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# The use of objective assessments in the evaluation of technical skills in cardiothoracic surgery: a systematic review

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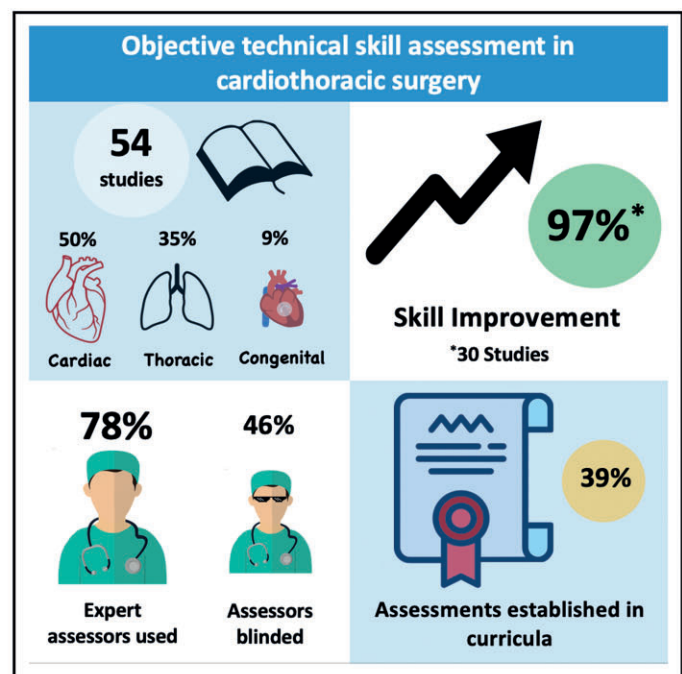
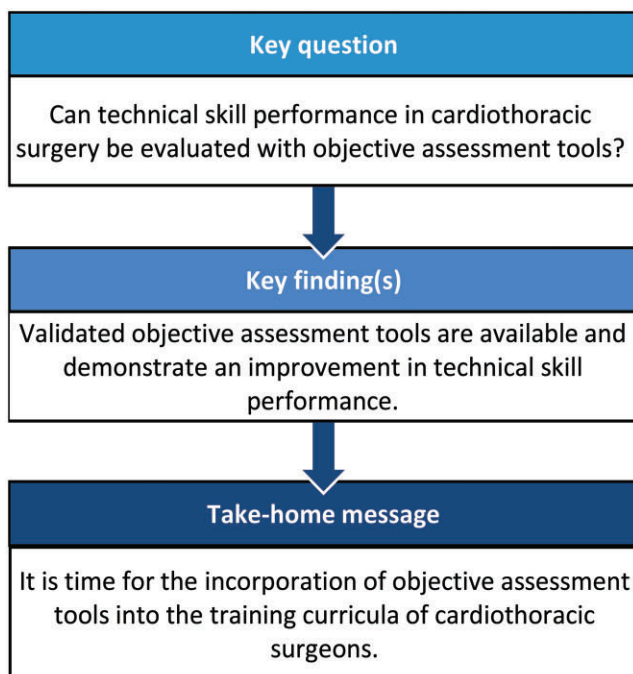
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## Abstract

**OBJECTIVES:** With reductions in training time and intraoperative exposure, there is a need for objective assessments to measure trainee progression. This systematic review focuses on the evaluation of trainee technical skill performance using objective assessments in cardiothoracic surgery and its incorporation into training curricula.

**METHODS:** Databases (EBSCOHOST, Scopus and Web of Science) and reference lists of relevant articles for studies that incorporated objective assessment of technical skills of trainees/residents in cardiothoracic surgery were included. Data extraction included task performed; assessment setting and tool used; number/level of assessors; study outcome and whether the assessments were incorporated into

training curricula. The methodological rigour of the studies was scored using the Medical Education Research Study Quality Instrument (MERSQI).

**RESULTS:** Fifty-four studies were included for quantitative synthesis. Six were randomized-controlled trials. Cardiac surgery was the most common speciality utilizing objective assessment methods with coronary anastomosis the most frequently tested task. Likert-based assessment tools were most commonly used (61%). Eighty-five per cent of studies were simulation-based with the rest being intraoperative. Expert surgeons were primarily used for objective assessments (78%) with 46% using blinding. Thirty (56%) studies explored objective changes in technical performance with 97% demonstrating improvement. The other studies were primarily validating assessment tools. Thirty-nine per cent of studies had established these assessment tools into training curricula. The mean  $\pm$  standard deviation MERSQI score for all studies was  $13.6 \pm 1.5$  demonstrating high validity.

**CONCLUSIONS:** Despite validated technical skill assessment tools being available and demonstrating trainee improvement, their regular adoption into training curricula is lacking. There is a need to incorporate these assessments to increase the efficiency and transparency of training programmes for cardiothoracic surgeons.

**Keywords:** Objective assessment • Technical skills • Cardiothoracic surgery • Simulation • Resident training

### ABBREVIATIONS

CTS	Cardiothoracic surgery
MERSQI	Medical Education Research Study Quality Instrument
OSATS	Objective Structured Assessment of Technical Skills

## INTRODUCTION

Technical skill development in cardiothoracic surgery (CTS) training has been primarily via direct experience in the operation room. The growth of simulation-based training has provided an adjunct to training with programmes successfully incorporating these methods into their curricula [1–5]. However, with the reduction in training time and intraoperative exposure, there is a greater need for the incorporation of objective assessments to facilitate trainee progression [1, 6–10]. This systematic review focuses solely on the use of objective assessments in the evaluation of technical skill performance for surgical trainees/residents in CTS. Furthermore, it will explore whether such assessment methods have been successfully incorporated into training programmes.

## METHODS

### Ethics statement

Institutional Review Board review was not required for this review as patient data were not used and participant data was anonymous.

### Eligibility criteria, databases and search strategy

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting guideline [11]. Inclusion criteria included original research studies (i.e. randomized controlled trials, observation, cohort, case control and cross-sectional studies) published in English-peer reviewed journals and related to adult and paediatric CTS. Only studies that incorporated objective assessment of technical skills in CTS were included. The following definitions were used for clarity: (i) ‘technical skill’—any hands-on action by a surgeon/trainee in the

operating room or simulated operating environment (including benchtop, wet-lab or virtual reality simulation); (ii) ‘assessment’—the reporting of a surgeon/trainees’ technical proficiency/performance of the specified task; (iii) ‘objective’—predefined, structured scoring criteria that is used to evaluate performance. Furthermore, only studies that included the technical skill assessment of trainee/resident surgeons were included (i.e. studies looking at only medical students or established/expert surgeons were excluded). Validation studies were also included if the above inclusion criteria were satisfied.

