

International Journal of Nursing and Health Care Research

Stolic S, et al. Int J Nurs Health Care Res 12: 1129.

DOI: 10.29011/2688-9501.101129

Research Article

An Integrative Review of Medication Calculation Assessment Strategies for Student Nurses

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Citation: Stolic S, Emmanuel E, Gore A (2019) An Integrative Review of Medication Calculation Assessment Strategies for Student Nurses. Int J Nurs Health Care Res 12: 1129. DOI: 10.29011/2688-9501.101129

Received Date: 17 November, 2019; **Accepted Date:** 02 December, 2019; **Published Date:** 06 December, 2019

Abstract

Administering the correct medication dose is an important nursing competency. To perform an integrative review comparing two or more assessment strategies used to assess student nurse's skills in calculating medication dosages. A literature searches of six health care databases, ScienceDirect, Cumulative Index of Nursing and Allied Health, PUBMED, PROQUEST, MEDLINE and Cochrane's library to identify journal articles. Research articles on safe medication calculation assessment strategies were considered for inclusion in this review. The search yielded 1663 papers of which 9 met the inclusion criteria. A sample size of 1274 student nurses from the nine papers were included in the final review. Assessments of medication calculation competency included medication dosage calculation and administration exams and simulation assessments. Traditional medication calculation tests are common practice among educators to assess medication calculation skills and have been found to predict student nurse's numeracy skills. However, simulation-based assessment or authentic online assessment may also be used to test student's performance on clinical placement; few studies into this emerging area exist; more rigorous research is needed.

Keywords: Integrative review; Medication dosage calculation; Student nurse

Introduction

Medications are the most common therapy used in health care to improve patient's outcomes [1]. Safe medication administration is a global concern [2]. In the clinical setting nurses are responsible for administering the correct dosage of prescribed medication [3]. Medication errors occur between 17% of hospitals' admission to approximately 9% [4]. Errors stem mainly from incorrect therapy, drug and dose, volume, rate or incompatibility of intravenous fluid administration [5]. Administering the wrong dose of a medication can result from poor medication administration and dosage calculation skills. Just one mistake in medication calculation can lead to a fatal error [6-8]. Despite this medication administration safety throughout hospitalization continues to be a significant problem [1].

Adverse effects of one quarter of medication calculation clinical errors can lead to increased health care costs, extended hospital stays, surgical intervention and death [1,8,9]. Therefore, attaining proficiency in medication dosage calculation is essential during the undergraduate nursing student studies and is often a critical factor in passing subjects and graduating into the health care profession [4].

Competencies in accurate drug calculations for nurses are required in order to safely administrate medications [10,11]. The ability to perform medication calculations accurately and administer medication precisely is reinforced through the standards of practice upheld by national registration boards such as Australian Nursing and Standards of Practice [12] and the American Nurses Association [13]. Research consistently highlights the need for improvements in safe administration of medications to the patient, yet, there is little consistency in the strategies used by

nurse educators to evaluate student nurses' competency of safe medication calculation [14-16]. In nursing education, several evaluation strategies of medication dose calculation competency exist, however, limited research reviewing these different strategies has been identified. Two large multisite surveys were conducted in the United States (US) (n = 239 nursing programs) and Finland (n = 22 nursing programs and n = 136 educators) reporting 96.2 - 95 % used theoretical medication administration to test medication administration and medication calculation examinations [17,18]. Ninety-five percent of universities used clinical skills assessment in laboratory settings on simulation manikins using Objective Structured Clinical Examination (OSCE) stations [17]. Between 55% in Finland and 3% of university programs in the US had medications assessment during clinical practice [18,19]. There was no standardized technique for assessing safe medication dosage calculation and administration. Davies also reported on tools used to assess nurses' medication administration practices and found these had limitations and they were either not validated or had poor reliability. There has been no comprehensive review of existing assessments strategies for medication administration and calculations. Hence, the aim of this integrative review is to compare existing assessment strategies used in undergraduate nursing programs to assess individuals' ability to safely calculate medication dosages.

