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Network Analysis of Team Structure in the Neonatal Intensive Care Unit

WHAT'S KNOWN ON THIS SUBJECT: For maximal effectiveness, NICU care requires the interaction of well-functioning teams composed of large, diverse groups of individuals.

WHAT THIS STUDY ADDS: By applying network analytic techniques to information contained in EHRs, we show that family perceptions of NICU nursing care are more strongly associated with nursing team structure than with team size.

abstract

OBJECTIVE: The goal was to examine nursing team structure and its relationship with family satisfaction.

METHODS: We used electronic health records to create patient-based, 1-mode networks of nursing handoffs. In these networks, nurses were represented as nodes and handoffs as edges. For each patient, we calculated network statistics including team size and diameter, network centrality index, proportion of newcomers to care teams according to day of hospitalization, and a novel measure of the average number of shifts between repeat caregivers, which was meant to quantify nursing continuity. We assessed parental satisfaction by using a standardized survey.

RESULTS: Team size increased with increasing length of stay. At 2 weeks of age, 50% of shifts were staffed by a newcomer nurse who had not previously cared for the index patient. The patterns of newcomers to teams did not differ according to birth weight. When the population was dichotomized according to median mean repeat caregiver interval value, increased reports of problems with nursing care were seen with less-consistent staffing by familiar nurses. This relationship persisted after controlling for factors including birth weight, length of stay, and team size.

CONCLUSIONS: Family perceptions of nursing care quality are more strongly associated with team structure and the sequence of nursing participation than with team size. Objective measures of health care team structure and function can be examined by applying network analytic techniques to information contained in electronic health records. *Pediatrics* 2010;125:e1460–e1467

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KEY WORDS

neonatal intensive care, network analysis, satisfaction, quality improvement, electronic health record

ABBREVIATIONS

EHR—electronic health record
RCI—repeat caregiver interval
MRCI—mean repeat caregiver interval

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Despite the incredible advances in neonatal intensive care in the past 3 decades, NICU patients remain at substantial risk of preventable medical harm, including adverse drug events, nosocomial infections, and morbidities that are unique to premature infants.[1–3] In addition to intrinsic patient susceptibility, the increased risk results in part from the complexity and long duration of NICU stays. Cohesive, well-functioning, multidisciplinary teams must assemble at the patient level to manage information flow accurately and to provide seamless care during extended, complex hospitalizations. However, maintaining effective, well-functioning teams is a daunting challenge during hospital stays that may include up to 300 nursing transitions/handoffs at shift changes. Identification of solutions has been hampered by the lack of robust methods for quantification of the nature of team interactions, to identify patterns that are potentially associated with adverse events.[4,5] The availability of network analytic tools to apply to complex systems such as those involved in NICU care provides an opportunity to enhance the research on effective team structure and function.

This project was designed as a demonstration of the use of network analysis to describe the structure of NICU nursing care teams. Using data from the electronic health record (EHR) of a large, tertiary care NICU, we explored the topologic features of nursing handoff networks and examined the relationship between network characteristics and one aspect of quality, namely, family satisfaction with care.

METHODS

Patient Population

Infants admitted to the NICU at the Beth Israel Deaconess Medical Center between January 1, 2002, and December 31, 2007, were considered for inclusion if ≥1 nursing care handoff occurred during their NICU stay. Demographic characteristics, including birth weight and gestational age, were recorded.

Creation of Nursing Handoff Networks

The NICU EHR was queried to identify all nurse-patient interactions during the study period. A nurse was considered to have cared for a patient if a progress note from the nurse was contained within the patient's record. During each nursing shift (generally 12 hours in length), ≥1 note is written by the nurse caring for a patient, according to unit policy. Notes written by patient care assistants and registered nurses working in other roles, such as case management, were not considered. If >1 note was written by an individual nurse during a shift, then the second note was excluded. Note timestamps were used to identify the sequence of nurse participation. From this data set representing nurse-patient interactions, we extracted patient-level networks, representing the handoffs that occurred between nurses in an individual patient's care.

