ trainees (n=6) were not connected in *product development* whereas other roles represented 0-33% of isolates. For *practice/policy dissemination*, 44.4% (n=8) of those with less than 5 years of experience in their field were not collaborating, compared to those categories with more experience (range 16.1%-16.9%). NCI staff (n=5) and trainees (n=4) also made up larger portions of isolates in the *policy/practice dissemination* network (45.5% and 33.3%, respectively).

Connectivity by Participant Characteristics

In *all collaboration activities* combined, the number of connections (degree) varied significantly across ISC³ roles ($\chi^2=10.59(4)$, $p=0.032$), IS expertise level ($\chi^2=34.42(2)$, $p=<0.001$), and racial/ethnic background ($\chi^2=13.14(4)$, $p=0.011$) (**Table 1**). Among groups with the highest median degree were those with advanced IS expertise (39.5 (range: 12-89) ties), NCI staff (28 (6-65) ties), and Hispanic or Latino network members (32 (24-45) ties). Median degree did not vary significantly across discipline, years of experience, or gender identity for all activities combined.

Network members had a median of 15 collaborations (range 1-48) in *planning/conducting research* which varied significantly across IS expertise level ($\chi^2=15.74(2)$, $p=<0.001$), network role ($\chi^2= 27.94(4)$, $p=<0.001$), and race/ethnicity categories ($\chi^2=25.52(4)$, $p=<0.001$). Those with advanced expertise in IS reported the highest number of collaborations (Mdn 20: range 5-48). Other groups with the highest median number of connections were faculty and staff (Mdn 17: range 5-48 and Mdn 17: range 4-29), and Hispanic or Latino respondents.

Median degree for *capacity building* activities was 10 (range 1-58) and varied across IS expertise level ($\chi^2=34.17(2)$, $p=<0.001$) and ISC³ role ($\chi^2=11.97(4)$, $p=0.018$). Members with advanced IS expertise (Mdn 24: range 4-58) and NCI staff (Mdn 20: range 6-53) had the most connections. The least connected members were staff (Mdn 7: range 1-48) and those with beginner IS expertise (Mdn 7: range 1-49).

The *product development* network members had a median of 6 collaborations (range 1-45), which varied significantly across years of experience in field ($\chi^2=17.81(3)$, $p=<0.001$), role ($\chi^2=10.06(4)$, $p=0.039$), and IS expertise level ($\chi^2= 20.21(2)$, $p=<0.001$). Across years of experience categories, those with more than 15 years of experience in their field were the most connected (Mdn 10: range 1-45). For role, NCI staff (Mdn 7.5: range 3-45) and faculty (Mdn 7.5: range 1-42) had the same median number of connections. And across IS expertise, advanced members had the largest number of connections in activities to develop products (Mdn 9: range 1-45).

Network members had a median of 5 collaborations (range 1-30) in *scientific dissemination* activities. The number of collaborations in this activity network varied significantly across years of experience in the field ($\chi^2=12.40(3)$, $p=0.006$), role

($c^2=11.31(4)$, $p=0.023$), IS expertise ($c^2=40.80(2)$, $p=<0.001$), and racial/ethnic background ($c^2=22.50(4)$, $p=<0.001$). The most connected members were Hispanic or Latino (Mdn 16: range 4-19) and advanced IS experts (Mdn: 12: range 1-30).

Practice/policy dissemination connections varied significantly across discipline ($c^2=7.20(2)$, $p=0.027$) categories and role ($c^2=12.10(4)$, $p = 0.017$) and had an overall median degree of 2 (range 1-22). Across disciplines, public health and medicine both had a median of 3 collaborations (range 1-21 and 1-22, respectively) and other disciplines had slightly less (Mdn 2: range 1-10). Across roles, staff had the highest median number of connections (Mdn 4: range 1-22), followed by faculty (Mdn 2: 1-21), trainees (Mdn 2: range 1-5), other (Mdn 1: range 1-6), and NCI staff (Mdn 1: range 1-2).