Exclusion criteria included unpublished abstracts, posters, opinions, case reports, reviews, letters to editors and editorials. Papers were also excluded if they reported on non-technical skills training or skills that are not directly CTS related. The latter comprised skills that are not routinely included in CTS training curricula, such as echocardiography, cardiac catheterization and endovascular skills.

The following sources were searched with the assistance of a medical librarian, for articles that met our inclusion criteria and were published by October 2021: EBSCOHOST (MEDLINE, Academic Search Premier, CINAHL complete), Scopus, Web of Science Core Collection and reference lists of relevant articles. Terms used for the search included the (i) type of surgery (i.e. cardiothoracic, cardio\*, cardiac, thoracic, congenital, heart, surgery), (ii) method of assessment (i.e. objective, competence\*, technical, skill\*, perform\*, assess\*, tool) and (iii) subject/participant (i.e. trainee, resident, registrar, fellow). The detailed search strategies are provided in [Supplementary Material, Appendix SE1](#).

The following steps were taken for study selection: (i) identification of titles through database search, (ii) removal of duplicates, (iii) screening of abstracts, (iv) assessment of full-text articles for eligibility and (v) final inclusion into the study. Studies were selected by 2 independent reviewers (N.H. and J.V.D.E.) according to the inclusion/exclusion criteria. When there was any conflict a third reviewer (C.C.) made the decision to include or exclude the study.

### Data collection

Data extraction was completed independently by 2 authors (N.H. and C.C.). Inconsistencies were resolved by consensus. Information was collected on the following 15 items: (i) study demographics, (ii) study type, (iii) CTS subspeciality, (iv) participant level (i.e. resident, consultant/attende, medical student), (v) number of participants, (vi) task performed/assessed, (vi) type of

**Table 1:** Data extraction table of all studies included in the systematic review

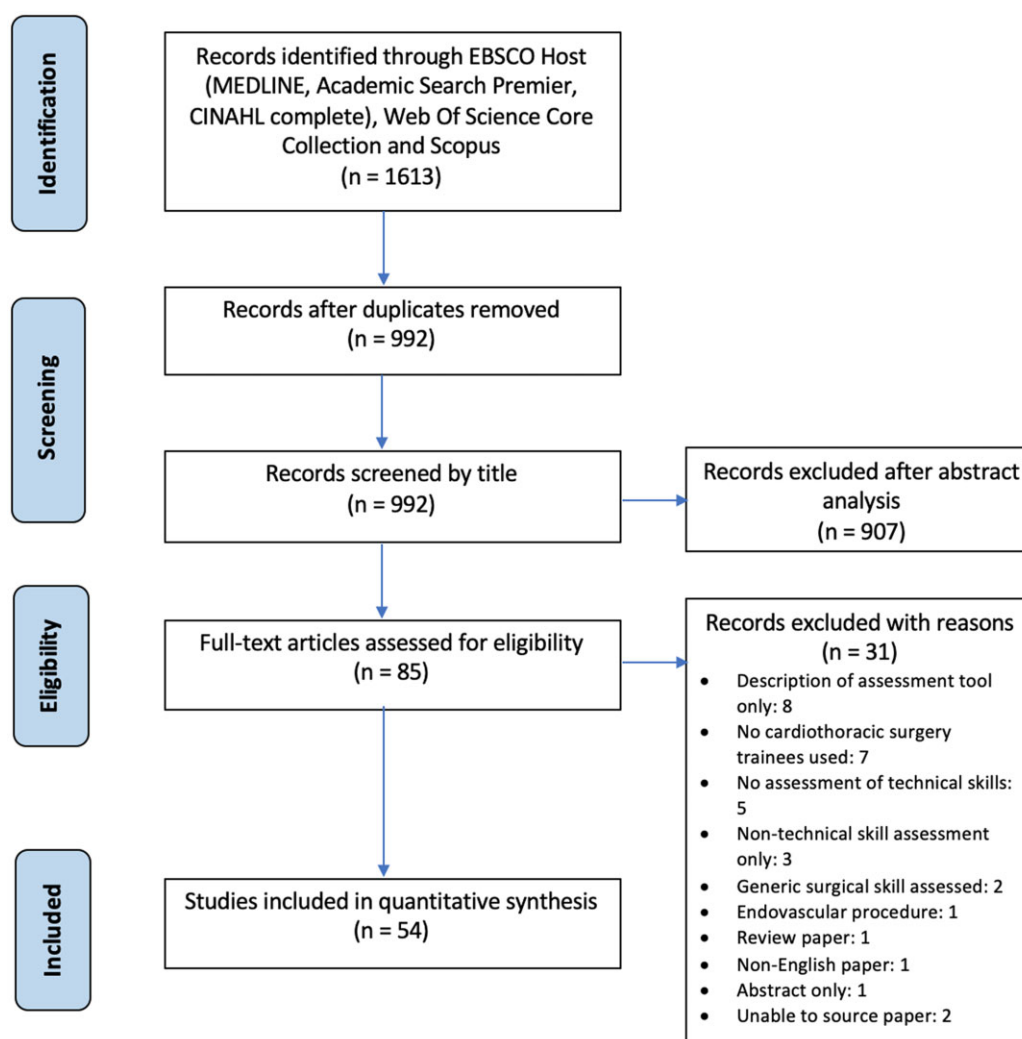
Author	Year	Study Type (cohort number)	Speciality	Participant (n)	Task performed	Format of assessment	Time assessment	Setting of assessment	Level of assessor (n)	Video used	Assessor blinded	Retrospective/prospective assessment	Outcome	Established in curriculum	Total MERSQI score
Bedetti [29]	2018	NR (2)	Thoracic	Trainee, surgeon (20)	Lobectomy	Likert	Y	Simulation VR	Simulator assessed	N	NA	P	Improvement	NS	11
Blum [30]	2004	R (3)	Thoracic	Trainee (13)	Bronchoscopy	Time + cues	Y	Intraoperative, simulation	Expert (1)	N	N	P	Improvement	Y	13.5
Bohnen [31]	2018	NR (2)	Thoracic	Trainee, surgeon (14)	Emergency thoracotomy	Likert	Y	Simulation-synthetic	Expert (2)	Y	Y	R	Validation only	N	13.5
Brandao [32]	2021	NR (1)	Cardiac	Trainee (16)	CABG, AVR, MVR	Likert	Y	Simulation-animal	NS	N	NS	P	Other trainees better prepared	NS	10.5
Duffy [33]	2019	NR (1)	Cardiac	Trainee, student, surgeon (14)	SVG harvesting	Likert	N	Simulation-synthetic	Expert + low experience (2)	Y	Y	R	Validation only	N	14.5