Network Visualization

Pajek (Available at: http://vlado.fmf.uni-lj.si/pub/networks/pajek/.),[6] a freely available, noncommercial program for network visualization, was used for network display. Data from the EHR-generated networks were transformed to Pajek-compatible input files. In these patient-based, directed network graphs, nodes represent nurses participating in the index patient's care, while edges represent the handoffs between nurses. The directionality of handoff is represented by the arrowheads at the ends of each edge. Node placement in graphical depictions of the networks was determined through application of the Kamadi-Kawai algorithm.[6]

Calculation of Network Statistics

For each patient, network size was calculated as the number of unique nurses (nodes) contained in the patient's handoff network. In addition, we examined other standard network statistics at the individual patient level, that is, a measure of the largest number of intermediate handoffs involved in the transfer of information from one nurse to another in that patient's care network (effective network diameter) and a measure of the degree to which the network has a center of influence (ie, has a group of central nodes that are positioned to control/affect information flow and communication), termed the network betweenness centrality index.[7] The final measure, which ranges between 0 and 1, quantifies the dispersion of each node's relative influence on communication within the network (node betweenness centrality). Higher values are seen in networks dominated by a smaller number of important nodes.[8] For each of these measures, we dichotomized the population on the basis of the median value seen among study subjects.

For each nursing shift, a nurse was considered a newcomer if he or she had not previously been part of the patient's handoff network. The proportion of newcomer shifts in a patient's nursing care team was calculated as the number of shifts provided by newcomer nurses divided by the total number of nursing shifts contained in the network.

To quantify the continuity of nursing care provided, we developed another network metric on the basis of the concept of network cycles.[7] The mean repeat caregiver interval (MRCI) was calculated as follows. For each patient, beginning at the first nursing shift, we counted the number of shifts until the first care provider who had already cared for that patient was encountered. This was considered the repeat

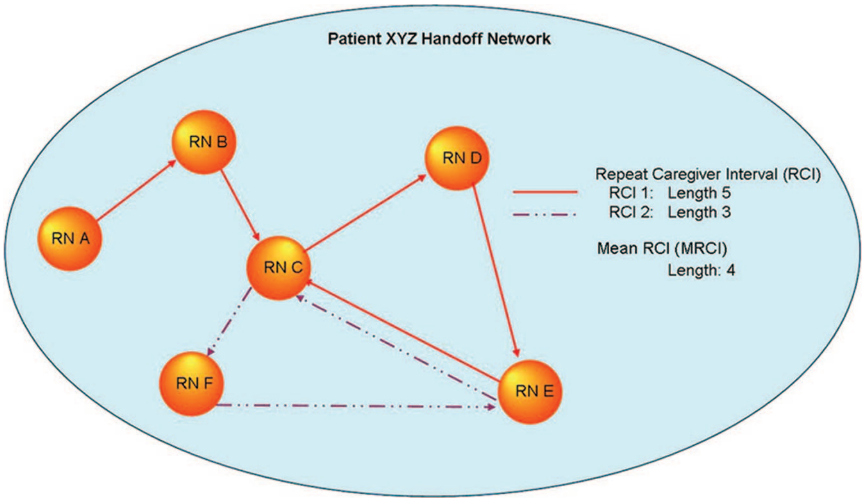


FIGURE 1
Construction of patient-based nursing care teams and handoff networks. The sequence of nurse handoffs for this hypothetical patient is nurse A to nurse B to nurse C to nurse D to nurse E to nurse C to nurse F to nurse E to nurse C. The nursing network size is 6, and the first RCI involves 5 handoffs (ie, nurse A to nurse B to nurse C to nurse D to nurse E to nurse C) (solid lines). The second RCI begins with the last nurse in the first RCI (eg, nurse C) and involves 3 handoffs (ie, nurse C to nurse F to nurse E to nurse C) (dashed lines). The MRCI is therefore 4. The proportion of shifts provided by newcomer nurses is 77% (eg, 7 of 9 shifts). RN indicates nurse.

caregiver interval (RCI). Beginning at the end of the previous RCI, this process was repeated iteratively to determine subsequent RCIs for the index patient. RCIs were then summed per patient and divided by the number of RCIs encountered, to provide a MRCI for the patient. This process is diagrammed in Fig 1. MRCI values were dichotomized as low or high relative to the median MRCI value for the cohort. We explored the relationship between MRCI values and family satisfaction with the nursing care received.