Sensitivity Analysis

Full results from our sensitivity analysis are available in **Additional File 3**, in which we adjusted for extreme outdegree levels. For example, for *all collaboration activities* combined, the number of ties was reduced from 2480 to 2419 as a result of removing outgoing unreciprocated ties from “outlier” respondents ($n=4$) with an outdegree more than $Q3+1.5*IQR$. Network- and node-level characteristics were generally similar across the full and reduced datasets for each type of collaboration, however we note the following exceptions: (1) when comparing across roles in ISC³, we observed nonsignificant differences in the number of connections for *product development* and *practice/policy dissemination*; (2) we observed a significant difference in the number of *practice/policy dissemination* connections by IS expertise, with the highest median number of connections among those reporting advanced expertise (Mdn 2.5; range 1-7) followed by those with beginner (Mdn 2; range: 1-9) and intermediate (Mdn 1; range: 1-8) expertise; (3) there were fewer median *capacity building* ties among Black or African American respondents (Mdn 11 in the full analysis vs. 6 in the sensitivity analysis); and (4) a large increase in the number of *practice/policy dissemination* isolates ($n=43$ in full analysis; $n=65$ in sensitivity analysis).

Discussion

Overall, the ISC³ network in its first year was highly connected within each center (intra) and had modest linkages between members from different centers (inter). We found that one-third of all ties were inter-center collaborations. Okamoto et al. (2015) demonstrated a similar measure of cross-center collaboration in their social network study across ten geographically distanced NCI Centers for Population Health and Health Disparities (CPHHD). CPHHD's findings reported 7% cross-center ties (17). Though direct comparisons across networks should be made with caution, Okamoto et al.'s methods and findings provide a similar approach to understanding linkages in a multi-center initiative. The infrastructure and time to develop and support a network-wide survey is considerable. This is likely reflected in the larger number of cross-center ties in CPHHD's prior funding 5-year funding cycle (17%). We surveyed ISC³ members at the end of our first year of funding, likely inflating our cross-center ties to some degree. ISC³ work groups had already begun to form and work on projects (including the Cross-Center Evaluation work group where the survey originated). Even so, cross-center ties were modest. While the ISC³ network is a newly funded initiative, a number of the centers' leaders have been collaborating and leading the IS field for quite some time. We see that with the advanced IS members being highly connected (beyond the fact that they have been cultivating connections longer) and with that expertise, building and facilitating connectivity is all the more important.

No “ideal” number for density exists as a target and it is necessary to balance access to network members with the cost of maintaining relationships. This balance – understanding the interplay between ideal inter and intra density – is an interesting intersection and warrants additional scientific inquiry. A common measure of inter-intra connectivity is the E-I index which compares ties to members within groups (internal) to those outside of that group (external), though interpreting changes in this measure over time is challenging. Our goal from the activities both planned within and across centers would increase connections in both inter and intra center connections. Future measures could include inter and intra center density to look at how connections change in tandem, instead of inversely to each other. In the interim, year one data helped locate where planned actions, or network interventions (24) should be prioritized and could be leveraged to increase scientific collaboration or overall “organizational efficiency.”

Among network activities, *practice/policy dissemination* collaborations were sparse, with five-fold fewer ties than *planning/conducting research*. This may be attributed to stalled dissemination collaborations in the first year (2020) given

community partners of interest pivoted to COVID-19 response. In addition, low collaboration compared to other activities could be due to investigators focusing on intra and inter-network project planning in the first year of a brand new initiative that more generally precede dissemination to non-science audiences. However, to enhance dissemination to audiences other than researchers, more attention is needed on designing for dissemination (in all stages of the initiative), or the “active process that helps to ensure that public health interventions, often evaluated by researchers, are developed in ways that match well with adopters’ needs, assets, and time frames (30, 31).” A number of processes could collaboratively be developed and implemented across the ISC³ including: participatory co-design; context and situation analysis; methods from marketing and business; communications and visual arts; and systems science (31). Such processes could be applied to cross-center projects and also funded pilot work with similar research themes. Processes to determine overlap in research interests can help direct shared, collaborative dissemination. Such information is currently being collected on an annual basis, but establishing systematic communication across centers could be a potential next step for the ISC³ work groups.