Method

With the aim to obtain current knowledge in regards to medication calculation assessment strategies, an updated integrative review method was applied [20]. Between the 19th to the 26th of March 2019, a literature search of six common databases was conducted by two independent raters including: Sciencedirect, Cumulative Index in Nursing and Allied Health Literature (CINAHL), Pubmed, Proquest, Medline and Cochrane's library. The following search terms, MeSH (Medical Subject Headings) terms or text words were used in various combinations and permutations: (i) Evaluation terms: "Dosage calculation, education" OR "medication calculation" OR "Numeracy" OR "Drug calculation" (ii) Population terms: ("Nurse" OR "Student nurse" OR "Education, Nursing" AND (iii) Design terms: ("Assign" OR "Experimental"). All potentially relevant articles were imported into Endnote X7 library for review according to the inclusion and exclusion criteria. All potentially relevant articles were imported into Endnote X7 library for review according to the inclusion exclusion criteria. Reading methodologically sound integrative reviews on assessment strategies takes less time than reading multiple research studies [21]. This paper used an integrative review method because of the few numbers of research studies investigating medication calculation assessment strategies which makes it difficult to compare tools and findings. The evidence to guide discussion on the use of clinical settings or simulations is growing in healthcare education, hence there are

issues due to the number of quality studies and standardization of assessment strategies [22].

To reach evidence of highest quality, peer reviewed experimental studies were selected [23]. Further, these articles have met with the following inclusion criteria (PICOT format):

P (population): Studies which focused on student nurses (≥ 18 years old).

I (intervention): Only studies which compared different strategies of evaluating medication calculation were qualified for inclusion.

C (comparison): To capture a general trend, studies which compared strategies of evaluating safe medication administration or calculation were compared.

O (outcome): Each eligible study measuring primary outcomes of medication administration or calculation.

T (time of data collection): data collected 19th to 26th of March 2019

The search process is presented in (Figure 1). A search of six electronic databases was conducted resulting in 1663 potential articles after reviewing titles, 125 met the inclusion criteria. Forty-five articles were excluded by duplicate, title, abstract or, resulting in 80 articles which were retrieved as full text for further consideration. The first author and third author independently and on separate days retrieved and judged the full text 80 articles. At this stage, 71 studies were excluded due to not meeting the inclusion criteria. The two raters agreed on nine studies to be included in this review. If disagreements occurred after the consensus meeting, a third reviewer (Second author) made the final decision. The full texts of the nine articles were then subject to four stages of data extraction:

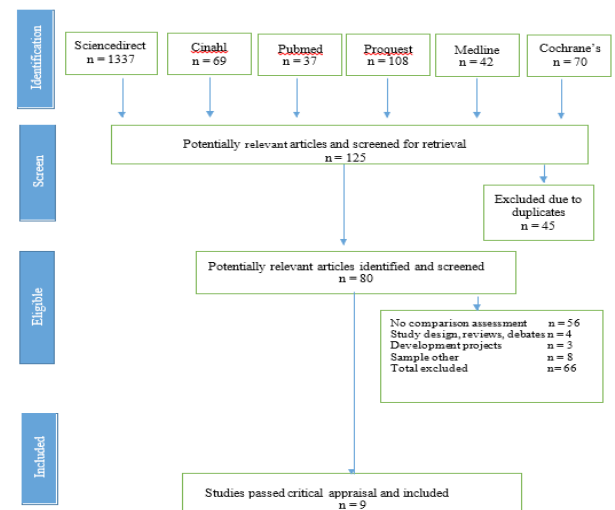


Figure 1: Database search process.

Characteristics of Study

- Bibliometric data (year, author, country and title); study design features (aim, method, sample, setting) (Table 1),
- Education used,
- Assessment tools used to evaluate,
- Findings relevant to pass marks and correlations between assessments.

The quality of the selected studies was scored using the quality critical appraisal tool for randomized controlled trials from Cochranes Handbook for Systematic Reviews of Interventions 5.1.0 [24]. The tool included seven entries concerning sequence generation, allocation concealment, blinding of participant and personnel, blinding of outcome assessors, incomplete data outcomes, selective outcome reporting, and other biases (baseline imbalance, early stopping and sources of funding). According to the Cochrane Handbook [24], each entry would be rated as ‘low risk of bias’, ‘unclear risk of bias’ or ‘high risk of bias’.

Blinding of outcome assessors was considered appropriate.

In general, we considered trials with adequate generation of allocation sequence, adequate allocation of concealment, adequate blinding (Assessor blinding), free from incomplete outcomes, free from selection outcomes reporting and free from other biases to be trials of low risk of bias.