Measurement of Family Satisfaction With Care

The Picker Institute Neonatal Intensive Care Unit Family Satisfaction Survey[8,9] was used to assess parental perceptions of the care provided to their family. This 74-item written questionnaire was administered as part of routine quality-improvement activities and was sent 1 month after discharge to families with a child who remained in the NICU for ≥2 weeks. Surveys were not sent to families of infants who died or were discharged to chronic care facilities. Results were available for infants admitted in 2006, and this subpopulation was used to examine the relationship between network structure and satisfaction with care.

Responses to each question were tabulated to form a problem score, representing the proportion of questions within a dimension that elicited a problem response. For example, 1 item asks, "How would you rate the way the NICU staff worked together?" Possible responses included poor, fair, good, very good, and excellent. The first 2 of these are characterized as problem responses. Provider-specific problem scores for nurses, physicians, respiratory therapists, and social workers were calculated by tabulating responses for questions relevant to each discipline. Primary analyses were restricted to infants who were discharged directly to home from the NICU. For twins and other multiple gestations, a single infant was chosen randomly for inclusion in these analyses.

Analyses

Statistical analyses were performed by using SAS 9.1 for Windows (SAS Institute, Cary, NC). Univariate comparisons of problem scores from the satisfaction survey were performed by using Student's *t* test. Multivariate testing to control for potential confounders was performed by using logistic regression analysis. The Beth Israel Deaconess Medical Center Committee on Clinical Investigation approved the study.

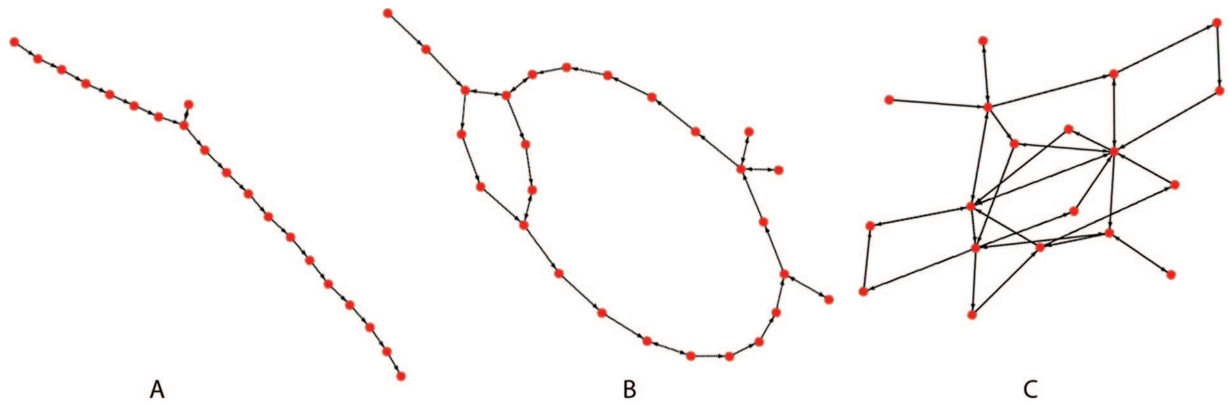
RESULTS

Patient Population

During the study period, 168 nurses provided care to the 3891 infants who were admitted and remained in the NICU for ≥1 nursing handoff. The median length of stay was 9 days (~18 handoffs), with the largest number of handoffs being 311. Characteristics of this group of infants are presented in Table 1. Across the years studied, there was no significant difference in the number of nursing handoffs per patient. The first year of study, 2002, had slightly smaller mean team sizes (19.1 ± 15.1 nurses).