Mentoring the next generation of IS investigators is imperative to “grow the network younger” and to assure that early career members have equal access to collaborative activities and can increase scientific production overall (32-35). We posit that early career and underrepresented minority researchers occupying central nodes is essential for a healthy scientific collaboration network. All centers provide funding for post-doctoral positions. Even if post-doctoral positions are not directly funded by ISC³, centers are able to connect early investigators to the larger ISC³ network, providing a platform to connect with other peers in the IS field from several other universities. In addition, a work group in Capacity Building formed to increase opportunities and access to resources in the ISC³ network. In examining isolates in each category, we found that half of the network’s trainees were not actively collaborating in cross-network work groups. Providing opportunities for leadership roles to early career and IS trainees could provide for more inclusion in specific activity networks and integrate them into the broader networks that serve ISC³ and cancer prevention and control more broadly. Currently, five work groups exist in the ISC³ and are specific places where purposeful engagement of trainees could connect them not only to network activities, but also potential senior mentors outside of their respective centers. Mentoring and access to external experts increased peer-to-peer collaborations (and mentoring) among trainees in an IS training program (33). With longitudinal surveys, we are able to examine any shifts in key connections for others in the network. For example, the NCI Transdisciplinary Research on Energetics and Cancer network demonstrated the utility of social network analysis in measuring changes in dispersion of responsibilities and other network functions through examining brokerage roles (15). Providing leadership roles in work groups, access to experts and pilot funding earmarked for early career investigators or trainees will likely result in shifting network dynamics. In addition, ISC³ developed a supplemental funding avenue to enhance IS health equity work across the network. Such funding could be a promising mechanism to design features to include less connected, investigators/researchers and also promote cross-center collaborations.

We found that Hispanic or Latino and white members were highly connected across the various network activities. It is important to note that Hispanic or Latino members only make up <3% of the entire network and white members the majority (79%). In general, Black, Hispanic or Latino, Native American, and other groups are under-represented in the ISC³ network. This points to the need for more efforts to assemble and engage a diverse set of network members. Recently, Leone Scialbolazza and team created a network alteration program that paired previously unconnected researchers within a university through a pilot awards (22). Researchers were introduced and offered a monetary incentive to submit a joint letter of intent for pilot funding. This is one of many opportunities to actively shape the composition and structure of the network.

While these findings inform strategies to enhance scientific linkages across the network, important limitations should be noted. First, it is possible that not every network member is positioned or skilled to be involved with every activity that we identified and collected information on. Social network surveys are self-report and can introduce some respondent bias, and symmetrizing ties has implications for both respondents who tend to over report and those that under report collaborations. However, our sensitivity analyses demonstrated that extreme cases had little impact on our overall network statistics. It is also possible that we missed people in the network with our center-identified roster approach, though with guidance on inclusion criteria, we believe this was likely minimized. Our network analysis included only researchers and given the importance of partnerships and stakeholders to all seven centers, we are not able to examine networks outside the university setting in the current study.

This study illustrates the range of insights offered by a network evaluation for multi-center research initiatives. The analysis highlighted several opportunities to increase participation in cross-center networks and activity-specific networks (e.g., dissemination to practice/policy audiences). The early evaluation of network participation also provides centers with an opportunity to improve engagement and retention of under-represented groups, including racial and ethnic minorities and trainees. Future directions include additional social network data collection and comparisons of network activity and growth as part of the outcomes of center-focused initiatives over the five-year funding period.

Conclusion

We presented baseline scientific linkages across a robust network of centers working in implementation science in cancer control. The centers are fairly cohesive and have considerable cross-center collaborations underway. Even so, this snapshot highlights parts of the network where linkages should grow in order for the ISC³ initiative to meet its objectives including increasing the number of trainees, enhancing practice and policy dissemination, and expanding engagement among members from underrepresented minority groups. Targeted interventions within the network are next steps with plans to use this study as a baseline to measure changes in the network over time.

Abbreviations

ISC³- Implementation Science Centers for Cancer Control

IS- Implementation Science

Declarations

Not applicable.

Ethics approval and consent to participate

This study was deemed nonhuman subjects' research by the National Cancer Institute Office of Human Subjects Research Protections (20-NCI-000084) and the Westat Institutional Review Board (No. 00005551).

Consent for publication

Not applicable.

Availability of data and material

The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests

Authors have no competing interests to declare.