Results

Contextual Information About Settings and Sample

All nine studies were quantitative non randomized experimental pre and/or posttest design. Qualitative studies were reviewed and included information on student’s satisfaction and self-efficacy, however, these did not measure the student’s performance on medication calculation skills and were excluded from this paper. Studies were from United Kingdom [16,25-27], Turkey [28], Spain [29], United States [30] and Australia [31] see (Table 1). Five studies had no comparison or control group [25,28,29,31-33]. Four studies had more than one group [30] and/or used cross over counterbalance and multistage design [16,26,27]. Sample size ranged from 567 undergraduate nursing students [31] to eight students [16] and determine the order listed in (Table 1).

Study	Design/sample	Education	Arithmetic or medication dosage exams	Clinical evaluation	Findings
Ramjan, et al. [31] Australia	Purposive sampling no control group N =567, 2 nd year SN, 4 settings	Tutorials	1. Test 1: Decontextualized diagnostic exam paper with 9 questions. 2. Test 2: Contextualized diagnostic exam paper with visual images, same 9 questions	No	Test 1: mean 5.54 ± 1.66 Test 2: mean 7.01± 1.18 Good correlations between the 2 tests Results indicated students’ scores improved from Test 1 to Test 2

MacDonald, et al. [25] UK	Multistage purposive longitudinal, no control group From entry to registration of SN; purposive n = 210, 2 cohorts	Software safeMedicate MDCS education; tutorials, additional support, simulation and clinical practice	<p>Prior to entry</p> <p>1. GCSE math's Entry:</p> <p>2. FNA: 40 MCQ developed by Huttton, 2013</p> <p>1st year:</p> <p>3. ADA: 90 point safeMedicate assessment</p> <p>2nd year:</p> <p>4. ADA: 150 point safeMedicate assessment</p> <p>Entry to register</p> <p>5. ADA: 150 point, AA: 50 point safeMedicate assessments</p> <p>Throughout BN program</p> <p>6. MDC-PS competence assessment; self- diagnostic assessment; and ADA</p>	<p>1st year:</p> <p>7. Functional competence assessment: NMC numeracy and medicines and clinical assessment</p> <p>2nd year:</p> <p>7. NMC numeracy and medicines clinical assessment</p> <p>Entry to register:</p> <p>7. NMC numeracy and medicines management clinical assessment</p> <p>Throughout BN program:</p> <p>7. NMC numeracy and medicines clinical assessment</p>	<p>GCSE: Neither math's entry qualification nor FNA score in first year predicted the number of attempts to achieve 100% in third year</p> <p>$r = 0.118$</p> <p>Good correlation between safeMedicate, ADA and MDC-PS and NMC</p>
Newton, et al. [32] US	Explorative descriptive, n = 127, 1 st year SN, 2 cohorts, 1 setting	Traditional	<p>1st mth of BN</p> <p>1. TEAS maths composite score + TEAS overall composite score</p> <p>Throughout 1st semester</p> <p>2. Medication calculation assessment</p>	No	<p>TEAS maths composite score</p> <p>Mean 64.6 ± 16.1 1st group</p> <p>Mean 63.8 ± 12.5 2nd group</p> <p>TEAS overall composite score</p> <p>Mean 74.5 ± 8.5 1st group</p> <p>Mean 73.9 ± 8.2 2nd group</p> <p>$p = 0.07$ and $p = 0.33$</p> <p>TEAS maths + medication calculation assessment $r = 0.264$; $p = 0.003$</p> <p>(weak positive relationship)</p> <p>TEAS maths + number of attempts of medication calculation assessment</p> <p>$r = -0.326$; $p < 0.001$</p> <p>(strong negative relationship)</p> <p>↑number of attempts on the medication calculation exam correlates to ↓TEAS maths scores</p> <p>Maths aptitude is negatively correlated to the number of attempts on the medication calculation assessment</p>