Fann [34]	2010	NR (1)	Cardiac	Trainee (33)	Coronary-anastomosis	Likert	N	Simulation-animal + synthetic	Expert (3)	Y	Y	R	Improvement	Y	13
Fouilloux [35]	2015	R (2)	Cardiac	Trainee (9)	CPB-management	Likert	N	Simulation-animal	Expert (2)	Y	Y	R	Improvement	NS	15.5
Ghazy [36]	2019	NR (2)	Thoracic	Trainee (10)	Flexible bronchoscopy	Time	Y	Simulation-synthetic	NA	N	N	P	Improvement	NS	13.5
Greenhouse [37]	2013	NR (3)	Cardiac	Trainee, surgeon (19)	MVR	Likert	Y	Simulation-synthetic	Expert (2)	Y	Y	R	Validation only	Y	13.5
Hance [6]	2005	NR (3)	Cardiac	Trainee, surgeon (40)	Coronary-anastomosis	Likert	N	Simulation-animal + synthetic	Expert (4)	Y	Y	R	Validation only	Y	15.5
Hermesen [26]	2020	NR (2)	Cardiac	Trainee, surgeon (6)	CPB	Checklist	Y	Simulation-animal	Expert (1)	N	N	P	Validation only	NS	13.5
Hicks [27]	2011	NR (1)	Cardiac	Trainee (32)	CPB	Hybrid	N	Simulation-animal	Expert (1)	N	N	P	No-comparison	Y	12
Hussein [38]	2020	NR (2)	Congenital	Trainee, surgeon (10)	Arterial switch operation	Hybrid	N	Simulation-synthetic	Expert + low experience(9)	Y	Y	R	Validation only	Y	14.5
Hussein [39]	2020	NR (1)	Congenital	Trainee, surgeon (30)	Arterial switch operation	Hybrid	Y	Simulation-synthetic	Expert (1)	Y	Y	R	Improvement	Y	14
Hussein [22]	2021	NR (2)	Congenital	Trainee, surgeon (30)	Norwood operation	Hybrid	Y	Simulation-synthetic	Expert + Low experience(10)	Y	Y	R	Improvement	Y	15.5
Hussein [4]	2020	NR (1)	Congenital	Trainee (7)	Congenital-operations	Hybrid	Y	Simulation-synthetic	Expert (1)	Y	Y	R	Improvement	Y	13
Iwasaki [40]	2008	NR (2)	Thoracic	Trainee, surgeon (8)	VATS-Lobectomy	Likert	Y	Simulation-synthetic	NS	Y	NS	R	Validation only	Y	12.5
Jebzan [41]	2019	NR (2)	Cardiac	Trainee, student (20)	MI-MV surgery	Likert	Y	Simulation-synthetic	Expert (1)	N	N	P	Improvement	N	13.5
Jensen [42]	2017	NR (3)	Thoracic	Trainee, student, surgeon (53)	VATS-Lobectomy	VR-simulator score	Y	Simulation-VR	Simulator-assessed	Y	NA	P	Improvement	NS	15.5
Jensen [18]	2019	NR (3)	Thoracic	Trainee, student, surgeon (53)	VATS-Lobectomy	Likert	N	Simulation-VR	Expert (3)	Y	Y	R	Validation-only	NS	15.5
Joyce [43]	2011	NR (1)	Cardiac	Trainee (11)	MV-repair	Likert	Y	Simulation-animal + synthetic	Expert (1)	Y	Y	R	Improvement	NS	13
Joyce [44]	2018	NR (1)	Cardiac	Trainee (12)	CPB	Likert	Y	Simulation-synthetic	Expert (4)	Y	N	P	Validation-only	Y	12.5
Karim [45]	2017	NR (1)	Cardiothoracic	Trainee (33)	Cardiothoracic-cases	Qualitative-feedback	N	Intra-operative	Expert (48)	N	N	P	Validation-only	NS	10
Kenny [46]	2018	NR (1)	Cardiothoracic	Trainee (20)	CPB, Wedge resection	Likert	N	Simulation-animal	Expert (1)	N	N	P	Improvement	Y	13
Konge [19]	2012	NR (3)	Thoracic	Trainee, Surgeon (14)	Wedge-resection	Likert	N	Intra-operative	Expert (2)	Y	Y	P	Validation-only	NS	15
Korte [47]	2020	NR (3)	Cardiac	Trainee, student (19)	Coronary-anastomosis	Likert	Y	Simulation-animal-synthetic	Expert (NS)	Y	NS	P	Improvement	Y	13.5
Lee [48]	2013	NR (4)	Cardiac	Trainee, student, surgeon (5)	Coronary-anastomosis	Likert	N	Simulation-animal-synthetic	Expert (10)	Y	Y	R	Validation only	Y	14.5
Li [49]	2020	NR (2)	Cardiac	Trainee (12)		Likert	N	Simulation-animal	Expert (2)	Y	Y	R	Improvement	NS	13.5