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Authors' contributions

All authors were involved in the conceptualization and design of this study. All authors were involved in the development of the social network survey tool. GCH distributed, collected, and processed/cleaned all survey data. ARK completed all social network

analysis for this study. All authors were involved with the interpretation of findings. RRJ led the write up of results in the original manuscript draft and subsequent drafts. All authors contributed to, read and approved the final manuscript.

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Contributions to the literature

We conducted a social network survey among the seven Implementation Science Centers in Cancer Control and the National Cancer Institute Division of Cancer Control and Population Sciences in order to track network growth and identify areas to target network interventions. The resulting snapshot is important to the field of implementation science because:

- Increasing network cohesion affects how we “do business” as researchers, cross-pollinating and likely speeding the production, dissemination, and adoption of scientific findings.
- Determining network actions to better engage disconnected and under-represented members can be used as a guide for other initiatives.
- Using social network data as an evaluation tool can be an effective way to understand the processes involved in enhancing scientific collaboration.

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Tables

Table 1. Implementation Science Centers for Cancer Control (ISC³) Year 1 network participant characteristics (n=192).

Characteristic	Participant Characteristics		Median (range) degree by collaboration activity <i># of collaboration ties</i>					
	n (%)	Range by center %, %	All collaboration activities	Planning/conducting research	Capacity building	Product development	Scientific dissemination	Practice/policy dissemination
Discipline								
Public health	99 (54.4)	18.2, 72.7	24 (2, 89)	15 (1, 48)	12 (1, 58)	8 (1, 45)	5 (1, 27)	3 (1, 21)
Medicine	44 (24.2)	9.1, 54.5	21.5 (6, 59)	17.5 (6, 41)	9 (2, 53)	6 (1, 42)	7.5 (1, 23)	3 (1, 22)
Other ^a	39 (21.4)	4.5, 42.9	20 (4, 58)	14 (1, 34)	9 (1, 44)	4 (1, 30)	4 (1, 30)	2 (1, 10)
Experience in field								
< 5 years	18 (9.9)	0, 20.0	20 (7, 39)	14 (4, 26)	8 (1, 26)	4 (1, 23)	2 (1, 26)	1.5 (1, 8)
5-9 years	37 (20.3)	4.8, 29.2	24 (2, 54)	13 (2, 28)	11 (1, 53)	4.5 (1, 23)	4 (1, 19)	2 (1, 14)
10-15 years	56 (30.8)	9.1, 43.5	22 (8, 58)	18 (4, 41)	9.5 (1, 49)	5.5 (1, 36)	7 (1, 23)	2 (1, 22)
> 15 years	71 (39.0)	20.8, 72.7	24 (4, 89)	15.5 (1, 48)	11 (2, 58)	10 (1, 45)	7 (1, 30)	3 (1, 21)
Role								
Trainee	12 (6.6)	0, 9.1	19.5 (2, 39)	8.5 (2, 21)	12.5 (1, 32)	2 (1, 5)	2.5 (1, 26)	2 (1, 5)
Staff	43 (23.6)	0, 58.3	20 (5, 55)	17 (4, 29)	7 (1, 48)	7 (1, 23)	3 (1, 30)	4 (1, 22)
Faculty	110 (60.4)	0, 100	24 (4, 89)	17 (5, 48)	11.5 (1, 58)	7.5 (1, 42)	7 (1, 27)	2 (1, 21)
NCI staff	11 (6.0)	0, 100	28 (6, 65)	6 (1, 16)	20 (6, 53)	7.5 (3, 45)	6 (1, 28)	1 (1, 2)
Other ^b	6 (3.3)	0, 13.0	12.5 (7, 33)	11 (4, 14)	9.5 (2, 25)	4.5 (2, 9)	5 (1, 8)	1 (1, 6)
IS expertise level								
Beginner	64 (35.2)	8.7, 58.3	20 (2, 57)	14 (1, 41)	7 (1, 49)	4 (1, 25)	3 (1, 21)	2 (1, 18)
Intermediate	76 (41.8)	28.6, 65.2	20 (4, 55)	14 (1, 29)	9 (2, 53)	5.5 (1, 32)	5 (1, 26)	2 (1, 22)
Advanced	42 (23.1)	8.3, 36.4	39.5 (12, 89)	20 (5, 48)	24 (4, 58)	9 (1, 45)	12 (1, 30)	3 (1, 21)
Gender identity^c								
Female	125 (68.7)	45.0, 79.2	24 (5, 65)	15.5 (1, 41)	12 (1, 53)	8 (1, 45)	6 (1, 30)	3 (1, 22)
Male	56 (30.8)	18.2, 55.0	20 (2, 89)	17 (2, 48)	8 (1, 58)	6 (1, 36)	5 (1, 28)	2 (1, 21)
Racial/ethnic background^d								
White	140 (78.7)	65.2, 100.0	23.5 (4, 89)	17 (1, 48)	11 (1, 58)	8 (1, 42)	7 (1, 30)	3 (1, 22)
Asian	18 (10.1)	0.0, 17.4	18 (2, 65)	11.5 (2, 20)	6.5 (1, 32)	5 (1, 45)	2 (1, 11)	2 (1, 5)
Black or African American	11 (6.2)	0.0, 14.3	13 (5, 50)	8 (1, 21)	11 (2, 48)	5 (2, 14)	2 (1, 9)	2.5 (1, 8)
Hispanic or Latino	5 (2.8)	0.0, 8.7	32 (24, 45)	21 (14, 24)	19 (10, 27)	7 (3, 24)	16 (4, 19)	1 (1, 13)
Other	4 (2.2)	0.0, 10.0	19 (11, 30)	6 (4, 18)	7.5 (6, 22)	7 (2, 15)	6 (4, 9)	2 (1, 7)

