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The Effect of a Structured Educational Program on Nurses' Knowledge and Performance Regarding Pediatric Cardiac Catheterization in Erbil City

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Abstract **Background and Aim:** Pediatric cardiac catheterization is a complex, high-risk clinical procedure that requires competent nurses with adequate knowledge and clinical skills to improve patient outcomes. Inadequate regular training programs for nurses in pediatric cardiac catheterization has been shown to increase the risk complications during and after the procedure. The aim of this study is to evaluate the effect of a structured educational program on nurses' knowledge and performance regarding pediatric cardiac catheterization. **Method:** A quasi-experimental study using a convenience sampling method was conducted among nurses working at the Surgical Specialty Hospital-Cardiac Center in Erbil City from February 5th, 2025, to August 28th, 2025. A total of 100 nurses were included in the study and equally allocated into intervention (n = 50) and control (n = 50) groups. Data were collected using a structured, self-administered questionnaires assessing nurses' sociodemographic characteristics, knowledge and clinical performance related to pediatric cardiac catheterization. Data were analyzed using SPSS version 25.0 through descriptive statistics, Mann-Whitney U-tests, Spearman's correlation, effect size analysis and multivariable linear regression. **Results:** No significant differences were observed between groups at baseline. Following the educational intervention, the intervention group demonstrated significantly higher knowledge and performance scores at posttest 1 and posttest 2 across all assed domains compared with the control group ($p<0.01$). A statistically significant positive correlation was observed between knowledge improvement and performance improvement ($r = 0.752$, $p<0.01$), while a negative correlation was observed between the pretest knowledge and performance scores with their respective improvements ($r = -0.530$ and $r = -0.487$, $p<0.01$). **Conclusion:** The structured educational program significantly improved nurses' knowledge and performance regarding pediatric cardiac catheterization, with sustained effects over time. Implementing structured educational interventions may enhance nursing performance and promote safer pediatric cardiac care.

Key Words Pediatric Cardiac Catheterization, Nurses, Educational Program, Knowledge, Clinical Performance, Quasi-Experimental Study, Erbil

INTRODUCTION

Pediatric cardiac catheterization is a highly complex, high-risk clinical procedure whose successful nursing care delivery relies on the highest level of nursing knowledge and performance [1]. However, limited opportunities for practice, the variability of clinical exposure, and the absence of structured education programs for nurses have led to a wide variation in competency levels of nurses working in cardiac centers worldwide [2]. While services for pediatric cardiac catheterization exist in areas outside of the United States, children that are treated in a low-resource health system with fewer accredited spaces for training are at an increased risk of complications post-catheterization [3]. Although cardiovascular care quality improvement initiatives began in the early 2000s, nursing education for pediatric cardiac catheterization has not been prioritized [4]. Formal international recommendations emphasizing standardized nursing education in pediatric interventional cardiology were only established nearly two decades later through updated clinical training frameworks [5]. The continued lack of adequate training for nurses in pediatric cardiac catheterization has been identified as a challenge for specialized cardiac centers [1].

Cardiac catheterization for congenital heart disease is performed in 1 to 2% of children per year, with 5-15% complications, depending on both institutional experience and nursing care [1,6].

Pediatrics cardiac catheterization unlike other routine cardiac procedures requires adequate nursing care due to complex anatomical and physiological response variations in this age group compared to adults as well as their increased susceptibility to the procedure complications [7]. Poor quality nursing care has been shown to increase the risk of bleeding, arrhythmias, vascular injury and hemodynamic instability during and after catheterization [8]. Vulnerable patients include pediatric age groups with complex congenital heart disease or comorbidities. Imprecise monitoring and delay in intervention may lead to meaningful clinical deterioration during or after a catheterization procedure [9]. Delay in the diagnosis and management of complications can lead to prolonged hospital admission, excessive cost, and even life-threatening consequences in a vulnerable child [10]. Evidence suggests that nursing-related factors contribute significantly to preventable adverse events during pediatric invasive cardiac procedures [11]. One of the essential components of high-quality nursing practice is continuing education. Active educational programs improve clinical knowledge and performance of procedures [12]. Non-standardized education causes inconsistent acquisition of competencies and poor retention of important pediatric cardiac care skills [13].

A critical gap exists in cardiac catheterization-specific training programs for nurses, with many cardiac centers depending on informal learning methods, such as on the job observation, rather than formal education [14]. Although this informal learning can provide adequate clinical performance, it also supports the persistence of outdated practices and limits adoption of evidence-bases practices [15]. This gap highlights the need for structured educational interventions tailored specifically to pediatric cardiac catheterization nursing performance [16].