Raurell-Torreda et al. [29] Spain	Posttest, no control group, convenience sample of n = 120, 4 th year SN	Traditional + SBL	1. Traditional content knowledge assessments (final grade)	1. OSCE stations with MCQ test and written medication calculation dosage exam; 2. CP	<p>OCSE: Mean OSCE score 5.6 ± 1.2; 7.5% failed CP :mean score 8.4 ± 0.6, no student failed Final grade knowledge: 7.7 ± 0.5, 12.3% failed Good correlation between OSCE score and final grade $r = 0.3$, $p < 0.001$, Good correlation between final grade knowledge and CP were $r = 0.21$ ($p = 0.03$) and $r = 0.37$ ($p < 0.001$) OSCE was a strong correlation for CP ($r = 0.68$, $p = 0.04$) Passing OSCE scored showed scant correlation with final grade ($r = 0.32$, $p = 0.001$) OSCE and CP scores were strongly correlated in students who failed OSCE ($r = 0.68$), therefore those who failed OSCE performed poorly on CP</p>
Mariani et al. [30] USA	Two groups Pretest posttest, convenience sample, n = 71 junior SN, 1 setting	Intervention group received additional simulations on medication administration	1. 29 MCQ, MSKA	2. MSCEC, Developed for medical students Clinical competency	<p>Intervention group scored higher than control group $p = 0.028$ No correlations between the two assessments were conducted</p>
Aydin & Dinc [28] Turkey	Pre- test, post- test, no control group n = 63; 3 rd and 4 th year SN, 1 setting	Online web based education over 8 weeks	1. AST, 35 questions 2. DDCST, 40 questions Author developed	No	<p>AST Pretest: 5% of SN scored >90% Posttest: 19.1% of SN scored >90% Pretest: mean 74.98 ± 12.14 (range 36-96%) Posttest: mean 82.03 ± 9 (range 56-100%) ($p < 0.001$) DDCST Pretest: 0% of SN scored >90% Posttest: 41.2% of SN scored >90% Pretest: mean 71.98 ± 12.29 (range 24-88%) Posttest: mean 82.03 ± 9 (range 60 -100%) ($p < 0.001$) Good correlation between AST and DDCST</p>

Sabin, et al. [27] UK	Counterbalance design, n = 63 3 rd year SN, half completed computer assessment and other half completed OSCE first then swapped, same day 4 universities	Software safeMedicate assessment and online education post data collection	1. Computer based safeMedicate computer simulation authentic assessment 28 items	2. OSCE environment-simulation suite 28- problem subset rubric	safeMedicate computer simulation test mean: 22.7 ± 4.8 were not statistically significantly different ($t(63) = 1.2$, $p = 0.25$) from OSCE mean: 23.1 ± 4.3 with small mean difference (Cohen's $d = 0.09$) Pearson correlation $r = 0.77$ and Spearman-Brown $r = 0.86$ Good correlation between OSCE format safeMedicate computer simulation format \uparrow scores on computer simulation tended to have \uparrow scores on OSCE, \downarrow scores on computer tended to have \downarrow scores on OSCE Supports the use of computer simulation for testing drug calculations for students
Hutton, et al. [26], UK	Multistage quantitative cross over design of purposive stratified sampling pre and posttest for n = 9; 3 rd year SN Half students completed computer and half completed OSCE, same day, 1 setting	No education reported	1. Pretest 40-item base line assessment invigilated in a computer lab (n = 50 SN) 2. Posttest computer 28- item test Authentic World (n = 9) developed by Weeks and Woolley	3. OSCE environment-simulation suite 28 - items similar questions to computer	Posttest: Computer assessment and OSCE yielded similar results

Weeks, et al. [34] UK and USA	Multistage purposive stratified sampling pre and posttest n = 44 SN Half completed education then swapped assessments, group X authentic then traditional and group Y, traditional then authentic UK and USA n = 8 completed all assessments	Computer a) Authentic environment developed by author (Weeks) and b) traditional lecture and tutorials	UK Prior to entry into BN program GCSE Baseline: 1. NA, 40-point Week 4 2. MDC-PS, 30-point Week 8 3. MDC-PS 30-point	US Baseline: 1. NA, 40- point Week 4 2. MDC-PS 100-point	UK 4. Week 9-25 Student case studies OSCE style clinical competency	<p>GCSE and NA Prior to entry Correlation between GCSE mathematics and scores on NA baseline $r = +0.271$ and $\rho = +0.233$ both + but not significant ($p = 0.128$ and $p = 0.076$) Knowledge of GCSE maths did not statistically significantly predict performance on NA Participants with no formal GCSE maths also did not predict NA, those without GCSE were not dissimilar to those who did hold GCSE</p> <p>Week 4 UK 30 point MDC-PS Group X computer group, committed less errors ($n = 32$; error frequency 4.8%) than Group Y traditional ($n = 82$: error frequency 12.4%): $\chi^2 = 14.03$ @1df, $p < 0.001$) Group Y (12.4%) made 2½ times more errors than Group X (4.8%) Statistically significant between the two groups Week 4 USA Statistically significant difference ($t = -4.428$, $df = 68$, $p < 0.001$) in posttest between traditional group Y (67.8 ± 20.6) and authentic group X (85.7 ± 13.5) Week 8 UK Group X from authentic to traditional ↓ error rate from ($n = 32$: 4.8% to $n = 7$: 1.0%) ↓ error reduction of 3.8% Group Y from traditional to authentic ↓ error rate reduction of 8.6% statistically significant difference $\chi^2 = 10.38$ @ 1df $p = 0.001$ OSCE style assessment similar assessment items to MDC-PS, students made similar errors on both the MDC-PS and OSCE high level of congruency between outcomes and errors types, highly predictive of clinical practice performance</p>
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Table 1: A Summary of 9 Studies Found to Meet the Inclusion Criteria on Medication Calculation Assessment Strategies for Student Nurses.