TABLE 1 Characteristics of Study Population

	n (%)
Gestational age	
≤28 wk	367 (9.4)
29–32 wk	820 (21.1)
33–36 wk	1667 (42.9)
≥37 wk	938 (24.1)
Data not available	99 (2.5)
Birth weight	
≤999 g	259 (6.7)
1000–1499 g	488 (12.5)
1500–2499 g	1652 (42.5)
≥2500 g	1388 (35.6)
Data not available	104 (2.7)
Length of stay	
≤7 d	1759 (45.2)
8–14 d	740 (19.0)
15–21 d	399 (10.3)
22–28 d	206 (5.3)
28–60 d	502 (12.9)
>60 d	285 (7.3)



Network Metric	Patient		
	A	B	C
Team Size	20	26	19
Length of stay (nursing shifts)	21	36	42
Percent Newcomer Nurses	95.2%	72.2%	45.2%
Network betweeness centrality index[a]	0.13	0.19	.35
MRCI score[b]	10.0	5.4	4.7

FIGURE 2
Nursing handoff networks for 3 different NICU patients. Nodes represent nurses who provided care during ≥1 shift. Arcs represent handoffs between nurses; each arc may represent more than a single handoff. Twenty nurses cared for patient A over a stay that encompassed 21 nursing shifts. Only a single nurse cared for the patient on >1 shift. Patient B was hospitalized for 36 nursing shifts and was cared for by 26 nurses. Finally, patient C was cared for by 19 nurses during 42 nursing shifts. [a] Possible values range from 0 to 1. A value of 0 indicates that all nurses have same centrality in the network. A value of 1 indicates that the network is organized around a single nurse, whereas intermediate values indicate that a larger group of more-central nurses is present. [b] The MRCI score indicates the average number of nursing handoffs that occur before the index infant is cared for by a repeat caregiver.

Satisfaction survey results were returned and were available for 93 (57%) of 165 eligible infants born in 2006 who were discharged to home. Responding families were similar to nonrespondents in terms of their infants' length of stay, birth weight, gestational age, and nursing team size.

Network Visualization

Figure 2 demonstrates the diversity of network structures seen. The nursing handoff networks varied from linear structures to more-densely connected networks with connections existing between many of the possible nurse dyads. Figure 2 presents 3 such networks and their associated topologic features. The networks in Fig 2 A and B are reminiscent of the game "telephone," in which information is passed from one participant to another, with limited possibilities for previous participants to verify that the retelling of information has been accurate. In contrast, the network in Fig 2C contains multiple opportunities for previous participants to review information and to correct inaccuracies that may result from "transmission" errors. Therefore, the handoff networks in Fig 2 A and B seem less likely to foster continuity of care and adequate, accurate, efficient communication, compared with the more-interconnected network in Fig 2C.

Team Size and Frequency of Newcomers to Care Team

The size of an infant's nursing team increased with longer lengths of stay (Fig 3). For example, for infants who remained in the NICU for 14 nursing shifts, the median number of nurses who cared for the infant was 9.7 nurses (interquartile range: 8–11 nurses). The rate of increase in team size remained high throughout the range of lengths of stay seen. When infants were grouped according to birth weight category (<1500, 1500–2499, or >2500 g), the changes in team size according to duration of hospitalization were similar, which suggests that similar approaches to incorporation of newcomers were used across birth weight categories.

Viewed from a slightly different perspective, the data on team composition could be used to identify the proportion of team newcomers providing care at individual points during a NICU stay (Fig 4). Given our definition of team newcomers, care in all first and second shifts was provided by newcomers. A rapid decrease in the proportion of newcomers was seen over the first 14 nursing shifts (corresponding to 7 days of age, in most cases). Even by the 14th shift, however, 53% of shifts still involved newcomers. Only

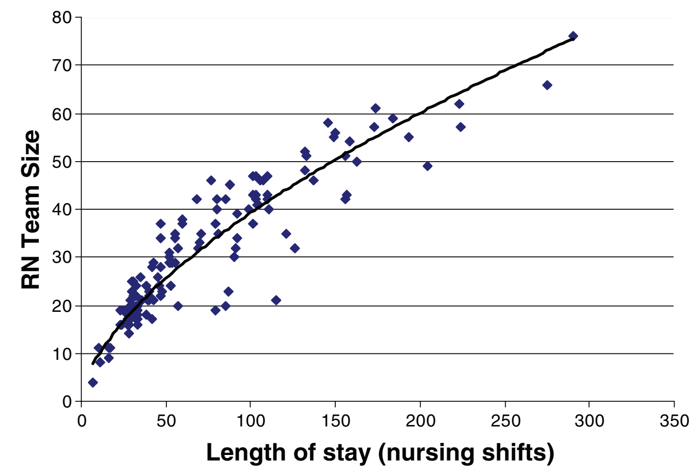


FIGURE 3
Number of nurses involved in a patient's care team as a function of the length of stay. RN indicates nurse.