Previous educational interventions in other specialized nursing fields have shown significant improvements in knowledge scores and procedural competence following implementation of the program [17]. Given the global expansion of pediatric cardiac catheterization procedures and the critical caring role of nurses in this field for ensuring procedure success, it is important to employ similar structured educational strategies to improve nurses' ability to early recognize, prevent and manage procedure-related complications urgently [1]. Engagement in such programs also supports professional development and promote adherence to evidence-based clinical guidelines within high-risk pediatric care environments. Therefore, the aim of this study was to evaluate the effect of a structured educational program on nurses' knowledge and performance regarding pediatric cardiac catheterization.

Research Question

Can a structured educational program improve nurses' knowledge and performances regarding pediatric cardiac catheterization at a cardiac center in Erbil city?

METHODS

This quasi-experimental study was conducted using a convenience sampling method from February 5th, 2025, to August 24th, 2025, at the Surgical Specialty Hospital-Cardiac Center in Erbil City. The study was carried out among nurses working in the Cardiac Intensive Care Unit (ICU), Cardiac Catheterization Laboratory, Pediatric Ward, Surgical Ward, Outpatient Department (OPD) and Cardiac Care Unit (CCU).

Because this was a quasi-experimental study, the sample size was based on the number of eligible nurses to be recruited from the cardiac-specific units at the study site rather than obtained from a population-based prevalence formula. According to staffing rosters, there were a total of 100 pediatric nurses in the nursing pool eligible to be recruited at the study site during recruitment. All eligible nurses were included, and participants were assigned to the intervention group (n = 50) or the control group (n = 50) using non-random allocation. Because the intervention was instructional in nature, neither the participants nor the researcher could be blinded to group assignment.

The nurses which were included in the study directly cared for patients undergoing cardiac catheterization. Nurses who did not work on the selected units during the time the data was collected, did not agree to participate in the study, and were not present during educational program sessions were excluded from the study.

The lead investigator reviewed pertinent nursing literature and current pediatric cardiac catheterization guidelines before developing the structured instruction session. Pre-procedural preparation, intra-procedural nursing duties, post-procedural care, problem identification and management, patient safety, infection control and documentation were all included in the instructional material**.** There were 4 sessions in the program each session lasted 30-45 minutes. The sessions were spread over a period one month. Lectures, PowerPoint presentations, group discussions, case-based learning, demonstrations and supervised practical sessions were among the teaching techniques used. Each participant received printed informative handouts. The lead investigator, who has experience in pediatric cardiac nursing and a master's degree in pediatric nursing, administered the intervention**.** Standardized teaching methods and the same instructional materials were utilized in every session to guarantee uniformity.

The data were collected using a researcher-constructed questionnaire designed by the researcher after a wide-ranging review of the literature and consultation with pediatric cardiology and pediatric nursing experts. A team of specialists in pediatric cardiology and pediatric nursing examined the draft questionnaire to assess its content validity in terms of appropriateness, comprehensiveness, relevance and clarity. Before the questionnaire was finalized, a few small changes were made based on their suggestions. Each item for the knowledge and performance of the nurses had one correct answer. The correct answer was scored 1 and the wrong response was scored 0. The questionnaire was

prepared in English language and self-administered questionnaires were distributed to the study participants by the principal investigator to ask for clarifications for any points during the questionnaire administration, the average time for filling out the questionnaire was between 15 and 20 minutes.

Prior to the study initiation, the study questionnaire was pilot-tested with 10 nurses to refine the study instruments for clarity, feasibility and reliability. The study pilot was aimed at establishing the clarity and comprehensibility of the questionnaire items, feasibility and applicability of the data collection procedures, duration of the questionnaire administration, and internal consistency of the knowledge and performance subscales. Reliability of the instrument was determined through the calculation of its Cronbach's alpha coefficient, which indicated very high reliability with a coefficient of 0.90 for the overall knowledge scale and 0.95 for the overall performance scale. The data from the pilot study were excluded from the final data analysis.

In the first section of the questionnaire, sociodemographic data of the nurses were collected, including age, sex, marital status, level of education, employment status, area of residence/working area, years of work in the cardiac center, previous participation in training programs on pediatric cardiac catheterization, and sources of information on pediatric cardiac catheterization.

The second part of the questionnaire assessed nurses' knowledge regarding pediatric cardiac catheterization, using multiple-choice questions, divided into four domains: general knowledge, pre-procedural knowledge, intra-procedural knowledge and post-procedural knowledge. Each item measured essential concepts related to indications, preparation, procedure and post-procedural care for pediatric cardiac catheterization.