Continued

Table 1: Continued

Author	Year	Study Type (cohort number)	Speciality	Participant (n)	Task performed	Format of assessment	Time assessment	Setting of assessment	Level of assessor (n)	Video used	Assessor blinded	Retrospective/prospective assessment	Outcome	Established in curriculum	Total MERSQI score
Liu [50]	2019	NR (1)	Cardiac	Trainee (5)	Coronary-anastomosis CPB	Checklist	Y	Simulation-synthetic	Expert (1)	N	N	P	Validation only	NS	11.5
Llado-Grove [51]	2015	NR (1)	Cardiac	Trainee (83)	Coronary-anastomosis	Likert	Y	Simulation-synthetic	NS (2)	N	N	P	Improvement	Y	14
Lou [16]	2014	NR (2)	Cardiac	Trainee, student (4)	Coronary-anastomosis	Likert	N	Simulation-synthetic	Low experience(9)	Y	Y	R	Validation only	NS	12.5
Macfie [20]	2014	NR (1)	Thoracic	Trainee (64)	Hilar-dissection	Likert	N	Simulation-animal	Expert (NS)	N	N	P	Improvement	Y	13
Malas [52]	2018	R (2)	Cardiac	Trainee (32)	Coronary-anastomosis	Likert	Y	Simulation-synthetic	Expert (2)	Y	Y	P	Improvement	NS	15.5
Maluf [53]	2015	NR (1)	Cardiac	Trainee (10)	Coronary-anastomosis	Likert	N	Simulation-animal + synthetic	Expert (NS)	Y	N	P	Improvement	Y	10
Maricic [54]	2016	NR (3)	Thoracic	Trainee, surgeon (39)	VATS-oesophageal atresia	Checklist	Y	Simulation-synthetic	NS	N	N	P	Validation only	Y	14.5
Marshall [55]	2012	NR (1)	Thoracic	Trainee (13)	Chest wall-resection	Hybrid	Y	Simulation-animal	Expert (1)	N	N	P	Improvement	Y	13
Miura [56]	2021	NR (1)	Thoracic	Trainee (3)	Lobectomy	Hybrid	N	Intra-operative	Expert (NS)	N	N	P	Validation only	NS	12
Nam [57]	2021	NR (1)	Congenital	Trainee (6)	ToF-repair	Time+ subjective-score	Y	Simulation-synthetic	Expert (1)	Y	NS	R	Improvement	NS	12
Nesbitt [17]	2013	NR (2)	Cardiac	Trainee, students (21)	Coronary-anastomosis	Likert	Y	Simulation-animal	Expert (3)	Y	Y	R	Improvement	NS	14.5
Ortiz [58]	2021	NR (1)	Cardiothoracic	Trainee (16)	CTS-trauma	Likert	Y	Simulation-animal	Expert (NS)	Y	Y	R	Improvement	NS	15.5
Petersen [59]	2018	NR (3)	Thoracic	Trainee, surgeon (18)	VATS-Lobectomy	Likert	N	Intraoperative	Expert (2)	Y	Y	R	Validation only	NS	16
Price [60]	2011	R (2)	Cardiac	Trainee (39)	Coronary-anastomosis	Likert	Y	Simulation-animal+synthetic	Expert (2)	Y	Y	R	Improvement	NS	15.5
Sardari-Nia [61]	2020	NR (3)	Cardiac	Trainee, surgeon (102)	MI-MV surgery	Suture-accuracy	Y	Simulation-synthetic	NS	Y	NS	R	Improvement	Y	13
Spratt [62]	2019	R (2)	Cardiac	Trainee (29)	Coronary-anastomosis	Likert	N	Simulation-synthetic	Expert (1)	Y	Y	R	No change	NS	13.5
Tanaka [63]	2021	NR (3)	Thoracic	Trainee, surgeon (29)	VATS-Lobectomy	Time	Y	Simulation-synthetic	NS	N	N	P	Validation only	NS	13.5
Tavlasoglu [64]	2013	NR (2)	Cardiac	Trainee (10)	MV-repair	Test of repair	N	Simulation-animal	Expert (3)	Y	Y	R	Improvement	NS	12
Tong [65]	2012	NR (3)	Thoracic	Trainee (13)	VATS-Lobectomy	Checklist	Y	Simulation-animal	Expert (NS)	Y	N	P	Validation only	NS	12.5
Turner [66]	2019	NR (1)	Thoracic	Trainee (5)	Mediastinal-staging	Likert	N	Intra-operative	Expert (NS)	Y	N	P	Validation only	Y	13.5
Turner [67]	2020	NR (1)	Thoracic	Trainee (7)	Lung-resection	Likert	N	Intra-operative	Expert (NS)	N	N	P	Improvement	NS	16
Valdis [68]	2016	R (4)	Cardiac	Trainee (40)	Robotic ITA+MV-repair	VR-simulator score	Y	Simulation-animal+synthetic	Expert (2)	Y	Y	R	Improvement	NS	15.5
Voduc [69]	2016	NR (2)	Thoracic	Trainees (19)	Flexible-Bronchoscopy	Likert	N	Intra-operative	Expert (NS)	N	N	P	Validation only	NS	14
Whittaker [70]	2019	NR (3)	Thoracic	Trainee, student, surgeon (30)	Robotic-lobectomy	VR-simulator score	Y	Simulation-VR	Simulator-assessed	N	NA	P	Validation only	NS	14.5
Wu [71]	2020	NR (1)	Cardiac	Trainee (26)	Coronary-anastomosis	Likert	Y	Simulation-animal	Expert (3)	Y	Y	R	Improvement	NS	13.5
Yasuda [72]	2021	NR (2)	Cardiac	Trainee, student (10)	Coronary-anastomosis	Likert	Y	Simulation-synthetic	Low experience (1)	N	N	P	Improvement	NS	13.5

AVR: aortic valve replacement; CABG: coronary artery bypass grafts; CPB: cardiopulmonary bypass; CTS: cardiothoracic surgery; ITA: internal thoracic artery; MI: minimally invasive; MVR: mitral valve replacement; NA: not applicable; NR: non-randomized; NS: not specified; R: randomized; SVG: saphenous vein graft; ToF: tetralogy of Fallot; VATS: video-assisted thoroscopic surgery; VR: virtual reality.



**Figure 1:** PRISMA flow diagram of studies include in data search. PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-analyses.

assessment tool (i.e. Likert scale, checklist, hybrid), (vii) time assessment, (viii) setting of assessment [i.e. intraoperative, simulation (animal, synthetic, hybrid, cadaveric)], (ix) number of assessor(s), (x) level of assessor(s), (xi) use of video assessment, (xii) blinding of assessor (i.e. participant identification or attempt number removed), (xiii) retrospective versus prospective assessment, (xiv) outcome of study (i.e. improvement in performance, validation only) and (xv) if the assessment method was established into the training curriculum (Table 1).

## MERSQI assessment

The methodological rigour of the included studies was scored using the Medical Education Research Study Quality Instrument (MERSQI). This is a validated assessment tool for quantitative appraisal of medical education across 8 domains including (i) study design, (ii) institution samples, (iii) response rate (i.e. percentage of participants who were objective assessed), (iv) type of data, (v) validity of evidence for evaluation of instrument scores, (vi) sophistication of data analysis, (vii) appropriateness of data analysis and (viii) assessment outcome [12, 13]. Descriptive statistics were used.