IS = implementation science; NCI = National Cancer Institute. Bold values indicate Kruskal-Wallis chi-square test value p<0.05.

^a Examples of other disciplines include psychology, social work, economics, health services research, and implementation science.

^b Examples of other roles included consultants and advisors.

^c n=181

^d n=178

Table 2. Implementation Science Centers for Cancer Control (ISC³) Year 1 collaboration network descriptive characteristics.

Network characteristic	All collaboration activities	Planning/conducting research	Capacity building	Product development	Scientific dissemination	Practice/policy dissemination
N Ties	192 2480	190 1470	190 1336	173 825	185 654	149 284
% cross-center	33.0	11.7	31.0	48.1	23.5	6.0
Median degree (range)	22 (2, 89)	15 (1, 48)	10 (1, 58)	6 (1, 45)	5 (1, 30)	2 (1, 22)
within-center	17 (2, 50)	13 (1, 44)	7 (1, 48)	4 (1, 25)	4 (1, 25)	2 (1, 21)
cross-center	7 (1, 56)	3 (1, 17) 8.2	3 (1, 43) 7.4	5 (1, 40) 5.5	2 (1, 20) 3.8	1 (1, 4) 2.6
Density (%) ^a	13.5					
Betweenness centralization ^b	0.07	0.12	0.13	0.11	0.23	0.20
Degree centralization ^b	0.33	0.17	0.23	0.21	0.12	0.12
Transitivity ^c	0.47	0.56	0.37	0.34	0.33	0.33
Isolates	0	2	2	19	7	43

IS = implementation science; NCI = National Cancer Institute.

^aDensity is the ratio of the number of ties to the total number of possible ties in the network; often used to measure the overall connectivity of a network or degree of cohesion among a network of collaborators [0, 1].

^bCentralization is used to assess the extent of hierarchy in the network; extent that connections in the network are associated with a select few most central nodes in the network [0, 1]. Degree centralization is based on the number of connections (higher degree centralization=one or more nodes hold most of the connections), whereas betweenness centralization is used to measure the extent to which each network member represents a bridge or gatekeeper to others in the network (based on the number of connections or paths in the network an individual lies between, higher betweenness centralization=one or a few nodes responsible for holding network together).

^cTransitivity is a measure of clustering [0, 1] with higher transitivity suggests that new ties are more likely to form between nodes that share a common collaborator (e.g. referred by an existing collaborator).