Section three included information about the nursing practices of pediatric cardiac catheterization delivery. This section focused on the pre, intra, and post-procedural care of the patient as it related to nursing delivered care including tasks, patient safety, identifying and monitoring for complications, and acting on complications that were either witnessed or suspected.

This study was conducted in accordance with the Institutional Research Ethics Board regulations and principles outlined in the Declaration of Helsinki [18]. The study was approved by the College of Nursing Ethics Committee at the Hawler Medical University on August 22, 2024, with an approval reference number of 2426. Informed consent was obtained from all subjects in the study, and the subjects were informed the study was voluntary and that findings would be confidential.

Qualitative variables (e.g., sociodemographic characteristics) were expressed as frequency and percentage, and quantitative variables were expressed as mean and standard deviation. Non-parametric tests were used due to the non-normal data distribution (Shapiro-Wilk test $p<0.05$). It has used Mann-Whitney U test to measure the difference in knowledge and performance scores between control and intervention groups, Spearman's rank correlation coefficient to measure the correlation between studied variables and multiple linear regression to analyze predictors of knowledge and performance improvement. Categorical variables were analyzed with the chi-square test or Fisher's exact test. Statistical analyzes were carried out on SPSS version 25.0 (IBM Corp., Armonk, NY). Statistical importance was defined as $p<0.05$. Because the outcome variables were not normally distributed, the Mann-Whitney U test was used for between-group comparisons at each assessment time point. The main goal of the current investigation was to compare the intervention and control groups at each predetermined assessment point, even if repeated-measures analytical techniques would also be suitable for longitudinal data.

RESULTS

Demographic Characteristics of Nurses by Study Group

A total of 100 nurses participated in the study, equally distributed between the control group (n = 50) and the intervention group (n = 50). The mean age of nurses was 30.30±7.21 years in the control group and 29.56±6.10 years in the intervention group, with most participants aged 22-27 years (48.00% in the control group and 46.00% in the intervention group). Males constituted 56.00% (n = 28) of the control group and 52.00% (n = 26) of the intervention group. Most nurses were married (58.00% control vs. 52.00% intervention) and had graduated from a nursing institute (68.00% in both groups). Detailed demographics and other variables are presented in Table 1.

Association between Sociodemographic Characteristics and Baseline Knowledge and Performance

The results revealed that, at pretest, education level and previous training were the only sociodemographic factors significantly associated with both knowledge and performance levels. A higher proportion of adequate knowledge was demonstrated among nurses with a nursing college degree (17 nurses, 53.1%) compared with nursing institute graduates (20 nurses, 29.4%), with a statistically significant association ($p = 0.02$). Similarly, a significantly higher proportion of nurses with a nursing college degree had adequate performance compared to nursing institute graduates (46.9% Vs 23.5%, $p = 0.02$). In addition, nurses who reported previous training showed substantially higher rates of adequate knowledge (25 nurses, 50.0%) and adequate performance (22 nurses, 44.0%) compared with those without prior training (24.0 and 18.0%, respectively), with both associations reaching high statistical significance ($p<0.01$). In contrast, age group, gender, employment type and years of experience were not significantly associated with either knowledge or performance levels at baseline ($p>0.05$), indicating comparable baseline competence across these characteristics. For more details, refer to Table 2.

Table 1: Sociodemographic and Professional Characteristics of Nurses by Study Group

Variable	Group Classification	Control Group F (%)	Intervention Group F (%)	p-value
Age Group (years)	22–27	24 (48.00)	23 (46.00)	0.89
	28–33	11 (22.00)	13 (26.00)	
	34–39	9 (18.00)	10 (20.00)	
	> 40	6 (12.00)	4 (8.00)	
	Mean ± SD	30.30 ± 7.21	29.56 ± 6.10	
Gender	Male	28 (56.00)	26 (52.00)	0.69
	Female	22 (44.00)	24 (48.00)	
Marital Status	Single	21 (42.00)	24 (48.00)	0.55
	Married	29 (58.00)	26 (52.00)	
Education Level	Nursing Institute	34 (68.00)	34 (68.00)	1.00
	Nursing College	16 (32.00)	16 (32.00)	
Employment Type	Permanent	13 (26.00)	14 (28.00)	0.82
	Contract	37 (74.00)	36 (72.00)	
Residency	Rural	1 (2.00)	2 (4.00)	0.84
	Urban	45 (90.00)	44 (88.00)	
	Suburban	4 (8.00)	4 (8.00)	

Note: Data are presented as frequency (percentage) and mean ± standard deviation where applicable. Group comparisons were conducted using the chi-square test. Some categories had expected cell counts less than 5 due to multiple response options. SD = Standard Deviation. A p-value <0.01 indicates statistical significance