## RESULTS

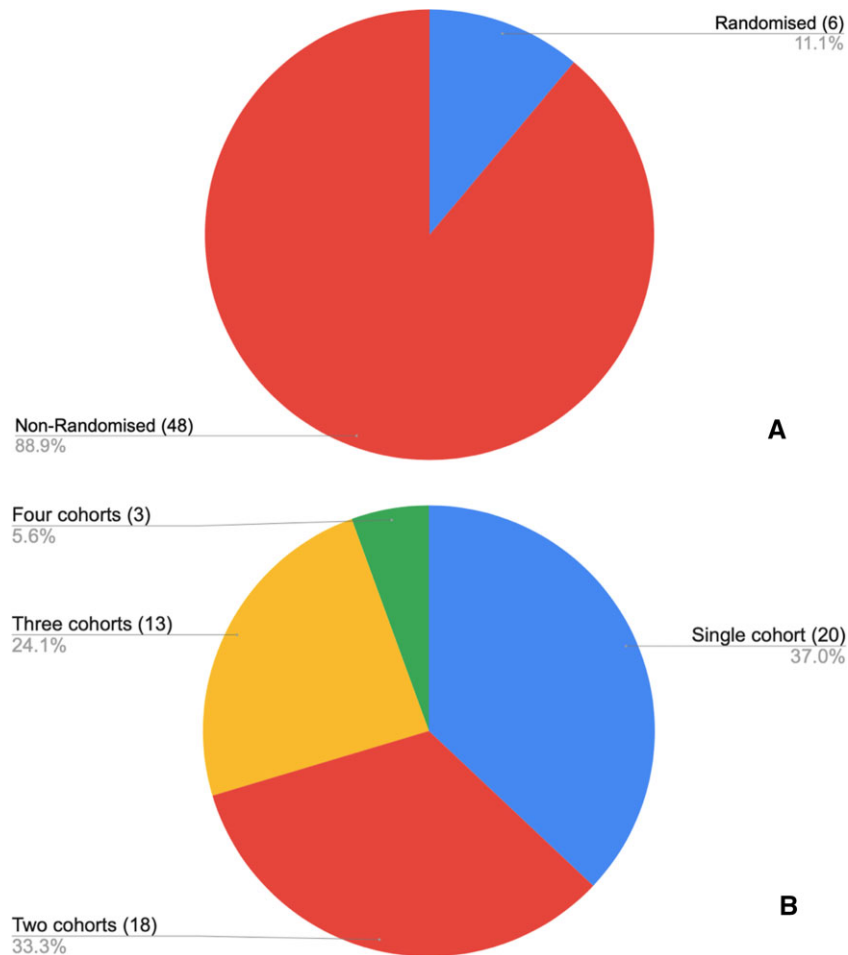
### Study selection and characteristics

The literature search identified 1613 potentially relevant papers (Fig. 1). Following the removal of duplicates, records were screened by title and abstract leaving 85 full-text articles to be assessed for eligibility. A further 31 papers were excluded following full-text review leaving a total of 54 to be included in the quantitative synthesis. Reasons for exclusion are given in Fig. 1. Six of the studies (11%) were randomized controlled trials. A single cohort was used in 37% of studies (20/54), with 2 cohorts being the next most common at 33% (18/54). Three and 4 cohort studies comprised 24% (13/54) and 6% of the sample, respectively (3/54; Fig. 2). Cardiac surgery was the most common subspecialty utilizing objective assessment methods at 50% (27/54), followed by thoracic surgery (35%, 19/54), congenital surgery (9%, 5/54) and CTS in general (6%, 3/54). There were no studies in cardiothoracic transplantation (Fig. 3A).

### Participant characteristics

Fifty-six per cent (30/54) of studies included only trainees/residents, while 28% (15/54) assessed trainees/residents + expert surgeons,





**Figure 2:** Chart demonstrating the number of studies which were randomized versus non-randomized (**A**) and number of cohorts that were included in the studies (**B**).

7% (4/54) used trainees/residents + medical students and 11% (6/54) used trainees/residents + medical students + experts. The average number of participants across all studies was 23 ranging from 1 to 5 participants (5/54) to >51 participants (5/54; Fig. 3B).

### Assessment characteristics

The most common task assessed was coronary anastomosis at 28% (15/54), followed by pulmonary lobectomy (19%, 10/54), cardiopulmonary bypass and mitral valve surgery (both 11% [6/54]). Table 2 demonstrates the full list of tasks included in all studies.

The objective assessment of technical skills was present in all studies. The Likert scale [i.e. Objective Structured Assessment of Technical Skills (OSATS tool)] was the most commonly used assessment tool at 61% (33/54), while a checklist-based assessment was used in only 7% (4/54) of studies. A hybrid assessment combining both the Likert and checklist assessment methods was used in 13% (7/54) of studies. Other objective assessments included: time only (7%, 4/54), automated virtual reality simulator score (6%, 3/54), suture accuracy, test of repair and qualitative feedback (2% each, 1/54). Time assessments were used in 60% of all studies (Fig. 4A).

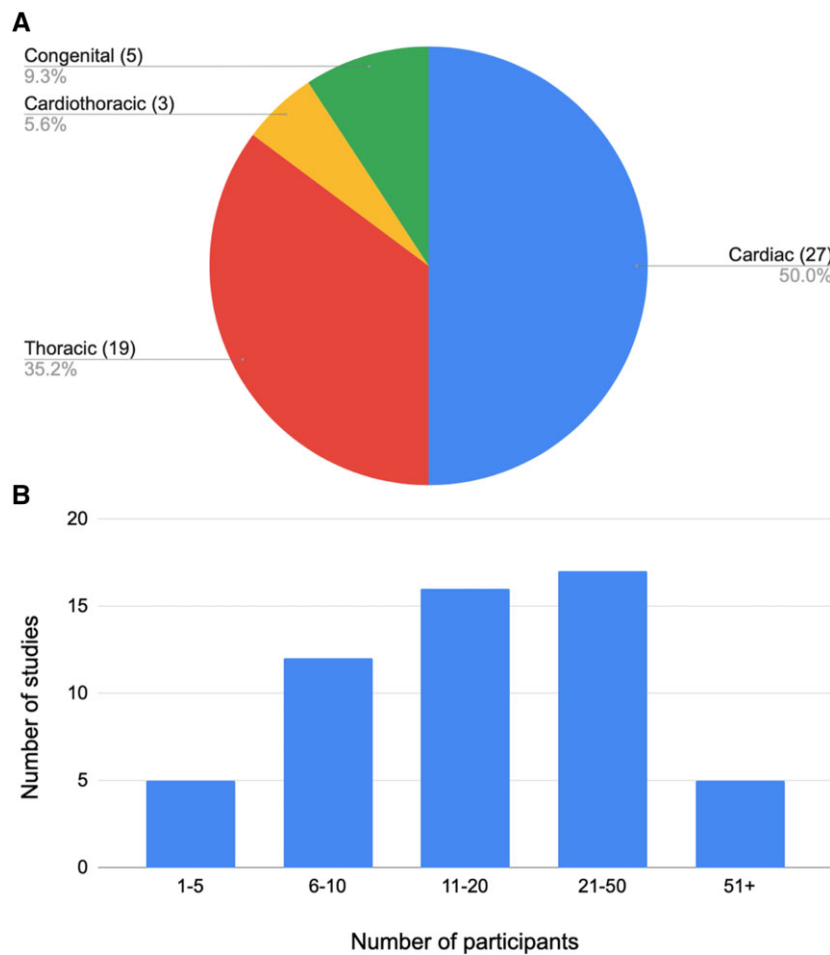
Eighty-five per cent (46/54) of assessments were made in the setting of simulation with only 15% being intraoperative assessments (8/54). Synthetic simulators were the most common at

39% (21/54) of all assessments, followed by animal (26%, 14/54) and hybrid simulation comprising both synthetic and animal simulators (13%, 7/54). Virtual reality simulator assessments were present in 7% (4/54) of studies (Fig. 4B).