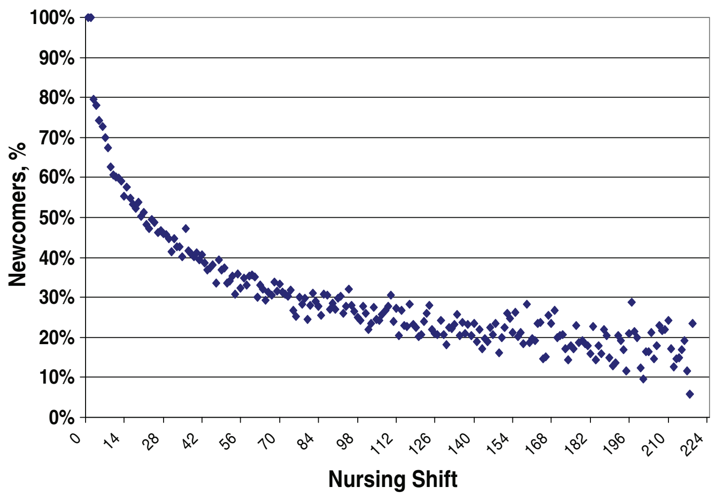


FIGURE 4
Proportion of shifts provided by newcomer nurses according to the duration of hospitalization.

after the 56th shift were $<$1 of 3 shifts provided by a nurse who had not previously cared for the infant.

Although nursing teams for less-mature infants were larger and included more newcomers, those teams showed higher levels of centralization (ie, the presence of a central core of nurses within the nursing team), compared with teams for more-mature infants (Fig 5). Similar trends were seen when infants were grouped according to birth weight. It is interesting to note that there was relatively greater variation in network centralization than in team size among infants with normal birth weights.

Parental Satisfaction With Nursing Care

For the 9 items related to nursing care, most families reported 0 (34.4% of respondents) or 1 (18.3% of respondents) problem responses. The number of problem responses did not differ according to birth weight category or length of stay.

Relationship Between Team Structure and Family Satisfaction

We saw no difference when nursing dimension problem scores for patients with small versus large nursing teams were compared (20% vs 27%; $P > .05$). Similarly, there were no differences in nursing problem scores for patients with large versus small proportions of newcomer nurses during the hospital stay (23% vs 24%; $P > .05$), large versus small nursing network diameters (23% vs 23%; $P > .05$), or high versus low values of group betweenness (15% vs 16%; $P > .05$).

Time Between Repeat Caregivers: Measure of Care Continuity

Finally, we examined the MRCI as a measure of continuity within the nursing care team. Higher MRCI values represent longer latency between repeat caregivers within a patient's care network. The median MRCI value was 5.2 nursing shifts (interquartile range: 4.7–5.8 nursing shifts). Over the years studied, increases in MRCI values were seen among infants born weighing $>$1500 g (4.8 $\pm$ 0.77 nursing shifts in 2002 and 5.1 $\pm$ 0.82 nursing shifts in 2007). However, similar trends were not seen for very low birth weight infants.

Nursing dimension problem scores were higher (ie, worse) for infants with longer intervals between repeat nursing caregivers (ie, higher MRCI values; 29.6% vs 17.6%; $P < .05$). As shown in Fig 6, for 8 of the 9 items constituting the nursing dimension, the rate of problem responses was higher for infants with high MRCI values, compared with their peers with low scores. These differences reached statistical significance for 3 of 9 questions, as well as the summary nursing dimension problem scores ($P < .05$). Even after controlling for birth weight, length of stay, and team size, we found that higher MRCI values remained a significant predictor of problem responses for the 3 questions found to be significant in univariate analyses. Of note, although physician (33% vs 24%) and neonatal nurse practitioner (29% vs 24%) problem scores were higher