Table 2: Association between Sociodemographic Characteristics and Knowledge/Performance Levels at Pretest

Variable	Category	Adequate Knowledge n (%)	Inadequate Knowledge n (%)	χ^2	p-value	Adequate Performance n (%)	Inadequate Performance n (%)	χ^2	p-value
Age Group (years)	22-27	19 (40.4)	28 (59.6)	0.89	0.83	16 (34.0)	31 (66.0)		
	28-33	9 (37.5)	15 (62.5)			8 (33.3)	16 (66.7)		
	34-39	6 (31.6)	13 (68.4)			5 (26.3)	14 (73.7)		
	≥40	3 (30.0)	7 (70.0)			2 (20.0)	8 (80.0)	1.42	0.70
Gender	Male	18 (33.3)	36 (66.7)	0.68	0.41	14 (25.9)	40 (74.1)		
	Female	19 (41.3)	27 (58.7)			17 (37.0)	29 (63.0)	1.44	0.23
Education Level	Nursing Institute	20 (29.4)	48 (70.6)	5.42	0.02*	16 (23.5)	52 (76.5)		
	Nursing College	17 (53.1)	15 (46.9)			15 (46.9)	17 (53.1)	5.89	0.02*
Employment Type	Permanent	12 (44.4)	15 (55.6)	0.92	0.34	11 (40.7)	16 (59.3)		
	Contract	25 (34.2)	48 (65.8)		0.69	20 (27.4)	53 (72.6)	1.71	0.19
Years of Experience	<5 years	22 (40.0)	33 (60.0)	0.74		18 (32.7)	37 (67.3)		
	5-10 years	10 (35.7)	18 (64.3)			9 (32.1)	19 (67.9)		
	>10 years	5 (29.4)	12 (70.6)			4 (23.5)	13 (76.5)	0.62	0.73
Previous Training	Yes	25 (50.0)	25 (50.0)	7.29	<0.01**	22 (44.0)	28 (56.0)		
	No	12 (24.0)	38 (76.0)			9 (18.0)	41 (82.0)	8.01	<0.01**

Note: Chi-square test was used for categorical comparisons. Fisher's exact test was applied when expected cell counts were <5. Adequate knowledge defined as score ≥60% of total (≥23/38); adequate performance defined as score ≥60% of total (≥9/15). *p<0.05, **p<0.01

Comparison of Knowledge Scores between Control and Intervention Groups across Measurement Times

The results showed that there were no statistically significant differences in baseline (pretest) knowledge scores between the control and intervention groups across all knowledge domains, including overall knowledge, general knowledge, pre-procedural, intra-procedural and post-procedural knowledge (all p>0.05), indicating comparability between groups at study entry. However, after the educational program, the intervention group demonstrated significantly higher knowledge scores compared with the control group at posttest 1 and maintained significantly higher scores at posttest 2 across all knowledge domains. Specifically, overall knowledge in the intervention group increased substantially from a pretest median of 9.5 to 21.0 at Posttest 1 and remained high with median of 20.0 at Posttest 2, whereas the control group showed only minimal improvement (Pretest median = 9.5, Posttest 1 median = 10.0 and posttest 2 median = 12.0), with these differences being highly statistically significant (p<0.01). Similar significant patterns were observed for general knowledge, pre-procedural, intra-procedural and post-procedural knowledge domains at both post-intervention measurements (p<0.01), demonstrating the effectiveness of the structured educational program and the maintenance of knowledge gains at follow-up. For further details, Table 3.

Comparison of Performance Scores between Control and Intervention Groups across Measurement Times

The Mann-Whitney U test results showed that the performance scores were comparable between the control and intervention groups at pretest, with no statistically significant differences in overall performance (control median: 6.0 Vs. intervention median: 6.0, p = 0.320), intra-procedural performance (1.0 Vs. 2.0, p = 0.298), or post-procedural performance (4.0 Vs. 3.0, p = 0.922), except for pre-procedure performance, where the intervention group demonstrated a slightly higher baseline score than the control group (p = 0.044). This baseline difference should be considered when interpreting the subsequent between-group comparisons. However, statistically significant improvements were observed in the intervention group at both posttest 1 and posttest 2 across all performance domains.