Twenty-six per cent (14/54) of studies did not specify the number of assessors/evaluators used for the objective assessments. Of the remaining studies (40), 35% (14) used a single evaluator, with 28% (11) using 2 evaluators. Three (5) and >4 (7) evaluators were used in 13% and 18% of studies, respectively. In 3 studies, the simulator was able to perform an automated assessment. Expert surgeons were primarily used to perform the objective assessments with 69% (37/54) of studies using only expert assessors. Nine per cent (5/54) of studies used an expert surgeon + other less-experienced evaluators. Studies using only less-experienced evaluators were present in 4% (2/54) of studies. Seven studies either did not specify the level of evaluator or this was not applicable (i.e. time only assessment). Assessors were blinded in 46% (25/54) of studies (Fig. 5) and video recordings were used in 63% (34/54). The number of assessments performed either prospectively (i.e. at the time of task) or retrospective (i.e. following task) were almost equal (52% vs 48%).

### Outcomes

Thirty (56%) studies explored objective changes in technical performance (i.e. minimum of 2 sessions/attempts) with 29 (97%)



**Figure 3:** Studies broken down by subspecialty in cardiothoracic surgery (A). Number of participants included in studies (B).

**Table 2:** List of technical skill tasks performed during studies that were objectively assessed

Task performed	Number of studies, n (%)
<b>Cardiac surgery</b>	
Coronary anastomosis	15 (28)
Cardiopulmonary bypass	6 (11)
Mitral valve surgery	6 (11)
Conduit harvesting	2 (4)
Aortic valve surgery	1 (2)
<b>Thoracic surgery</b>	
Pulmonary lobectomy	10 (19)
Bronchoscopy	3 (6)
Wedge resection	2 (4)
Hilar dissection	1 (2)
VATS oesophageal surgery	1 (2)
Invasive mediastinal staging	1 (2)
<b>Cardiothoracic surgery</b>	
Emergency scenarios	3 (6)
<b>Congenital cardiac surgery</b>	
Arterial switch operation	2 (4)
Norwood operation	1 (2)
Tetralogy of Fallot repair	1 (2)
Multiple congenital procedures	1 (2)

demonstrating improvement. A large proportion of studies (39%, 21/54) were designed to validate the simulator or assessment tool (i.e. demonstrate construct validity) and were not focused on demonstrating objective improvement in performance (Fig. 6A). Thirty-nine per cent (21/54) of studies had established these objective assessment methods in the training curriculum of their respective training programmes (Fig. 6B).

## METHODOLOGICAL QUALITY

The mean  $\pm$  standard deviation MERSQI score for all studies was  $13.6 \pm 1.5$  (maximum score: 18). Fifty-two per cent (28/54) of studies were performed by a single institution with the rest involving  $\geq 2$  institutions. Most studies had a very high response rate with 96% (52/54) reporting a  $>75\%$  response. Over 68% (37/54) of assessment tools demonstrated either a moderate (48%, 26/54) or high validity (20%, 11/54) due to the inclusion of content/construct validity and internal structure in their development and evaluation. Ninety-one per cent (49/54) of studies used more than descriptive statistics, which was deemed appropriate on review. The majority of studies (87%, 47/54) assessed knowledge/skills with 13% (7/54) being performed on real-life patients. No study used patient outcomes as a measure of technical skill performance.

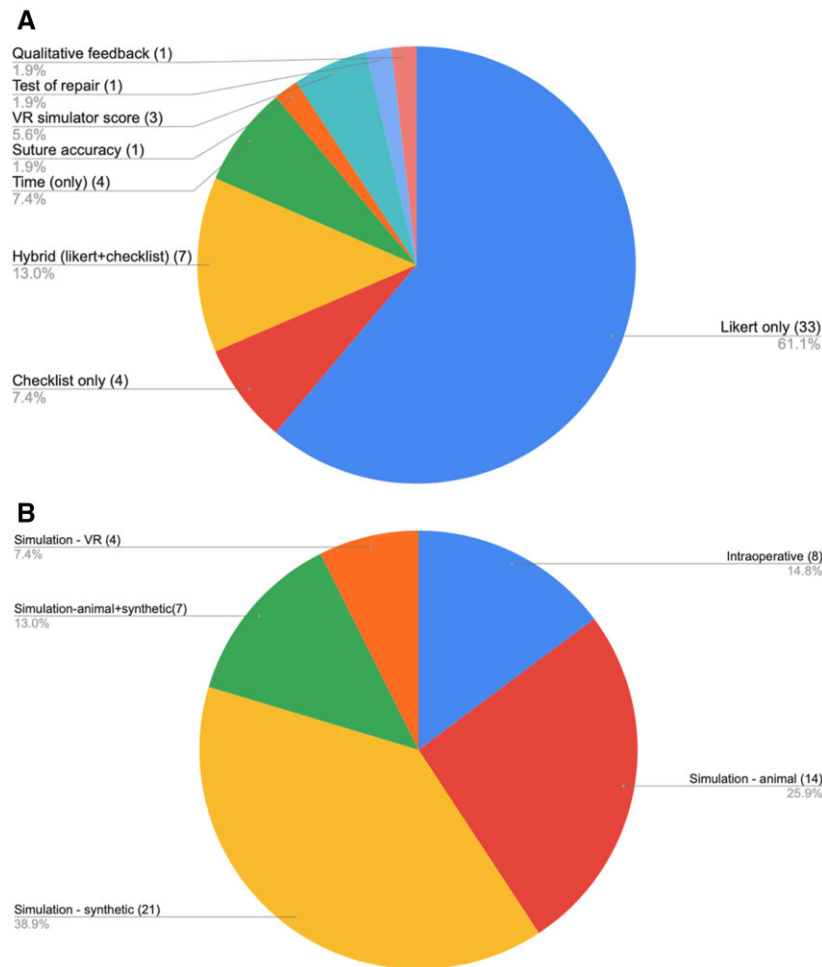


Figure 4: Chart demonstrating the types of objective assessment methods used to assess technical skill performance (A) and the setting of the assessment (B).

## DISCUSSION

Within this review, 85% of assessments were made in the setting of simulation with 15% being in the intraoperative environment. Although simulation assessments are more readily available and can be performed outside of the operating environment, intraoperative assessments provide trainee surgeons with real-life experience and the associated pressures. In the ideal training curriculum, a trainee surgeon would initially train on simulators to refine their technical skills, fluency and operative sequencing. Once proficient they would transfer these learnt skills into the intraoperative environment, where further objective assessment is performed to focus on learning and progression.

The 2 most commonly assessed tasks were in coronary anastomosis (28%) and pulmonary lobectomy (19%), which are the fundamental index procedures. Surprisingly, there was only one study which included objective assessment in aortic valve surgery and none in cardiothoracic transplantation. Although validated aortic valve simulators exist, the lack of studies using objective assessments may be related to no assessment tool being available and/or validated, which may be a focus for future work [3, 5].