Education

So, few studies were found that this review has included studies that have included education programs as well as more than one assessment strategy. Four studies reported using online software education programs, safe Medicate [25,27], online computer-based education [28] or Authentic environment (World) [16] and two used simulation-based learning [29,30]. Two studies provided traditional learning [26,32]. Ramjan [31] reported providing a tutorial between the two assessments.

Measurements of Medication Calculation Assessment

All nine studies reported using medication calculation or medication knowledge exam assessment, seven studies used written dosage calculation exam papers and/or online format [16,25,28-32]. Four used online format of authentic environment exams [16,25-27]. Six studies employed clinical simulation objective structure clinical examinations or competency-based assessments [16,25-27,29,30] See (Table 1).

Instruments

The reviewed studies used a variety of invalidated, valid and reliable instruments to evaluate medication dosage calculations. Newton [32] reported using Test of Essential Academic Skills Test (TESA) from Assessment Technologies Institute and Ramjan [31] used author developed medication calculation exams neither reported validity or reliability. Valid and reliable instruments were Medication Safety Knowledge Assessment (MSKA) [30], Medication Safety Critical Element Competency Checklist (MSCEC) [30] and Fundamental Numeracy Assessment (FNA) [16,25]. Other studies reported the use of validated and reliable instruments including: Functional Competency Assessment [25], Medication Dosage Calculation Skills (MDCS) [16], Drug Dosage Calculation Skills Test [28] and Medication Dosage Calculation Problem Solving (MDC-PS [16,25]. Authentic Diagnostic Assessment (ADA) using online software packages such as safeMedicate or Authentic World [16,25,26] and/or OSCE were also used and had reported good validity and reliability [16,26,27,29].

Reviewed Study's Findings

Good correlations were reported between students' performance on medication calculation exams, mathematic ability, and number of attempts required to pass a medication calculation exam. These were negatively correlated with mathematical aptitude [28,32]. Good correlations were also reported between online software packages such as safeMedicate and Authentic World, OSCE [26,27] and written exams [16]. Good congruency was found between OSCE and clinical practice [25,29]. Ramjan [31] reported positive predictability between decontextualized (words) and contextualized (visual aids) medication calculation exams. Weeks, et al. [16] suggests authentic training was better for

all CSM groups.

Discussion

Incorrect medication dosing errors can be fatal, can impair patient's outcomes and increase health care costs [1,9]. The importance of safe medication administration and dosing calculations for nurses is becoming increasingly recognized by the profession. However, there are multiple strategies on how medications calculations are assessed [17,18]. There are very few studies assessing effective medication calculation assessment strategies. This review has identified that there are several assessment strategies employed by nurse educators to test medication calculation dosage competencies of student nurses. The reviewed studies have suggested good correlation between the use of theoretical medication calculation exams, student perception of their mathematical abilities, students' readiness to deliver safe medication doses, students' performance with authentic clinical computer-based environments, and clinical skill assessments. No reviewed study reported utilizing clinical teachers during clinical placements as a time or strategy for assessments.