Figures

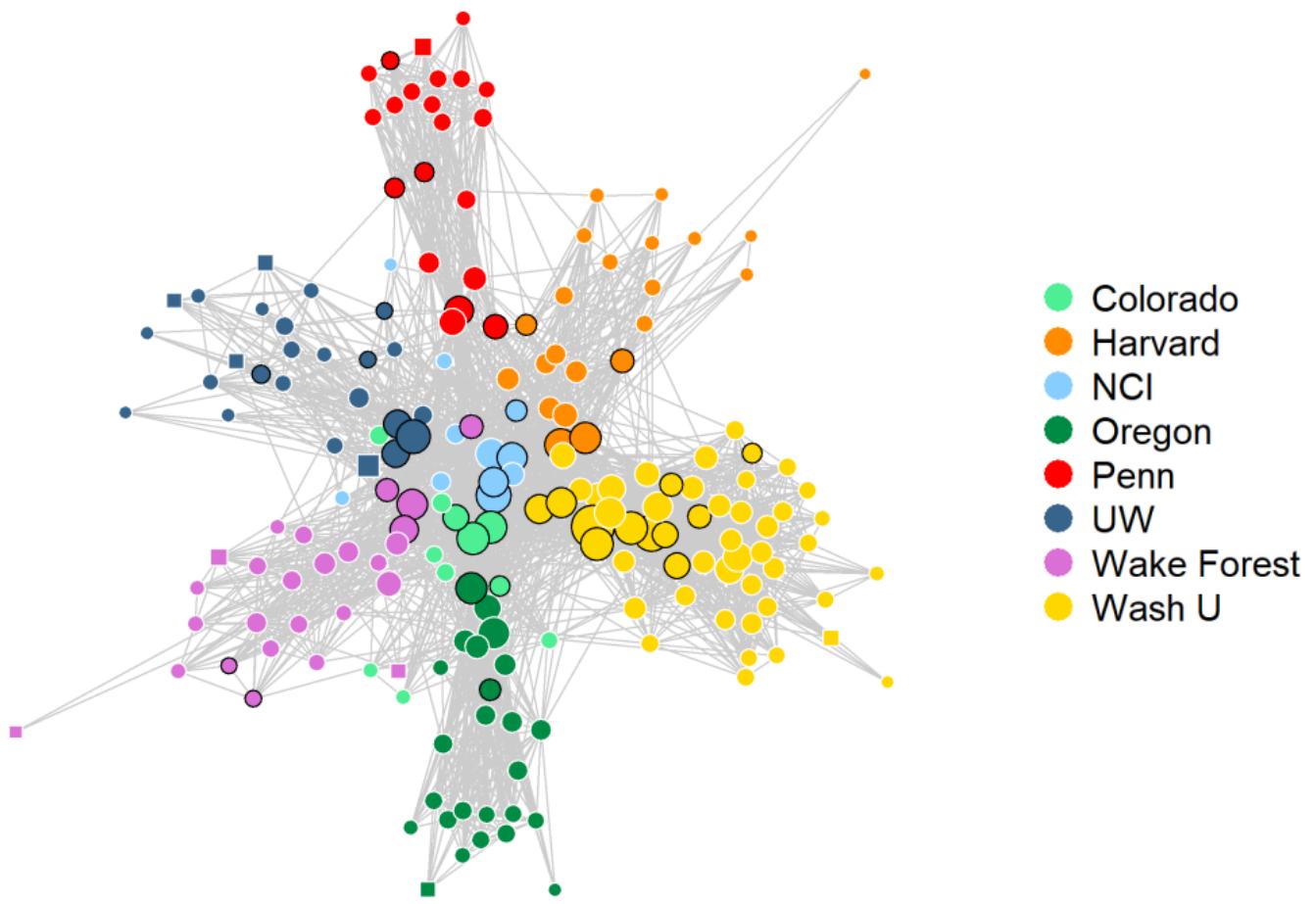


Figure 1

ISC3 network of all collaboration activities combined (n=192). Node color represents ISC3 center, node size represents degree centrality scores, and nodes with black borders indicate those reporting "advanced" expertise in implementation science. Square nodes represent those with missing information about IS expertise (n=10).