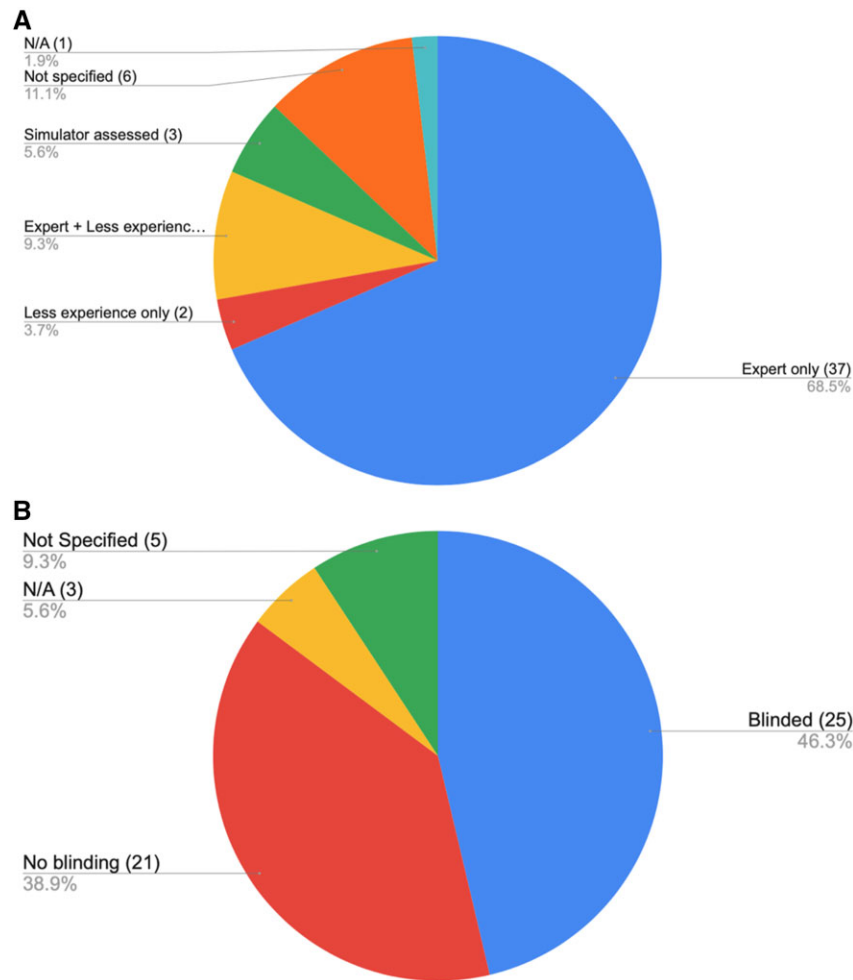
## Improvement in objective assessment scores

One crucial aspect to simulation training is the demonstration of improvement and surgical skill progression. Not only does this allow simulators to be validated but it can also be used to identify when a trainee has gained competence in a particular skill and can progress to the next step in their training. Furthermore, the regular objective assessment will allow surgeons to focus their ongoing training needs which will potentially streamline the efficiency of technical skill acquisition. Fifty-six per cent of studies explored objective changes in technical performance with 97% of these (all except one) demonstrating improvement. The primary goal of the remaining studies was to validate the assessment tool rather than demonstrate the effects of objective assessment.

## MERSQI score

The mean MERSQI score across all 54 studies was 13.6. Using a score of 14 as a cut-off for high-quality research 39% (21/54) of studies fell into this category [14]. Although the majority of studies were non-randomized, nearly half of the studies involved more than one institution with a high sampling rate (>75%). The majority of studies demonstrated both moderate or high validity





**Figure 5:** Chart demonstrating the level of assessors used in the studies (A) and whether assessors were blinded or not (B).

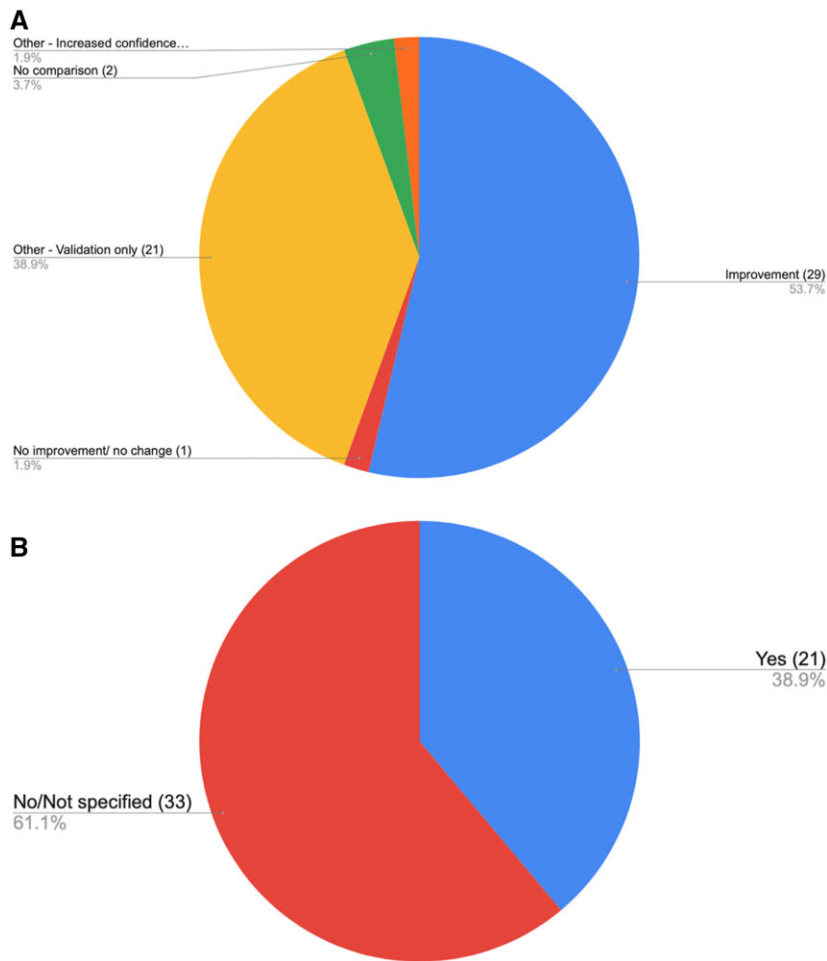
and reliability. Validity refers to whether a test measures what it intends to test, whereas reliability refers to the precision of the assessment (i.e. if the assessment was repeated would it produce the same result). Most studies included a combination of the following methods: (i) face ± content validity (i.e. assessment tool contents were reviewed by experts to deem if they assessed what they intended to ± appropriateness), (ii) internal structure (i.e. assessment of inter-rater reliability, or test-retest) and (iii) construct validity (i.e. demonstrating a difference in performance between expert and trainee/junior surgeons). Although no study demonstrated the actual effect on real patients, all studies assessed technical skill with 13% assessing performance on real patients. This is further evidence that the use of objective assessment methods in technical assessment evaluation renders itself to high-quality educational research, encouraging such methods to be incorporated into training programmes if feasible.