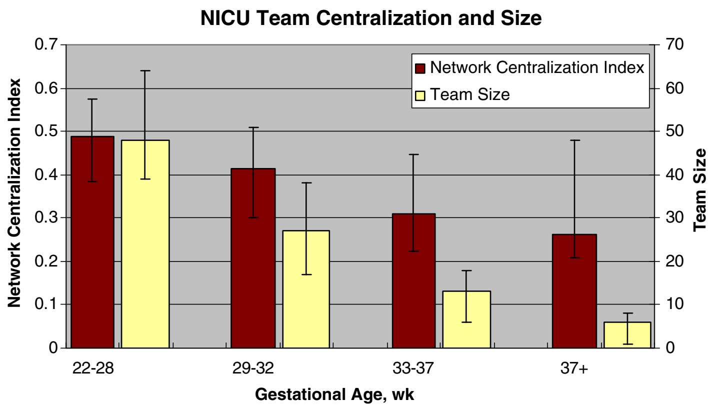


FIGURE 5
Relationships between gestational age category, NICU nursing team centralization index, and team size. Values are medians for each measure, with error bars representing interquartile ranges.

among patients with higher MRCI values, these differences did not reach statistical significance. This suggests that the MRCI value for nursing handoff networks specifically measures an aspect of nursing care that is important to families' perception of nursing care.

DISCUSSION

To our knowledge, these analyses represent the first large-scale application of network analytic methods to quantitative assessment of health care teams at the patient level. Many of these metrics have immediate face validity for clinicians, and we showed that one, the MRCI score, has a strong relationship with family satisfaction with care, which is an important measure of care quality. In addition, we demonstrated that information drawn from an EHR can be used for efficient collection of data needed for these analyses.

Our analyses suggest that the pattern of nursing assignments for an individual patient is strongly associated with parental satisfaction. Families that experience shorter intervals between care by familiar faces express higher levels of satisfaction with nursing care. Certainly, our results regarding the large size of teams encountered by NICU families and the persistent introduction of new nursing faces over the course of NICU hospitalization are of interest and likely to be of concern to clinicians and families. However, it is somewhat reassuring that the teams

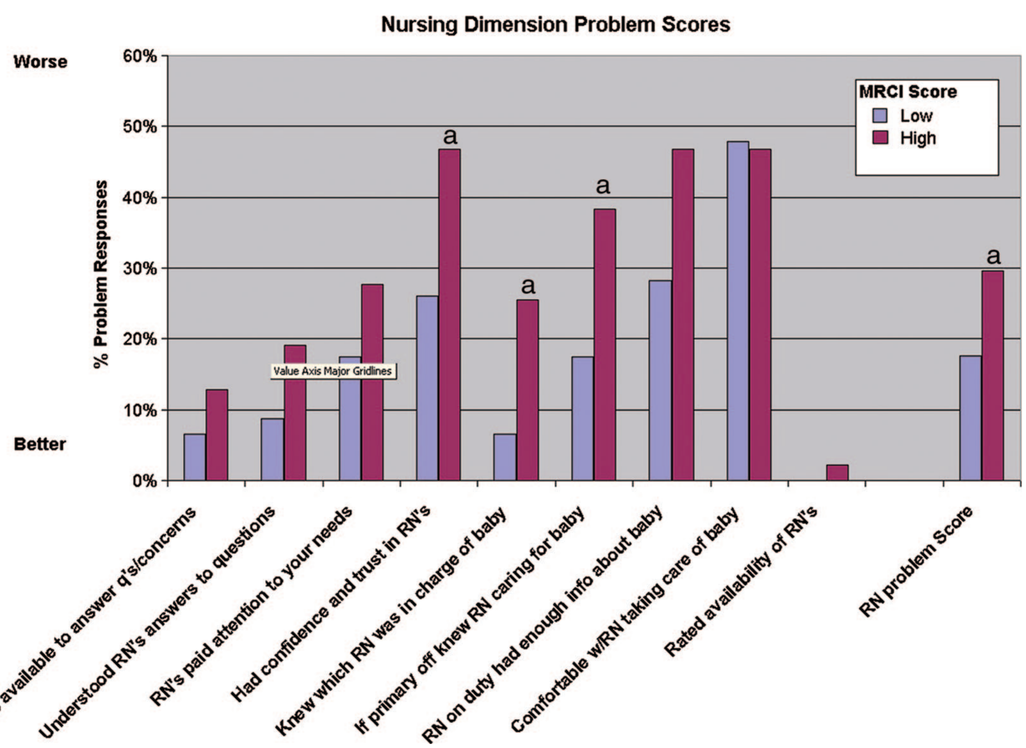


FIGURE 6
Relationship between MRCI values and rates of problem responses to questions contained in the nursing dimension of the Picker NICU Family Satisfaction Survey. Patients with MRCI values that exceeded the median value were considered to have high values. RN indicates nurse; q, question. $^{a}P < .05$.