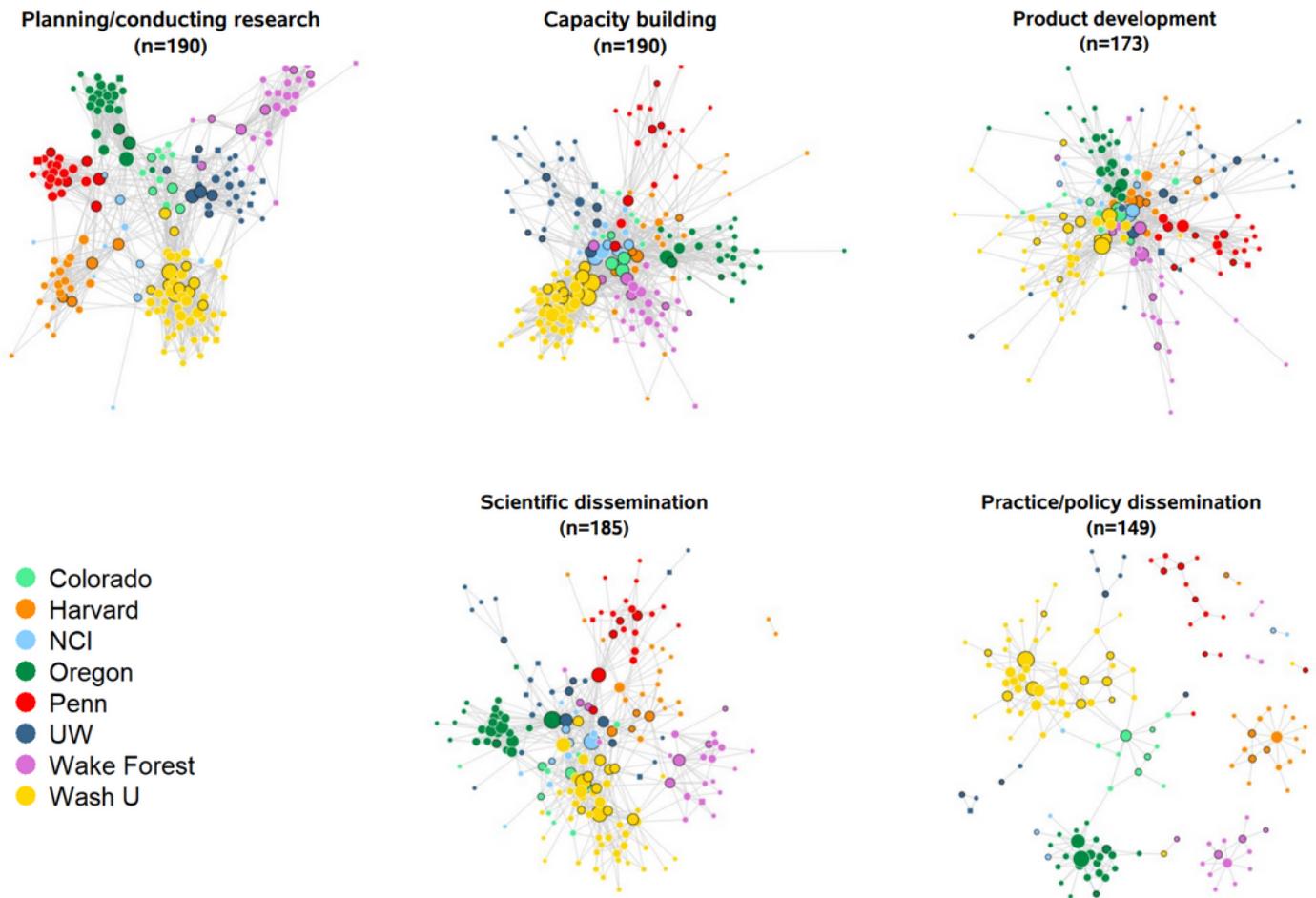


Figure 2

ISC3 collaborations in five network activities. Node color represents ISC3 center, node size represents degree centrality scores, and nodes with black borders indicate those reporting “advanced” expertise in implementation science. Square nodes represent those with missing information about IS expertise (n=10).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalfile1.Survey.docx
- Additionalfile2.STROBEchecklist.docx
- Additionalfile3.Sensitivityanalysistables.docx