Table 3: Comparison of Knowledge Scores between Control and Intervention Groups across Measurement Times

Domain	Time	Control median (IQR)	Intervention median (IQR)	U	P-value
General Knowledge	Pretest	5.0 (3.25)	4.0 (3.25)	1220	0.835
	Posttest1	5.0 (3.25)	9.5 (4.0)	344	<0.001
	Posttest2	6.0 (3.0)	9.0 (4.0)	441	<0.001
Pre-procedure knowledge	Pretest	2.0 (1.0)	2.0 (2.0)	1223	0.847
	Posttest1	2.0 (1.25)	4.0 (2.0)	472	<0.001
	Posttest2	2.0 (2.0)	3.0 (2.0)	583.5	<0.001
Intra-procedure knowledge	Pretest	1.0 (1.0)	2.0 (2.0)	1094	0.265
	Posttest1	1.0 (1.0)	3.0 (2.0)	513.5	<0.001
	Posttest2	2.0 (1.0)	3.0 (2.0)	614.5	<0.001
Post-procedure knowledge	Pretest	2.0 (2.0)	3.0 (3.0)	1126.5	0.386
	Posttest1	3.0 (2.25)	5.0 (2.25)	574	<0.001
	Posttest2	3.0 (2.0)	5.0 (2.0)	771	<0.001
Overall knowledge	Pretest	9.5 (6.0)	9.5 (7.25)	1200	0.730
	Posttest1	10.0 (6.0)	21.0 (3.50)	341	<0.001
	Posttest2	12.0 (7.0)	20.0 (4.0)	392	<0.001

Note: Mann-Whitney U test was used to compare median scores between control and intervention groups at each measurement point. Values are presented as medians and interquartile ranges. Pretest, Posttest 1 and Posttest 2 represent baseline, immediate post-intervention and follow-up assessments, respectively. A p-value <0.05 was considered statistically significant

Table 4: Comparison of Performance Scores between Control and Intervention Groups across Measurement Times

Domain	Time	Control median (IQR)	Intervention median (IQR)	U	P-value
Pre-procedure performance	Pretest	0 .0(1.0)	1.0 (2.0)	975.5	0.044
	Posttest1	0.5 (1.25)	2.0 (1.0)	373.5	<0.001
	Posttest2	1.0 (1.25)	2.0 (1.0)	741.5	<0.001
Intra-procedure performance	Pretest	1.0 (1.25)	2.0 (2.0)	1104.0	0.298
	Posttest1	1.5 (2.0)	4.0 (1.0)	359.0	<0.001
	Posttest2	3.0 (3.0)	4.0 (1.0)	760.0	<0.001
Post-procedure performance	Pretest	4.0 (3. 25)	3.0 (2.0)	1236.0	0.922
	Posttest1	4.0 (3.0)	6.0 (2.25)	509.5	<0.001
	Posttest2	3.0 (2.0)	5.0 (2.25)	596.5	<0.001
Overall performance	Pretest	6.0 (4.0)	6.0 (2.0)	1107.5	0.320
	Posttest1	6.0 (3.25)	12.0 (2.25)	314.0	<0.001
	Posttest2	6.5 (3.25)	11.0 (5.0)	592.0	<0.001

Note: Mann Whitney U test was used to compare median performance scores between control and intervention groups at pretest, posttest 1 and posttest 2. Values are presented as medians and interquartile ranges. Pretest represents baseline assessment, posttest 1 represents immediate post-intervention assessment and posttest 2 represents follow-up assessment. A p-value <0.05 was considered statistically significant

Specifically, overall performance scores increased substantially in the intervention group at posttest 1 (12.0 Vs 6.0 in controls) and remained high at posttest 2 (11.0 Vs 6.5), with both comparisons reaching statistical significance (p<0.01). Similar significant patterns were noted for pre-procedural, intra-procedural and post-procedural performance domains, where the intervention group consistently demonstrated higher median scores than the control group at both post-intervention assessments (p<0.01). Detailed comparison of performance scores between the two groups is presented in Table 4.

Effect Size of the Educational Intervention on Knowledge Domains

The results showed that the structured educational program produced large and consistent effects on nurses' knowledge across all assessed domains. The effect sizes were either negligible or small at pretest for all knowledge domains with no statistically significant differences between the two groups (p>0.05). However, following the intervention program, statistically significant large effect sizes were observed across all knowledge domains at posttest 1 (p<0.01), including general knowledge (r = 0.63), pre-procedure knowledge (r = 0.55), intra-procedure knowledge (r = 0.52), post-procedure knowledge (r = 0.48) and overall knowledge (r = 0.63). Similar sustained statistically significant effect sizes were observed on nurses' knowledge at posttest 2 (p<0.01), with large effect sizes for most domains and medium effect size for post-procedure knowledge (r = 0.34). For more details, refer to Table 5.