for more immature infants continued to demonstrate relative centralization, with a core group of nurses providing care, and that team size and proportion of newcomers were not related to family satisfaction in the study cohort. In our analyses, the structure of the nursing team was more important than simply its size. Therefore, interventions designed to optimize the structure and timing of nurse participation in a patient's care, such as with a core nursing group, would be beneficial.

The lack of relationship between parental satisfaction and measures such as team size and proportion of newcomers should not be taken as evidence that these measures are unimportant. These metrics have been found to be valuable predictors of success in other types of collaborative teams,[10,11] and such characteristics may play a role in determining the quality of care in domains other than that measured in this study. For example, these metrics may influence the quality of handoffs between clinicians. Given the role of handoffs in the genesis of preventable harm, further quantitative investigation into the relationship between care team structure and preventable harm is warranted.

In other disciplines, the past decade has seen an explosion in the use of network analytic approaches to examine a diverse array of complex systems, ranging from the Internet to teams involved in scientific and artistic collaborations. The increase has been fueled in part by the development of new analytic approaches and tools and the recent availability of highly granular data sets that describe these systems.[12] Those investigations have led to improved understanding of the functioning of those complex systems. Across a diverse spectrum of system types, it has become clear that the performance and fault tolerance of networks or teams are related to both network topologic features and the ways in which they form over time.[11,12]

A large body of evidence demonstrates the importance of organizational characteristics of care as predictors of performance across multiple domains.[13–16] These characteristics are predictors not only of clinical outcomes but also of patient and provider satisfaction. Although the term "team" is often applied to the groups of providers who come together to care for a patient, it is not always clear that these groups truly are teams. Grumbach and Bodenheimer[17] suggest that 2 elements, appropriate composition and successful communication, are crucial if these groups are to function successfully.

Unfortunately, most research on these topics has required data collection strategies that rely on dedicated research associates to administer surveys, to observe practices and interactions, and to assess outcomes. Therefore, these approaches are unsustainable in settings outside a research paradigm. Approaches that allow automatic collection and analysis of data that identify individuals and groups involved in a patient's care could allow these techniques to be integrated into quality-improvement efforts and may expand opportunities for further research. The availability of information gathered routinely through the use of EHRs provides the highly granular data sets needed for such endeavors. In health care, EHRs can serve as the rich data sets that in other domains, through the application of network analytic methods, have allowed major breakthroughs in understanding complex systems such as electric power grids, social networks of smokers, intracellular metabolic networks, and the entity now referred to as the "diseasesome."[18–20]

It is important to note that these initial analyses were performed in a single, highly specialized, care area and examined care networks consisting of only one professional discipline. Although these results are likely to be generalizable to other locales and disciplines, examination of these methods across the continuum of care is needed to test this hypothesis and to identify modifications in approach that may be needed in other areas. In addition, these analyses used data drawn from only one source within the EHR, the NICU electronic documentation system. Including other sources, such as computerized provider order entry, medication administration records, ePrescribing, and picture archiving and communication systems would expand the ability to characterize the care team across many disciplines and might prove valuable.

CONCLUSIONS

Taken together, our results suggest that simple measures such as team size are not sufficient to characterize health care teams at the patient level. More complex constructs, drawn from the field of network analysis, that assess both team structure and the sequence of participation for individual team members provide more robust characterization of health care teams. Data from EHRs can support the application of such methods in health care settings. The combined use of network science methods and EHR data is likely to enhance efforts to monitor and to improve team function and may be a valuable tool in other types of quality-improvement endeavors.

ACKNOWLEDGMENT

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