### Ideal assessment tool for objective assessment in cardiothoracic surgery

The evaluation of technical skill is crucial for CTS; however, the ability to generate objective assessment from unbiased experts and create reproducible results remains challenging. Various methods have been described to address this. The Likert scale

utilizing an OSATS format was the most commonly used assessment tool with checklist methods appearing infrequently. This is likely related to the Likert scale being a thoroughly validated tool and its general format makes it easier to be tailored to multiple surgical procedures [6, 16–20]. The disadvantage of this method is the limitation on feedback it may provide the trainee surgeon as it does not focus on the specific aspects of the technical skill the surgeon failed on.

The evaluator is an important factor to consider in establishing objective assessment. Within this review, the majority of studies (63%) used ≤2 evaluators and experts were primarily used (69%). Although the use of expert assessors is the most robust method of assessment their reliance adds an additional limitation to its regular use. Ideally, objective assessments should be validated to be performed automatically or by less-experienced personnel to increase use. A number of studies have demonstrated that objective improvement can occur without supervisor/expert supervision within CTS [16, 21, 22]. Crowd-sourced evaluations using lay persons may be a potential solution with studies demonstrating that as well as being cost-effective and efficient, can generate results comparable to experts [23]. Barriers to crowd-sourcing include cost as local experts usually provide feedback free of charge, albeit their availability may be limited [23]. However, if such methods are used to assess trainee progression, there must be input from experts, whose assessment is



**Figure 6:** Chart demonstrating the outcome of the assessment (e.g. improvement in technical skill performance) (**A**) and whether the assessment method was incorporated into the training curricula (**B**).

crucial to assess the holistic aspects of performance and ensure continued assessment validity and reliability. Video recordings were used in most studies (63%), which maybe a potential solution to the above limitation as it allows retrospective, blinded assessment which was apparent in 46% of studies. If methods like crowd-sourcing are established it could potentially allow trainees to benefit from regular, unbiased, objective assessments in an efficient and cost-effective manner and promote better utilization of expert surgeon input [23–25].

In order for objective assessments to be successfully incorporated into training curricula, there is a need for the tool to be reproducible, easy to use and potentially have the ability to be assessed by less-experienced evaluators. There are a number of examples within this review which meet these criteria and are available for training programmes to adopt now. Lou *et al.* [16] describe the JCSTE (Joint Council on Thoracic Surgery Education) coronary anastomosis assessment tool, which utilizes the OSATS method. Hermsen *et al.* [26] and Hicks *et al.* [27] utilized the checklist method to assess the establishment of cardiopulmonary bypass and crisis management. Within thoracic surgery, the OSATS-based VATSAT (Video-Assisted Thoracoscopic Surgery Assessment tool) is a validated tool for pulmonary resection [18]. In congenital heart surgery, the HOST-CHS (Hands-On Surgical Training-in-Congenital Heart Surgery) assessment tool uses a

hybrid checklist and Likert scale to objectively assess technical performance across the spectrum of congenital heart surgical procedures [4].

### Objective assessments within cardiothoracic surgery curricula

Despite concerted efforts to incorporate objective technical skill assessment into CTS training curricula, its utilization worldwide is lacking. Although this study demonstrated that only 39% of studies had incorporated assessment methods into their local curricula, this may be under-represented as a large proportion of studies were for validation purposes only. However, when considering this number as a proportion of CTS institutions worldwide it is likely that is an overestimation due to selection bias. Institutions that are able to conduct such research and publish their experiences are more likely to be actively involved in incorporating assessments into their curricula. Conversely, poorly represented institutions/countries in the literature are unlikely to be involved in or utilize such methods and should be a focus of future research. Validated objective assessment methods will provide more granular evaluations of surgical performance, which can be provided through

both simulation and intraoperative environments as demonstrated in this review.

Although this review sought to comprehensively evaluate the use of objective assessment in technical skill evaluation in CTS, it is not without its limitations. Firstly, there was an exclusion of non-English text which potentially leads to selection bias. Secondly, only published articles were reviewed which leads to potential publication bias. Due to the nature of the studies and lack of data incorporated made more detailed quantitative synthesis not feasible. This paper purposely focuses on the technical skill performance of trainee surgeons, which is only one aspect on becoming a competent cardiothoracic surgeon albeit an important one. Trainee surgeons must not only show technical perfection but also demonstrate competency in non-technical skills. This includes clinical judgement, critical thinking, academic scholarship/education and competency in emotional capabilities like empathy and emotional intelligence [28]. Not all of these skills can be trained in simulation environments or objectively assessed and can only be achieved during a surgeon's lifetime through experience. However, dedicated training alongside objective assessment is the key to perform technically on a high level. The validated evaluation methods included in this review are helpful to assess technical improvement after simulation training. However, questions remain regarding the predictive validity and the translation to real-patient performance [28]. The constructs of real-life operations are vastly different to the low-risk provided during simulation. There is a need to establish if improvements in simulation are translatable to intraoperative performance and should be the focus of future research.

## CONCLUSION

The reductions in training time and intraoperative exposure for trainees in CTS has driven the growth in simulation-based training and the validation of objective assessment methods of technical skill. Although most studies were for validation purposes only, out of the studies that investigated performance outcomes all but one demonstrated an objective improvement in technical skill performance. Despite these assessment tools being available its adoption in training, curricula is still sparse. With the current and future challenges to training, there is a greater need to incorporate objective technical skill assessments. These will eventually help increase the efficiency and transparency of training programmes and ensure the development of the next generation of cardiothoracic surgeons.

## SUPPLEMENTARY MATERIAL

[Supplementary material](#) is available at *ICVTS* online.

**Conflict of interest:** none declared.

## Data availability

The data underlying this article are available in the article and in its online [supplementary material](#).

## Author contributions

**Nabil Hussein:** Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Software; Validation; Visualization; Writing—original draft; Writing—review & editing. **Jef Van den Eynde:** Data curation; Formal analysis; Investigation; Methodology; Software; Validation; Visualization; Writing—original draft; Writing—review & editing. **Connor Callahan:** Data curation; Formal analysis; Investigation; Methodology; Software; Validation; Visualization; Writing—original draft. **Alvise Guariento:** Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing—original draft; Writing—review & editing. **Can Gollmann-Tepeköylü:** Investigation; Methodology; Validation; Visualization; Writing—original draft; Writing—review & editing. **Malak Elbatarny:** Investigation; Methodology; Validation; Visualization; Writing—original draft; Writing—review & editing. **Mahmoud Loubani:** Conceptualization; Formal analysis; Project administration; Resources; Software; Supervision; Validation; Visualization; Writing—original draft; Writing—review & editing.

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