Effect Size of the Educational Intervention on Performance Domains

The results of the effect size analysis of educational intervention on nurses' performance similarly showed large and sustained improvements across also studied domains. At pretest, the effect sizes were either negligible or small for all performance domains with no statistically significant differences between the two groups (p>0.05). However, statistically significant large effect sizes were observed after the intervention at posttest 1 across all performance domains (p<0.01), including pre-procedure performance (r = 0.64), intra-procedure performance (r = 0.63), post-procedure performance (r = 0.52) and overall performance (r = 0.65). The intervention effect remained statistically significant at posttest 2 (p<0.01), with large effect sizes for post-procedure and overall performance and medium effect sizes for pre-procedure and intra-procedure performance (r = 0.37, r = 0.35 respectively). For more details, refer to Table 6.

Table 5: Effect Size Analysis of Educational Intervention on Knowledge Domains

Domain	Time	Mann-Whitney U	Z	p-value	Effect size (r)	Effect magnitude
General Knowledge	Pretest	1220.0	-0.209	0.835	0.02	Negligible
	Posttest1	344.0	-6.288	<0.001	0.63	Large
	Posttest2	441.0	-5.611	<0.001	0.56	Large
Pre-procedure knowledge	Pretest	1223.0	-0.194	0.847	0.02	Negligible
	Posttest1	472.0	-5.454	<0.001	0.55	Large
	Posttest2	583.5	-4.717	<0.001	0.47	Large
Intra-procedure knowledge	Pretest	1094.0	-1.115	0.265	0.11	Small
	Posttest1	513.5	-5.203	<0.001	0.52	Large
	Posttest2	614.5	-4.515	<0.001	0.45	Large
Post-procedure knowledge	Pretest	1126.5	-0.866	0.386	0.09	Small
	Posttest1	574.0	-4.763	<0.001	0.48	Large
	Posttest2	771.0	-3.393	<0.001	0.34	Medium
Overall knowledge	Pretest	1200.0	-0.346	0.730	0.03	Negligible
	Posttest1	341.0	-6.282	<0.001	0.63	Large
	Posttest2	392.0	-5.932	<0.001	0.59	Large

Note: Effect size (r) was calculated using the formula $r = Z / \sqrt{N}$, where N is sample size. Effect size interpretation: <0.10 is negligible effect, 0.10-0.29 is small effect, 0.30-0.49 is medium effect and ≥0.50 is large effect

Table 6: Effect Size Analysis of Educational Intervention on Performance Domains

Domain	Time	Mann-Whitney U	Z	p-value	Effect size (r)	Effect magnitude
Pre-procedure performance	Pretest	975.5	-2.019	0.044	0.20	Small
	Posttest1	373.5	-6.354	<0.001	0.64	Large
	Posttest2	741.5	-3.682	<0.001	0.37	Medium
Intra-procedure performance	Pretest	1104.0	-1.042	0.298	0.10	Small
	Posttest1	359.0	-6.335	<0.001	0.63	Large
	Posttest2	760.0	-3.522	<0.001	0.35	Medium
Post-procedure performance	Pretest	1236.0	-0.098	0.922	0.01	Negligible
	Posttest1	509.5	-5.177	<0.001	0.52	Large
	Posttest2	596.5	-4.575	<0.001	0.46	Large
Overall performance	Pretest	1107.5	-0.994	0.320	0.10	Small
	Posttest1	314.0	-6.494	<0.001	0.65	Large
	Posttest2	592.0	-4.554	<0.001	0.46	Large

Note: Effect size (r) was calculated using the formula $r = Z / \sqrt{N}$, where N is sample size. Effect size interpretation: <0.10 is negligible effect, 0.10-0.29 is small effect, 0.30-0.49 is medium effect and ≥0.50 is large effect

Table 7: Correlation Matrix between Study Variables and Outcome Measures

Variable	1	2	3	4	5	6	7	8	9	10
Age	1									
Years of Experience	0.829**	1								
Pretest Knowledge	0.404**	0.381**	1							
Posttest 1 Knowledge	-0.072	-0.120	0.017	1						
Posttest2 Knowledge	0.044	0.016	0.095	0.378**	1					
Pretest Performance	0.375**	0.313**	0.576**	0.046	-0.004	1				
Posttest 1 Performance	0.089	0.055	0.085	0.740**	0.346**	0.128	1			
Posttest 2 Performance	0.048	-0.022	0.024	0.353**	0.462**	0.101	0.324**	1		
Knowledge Improvement ^a	-0.327**	-0.359**	-0.530**	0.811**	0.253*	-0.320**	0.579**	0.309**	1	
Performance Improvement ^a	-0.193	-0.198*	-0.309**	0.639**	0.282**	-0.487**	0.766**	0.195	0.752**	1