Previous research has suggested assessment techniques such as decontextualized paper-based medication calculation exams did not necessarily translate to competence in administration of medications as they were dissimilar to the reality of health care practice [33]. Paper based medication calculation exams provide a narrow assessment of mathematical knowledge acquisition rather than its application of medication administration in practice [27]. Paper based mathematics qualifications alone do not appear to be valid predictors of nurse's medication calculation efficacy [16,34,35]. Tests using decontextualized arithmetic functions or contextualized in clinical scenarios do not offer reliable indications of future calculation errors in practice [31]. There is limited evidence to suggest that numeracy skills are deteriorating among nurses, merely that they are not addressing the new developing roles of nurses [36] such as the use of electronic medication administration records (eMARs) [37,38].

Practice errors are multifactorial, involving knowledge of medications, shift patterns, prescription quality [36], administration errors including interruptions or distractions occurring [9], staff workloads, stress and fatigue or lack of sleep [39]. The assumption that written paper-based medication calculation test or numeracy test measure student nurses' medication administration abilities neglects to consider the other indicators that are required to successfully calculate and administer medications in clinical practice and can be argued as an invalid assessment [40-44]. Hence the shift from paper based to clinical assessment methods such as web-based online tools, OSCE and simulations [33]. OSCE have been used to assess medical students since the mid 1970's [45]. There is evidence linking nursing student's achievement in

medication calculation test with subsequent clinical practice [36]. Online assessment packages offer efficient and effective ways of measuring staff competency, provides immediate feedback and saves time in grading and analysis. Benefits of online technology tools are that they are flexible, can be provided on multiple sites, cost effective once set up and involve less travel and time for student and educators [39,46].

Traditional evaluations of medication calculation abilities have been based on the assumption that the medication calculation results will correlate to the students' clinical abilities. A new integrated approach with the use of real-life scenarios is needed for the development of this vital professional skill. The challenge for nurse educators is to ensure that the student has an understanding of medication administration rather than the mere knowledge of mathematical skill. This review has limitations. Undertaking the review identified that there are limited number of studies in comparing one type of assessment to another when testing medication calculation skills of student nurses. Therefore, it lacked a systematic approach which could have enriched rigor; this review allowed primary experimental designs to be included in which to enhance the breadth. This review captured so few studies comparing assessments however there is a large amount in education strategies of medication calculation for health care professionals that exists. The intention of this study was to focus on student nurses and the use of simulation or clinical based assessment to test medication calculation skills to gather information as to the best practice for assessing medication calculation skills. This approach limited the search removing registered nurses as trained nurses have already established medication calculation skills and were considered more knowledgeable in the administration of medications than student nurses. Nurses' years of experience is a contributing factor to errors, with errors occurring more frequently with less experience than experienced nurses, reducing by 11% per year for each additional year of experience up to the first six years [1,9]. Additional limitation was that other health care professionals such as pharmacy, medical and paramedic students were excluded as there are different approaches in the education of medication skills and administration responsibilities. As calculations of medications and medication drug errors continue to be problematic, [5] this area continues to remain a serious concern. The following are a set of recommendations for tertiary educators to assist with the effects of medication calculation and administration for nurses:

Medication dosages calculation test remain the most common method of assessing medication calculation skills, which are strongly correlated to mathematical skills. This review has reported that simulated clinical based assessments are strongly correlated to medication calculation abilities. Tertiary institutions should aim to enhance medication calculation learning with the use of simulations, contextualized situations, online authentic experiences and clinical practice as opportunities to assess

medication administration competence. The assessment of medication dosage calculation competency using simulation assessments should use valid and reliable instruments. If tertiary educators increase simulation-based learning and assessments early within the curriculum, the effects are likely to improve effective medication calculation and safe medication administration, with the intention of reducing medication errors when students reach placement which then strengthens the workforce. Education in health care is rapidly shifting from traditional didactic lectures and tutorials to authentic simulation-based environments which more closely resemble the real-world experiences of health care settings. The use of simulation-based learning would be ideal to adequately prepare students by closely presenting patient scenarios. Online education is expanding and there is an increase in the use of virtual learning which can be one way of delivering effective training of medication administration.

Conclusion

This is a dynamic time in nursing education as educator attempt to incorporate technology with the use of manikin simulators and online virtual software programs to improve training of what and hence patients' outcomes. The need for improved medication dosage calculations and administration is required. The many and varied teaching styles in the delivery of medication calculation competence could be mitigated with the use of online resource package and valid and reliable simulation-based assessment instruments. According the few studies in this review, simulation and online assessments have been demonstrated to improve the effectiveness of medication administration and calculation assessment strategies. This review recognizes that more research is needed in this exciting new direction of health care education.

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