Note: Spearman correlation coefficient (r) used for continuous variables. ^a Knowledge/Performance improvement calculated as Posttest 1 score minus Pretest score. *p<0.05, **p<0.01

Correlation between Demographic Variables, Knowledge and Performance Outcomes

The results showed strong and statistically significant correlations between nurses' knowledge and performance scores across measurement points. Posttest 1 knowledge had moderate positive correlation with posttest 2 knowledge (r = 0.378, p<0.01), indicating consistency of knowledge retention over time. Similarly, posttest 1 performance demonstrated a moderate positive correlation with posttest 2 performance (r = 0.324, p<0.01), reflecting sustained improvement in clinical performance after the intervention at follow up. Knowledge improvements were strongly correlated with posttest 1 knowledge (r = 0.811, p<0.01) and with performance improvements (r = 0.752, p<0.01), suggesting that improvements in theoretical knowledge translated into enhanced performance outcomes. A statistically significant negative correlation was observed between knowledge improvement and pretest knowledge scores and between performance improvement and pretest performance scores (r = -0.530 and r = -0.487, p<0.01). This negative correlation indicates that the greater improvement in nurses' knowledge and performance is among participants with lower pretest scores. For more details, refer to Table 7.

Table 8: Multiple Linear Regression Analysis of Predictors of Knowledge and Performance Improvement

	Knowledge improvement					Performance improvement				
Predictor	B	SE	B	p-value	95% CI for B	B	SE	β	p-value	95% CI for B
Group (Intervention = 1)	8.14	1.05	0.501	<0.001	(6.05,10.22)	2.84	0.61	0.318	<0.001	(1.61,4.05)
Age (years)	0.08	0.14	0.067	00.558	(-0.20,0.36)	0.04	0.07	0.054	0.585	(-0.10,0.17)
Gender (Female = 1)	0.93	1.09	0.057	0.397	(-1.24,3.10)	-0.69	0.52	-0.077	0.189	(-1.73,0.35)
Education (College = 1)	-0.72	1.20	-0.041	0.549	(-3.10,1.66)	0.65	0.57	0.068	0.261	(-0.49,1.78)
Years of Experience	-0.39	0.19	-0.255	0.046	(-0.77, 0.01)	0.18	0.09	0.216	0.056	(-0.01,0.37)
Employment (Permanent = 1)	-3.19	1.58	-0.174	0.047	(-6.33,-0.04)	0.99	0.78	0.099	0.205	(-0.55,2.53)
Pretest Score	-0.92	0.14	-0.548	<0.001	(-1.19,-0.65)	-0.72	0.11	-0.467	<0.001	(-0.94,-0.50)
Knowledge improvement	—	—	—	—	—	0.28	0.04	0.518	<0.001	(0.20,0.37)
Model Summary										
R^2	0.626					0.723				
Adjusted R^2	0.598					0.698				
F-statistic	22.00					29.64				
p-value (model)	<.001					<0.001				

Note: B = Unstandardized Coefficient; SE = Standard Error; β = Standardized Coefficient; CI = Confidence Interval. Reference categories: Group (Control), Gender (Male), Education (Nursing Institute), Employment (Contract). Model assumptions tested: linearity, normality of residuals (Shapiro-Wilk p>0.05), homoscedasticity (Breusch-Pagan p>0.05) and independence of errors (Durbin-Watson = 1.89-2.12)

Multiple Linear Regression Analysis of Predictors of Knowledge and Performance Improvement

The results of the multiple linear regression analysis showed that the educational program had the greatest impact on knowledge and performance improvement. Participants in the intervention group had significantly greater knowledge improvement (β = 0.501, p<0.001) and performance improvement (β = 0.318, p<0.001). Pretest knowledge and performance scores were significant negative predictors of the respective knowledge improvement (β = -0.548, p<0.001) and performance improvement (β = -0.467, p<0.001), indicating that nurses with lower pretest scores showed greater improvement following the program. Improvement in nurses' performance was significantly associated with improvement in their knowledge (β = 0.518, p<0.001), showing the positive impact of theoretical knowledge gains following the intervention program on clinical performance. Other significant negative predictors of knowledge improvement with smaller effects sizes, were years of experience (β = -0.255, p<0.046) and employment status (β = -0.174, p<0.047), demonstrating that experienced nurses and permanent employees had lower knowledge gains after the educational program. Sociodemographic variables had no significant impact on performance improvement. For further details in Table 8.

DISCUSSION

Pediatric cardiac catheterization is a high risk clinical procedure in cardiovascular care, requiring nurses with a good level of knowledge and clinical skills to ensure patient safety and provide optimal patient care [19]. In the developing countries, despite the rapid development of pediatric cardiac services and its availability, significant gaps remain in the cardiovascular care specialized training available to nursing staff working in this field with limited evidence highlighting the importance of educational training of nurses caring for children undergoing cardiac catheterization. The present study was conducted to evaluate the effect of a structured educational program on nurses' knowledge and performance regarding pediatric cardiac catheterization at a cardiac center in Erbil.

In our study, the demographic profile of the nurses working at the Erbil cardiac center were predominantly young nurses in their late twenties with nursing institute degrees, employed under contract terms in urban settings. The majority of the nurses in our study had nursing institute diplomas rather than bachelor's degrees and this is consistent with current nursing workforce in developing healthcare systems, showing the importance of employing continues educational programs in these regions to bridge the skill gap and improve patient care [20].

Nurses' education level and previous training were significantly associated with their knowledge and performance levels at the pretest, while other demographic factors showed no association. These results suggest that formal educational qualifications and subsequent exposure play crucial roles in shaping nurses' competencies in specialized areas, a finding consistent with research from other healthcare settings [21]. An exceptional factor observed in our study is regarding previous training, where all control group participants had received prior training compared with none in the intervention group. However, despite having no previous training background, the intervention group achieved substantially higher scores, indicating the effectiveness of the intervention in our study.

Following the structured educational program, there was a significant improvement in the nurses' level of knowledge in all domains immediately after and at follow up assessment from completion of the program. For instance, the overall knowledge scores of the nurses nearly doubled from their pre-intervention scores with slight decline observed during follow up period. This finding aligns with previous research demonstrating the effectiveness of educational interventions in enhancing nurses' theoretical understanding of specialized procedures [17,22]. The consistency of these improvements across all knowledge domains, including general, pre-procedural, intra-procedural and post-procedural knowledge, suggests the effectiveness of the content of educational program which was developed based on nurses' needs. There was also significant gain in the performance level of our participants across all domains after implementation of the intervention,

with sustained improvement observed during subsequent follow ups. This finding is consistent with the results from other research that have showed satisfactory level of nurses' practice in cardiovascular care after coaching programs [6,23]. The present results highlight the importance of providing ongoing training programs to enhance nurses' clinical competency, thereby improving patient's outcomes and the overall quality of care.

The structured educational program implemented in our study demonstrated high effectiveness, yielding adequate theoretical and clinical performance outcomes as indicated by the large effect sizes observed on the nurses' knowledge and performance across all domains (r = 0.52-0.65) immediately after the intervention. The large effect sizes observed in our study may reflect the combination of structured didactic content of the training program with practical application opportunities for the nurses. This simulation-based educational approach has similarly been shown through existing literature to significantly enhance knowledge and skill acquisition [24-26]. Furthermore, the medium effect sizes noted across nurses' knowledge and performance at follow up assessment indicate sustained retention of the educational impact over time. Retention of improvement among nurses has likewise been reported in previous research, indicating the importance of ongoing training and continuous reinforcement to maintain knowledge and performance gains [25,27,28].

There was statistically significant positive correlation between overall nurses' knowledge improvement and performance improvement following the educational program regarding pediatric cardiac catheterization, demonstrating that enhanced theoretical understanding translated into improved clinical performance. This knowledge-performance correlation has been documented in similar nursing education studies [29,30] and represents a critical outcome, as knowledge alone without corresponding performance improvement offers limited clinical benefit. The negative correlation observed between nurses' baseline knowledge and performance scores and their respective improvements indicates that participants with lower pretest scores showed greater improvement and benefited more from the intervention. Similar findings have been reported in previous research assessing the impact of educational interventions on nurses' knowledge and practice, where baseline scores were low and improved significantly following training programs [31,32]. Although significant correlations were observed between knowledge improvement and performance improvement, these findings indicate association rather than causation and should be interpreted accordingly. Participation in the educational program was 2 improvement outcomes, may account for the comparatively high coefficients of determination ($R^2 = 0.626$ and 0.723). However, since individual motivation, learning styles, workplace support and clinical experience-all of which were excluded from the regression models-may also have an impact on educational achievements, these results should be interpreted with caution.

CONCLUSION

This study showed that the structured educational program significantly improved nurses' knowledge and clinical performance regarding pediatric cardiac catheterization and this improvement was sustained at follow up periods. Therefore, it is important to provide continuous training programs for nurses working within cardiac centers to improve their clinical skills, promote patient safety and provide high quality care for pediatric patients undergoing cardiac catheterization.

Limitations

This study was conducted at a single cardiac center in Erbil, which may limit generalizability to other healthcare settings and it included a relatively limited sample size of 100 pediatric nurses, which may affect the precision of the statistical analysis.

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