Trauma and Orthopedic Surgery Curriculum Concordance: An Operative Learning Curve Trajectory Perspective

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INTRODUCTION: Certification of completion of training in Trauma and Orthopedic (T&O) surgery in the UK requires the demonstration of operative competence in 12 index procedures, achieved through attaining a level 4 consultant-validated procedure-based assessment (PBA). The aim of this study was to evaluate the trajectory of operative learning curves related to PBA performance with respect to operative caseload and training time.

DESIGN: Logbook data from consecutive 24 higher T&O trainees were compared with PBA evaluations to determine the relationship between PBA level, operative experience, training time, and indicative numbers. Learning curve gradients were calculated using trigonometry related to operative experience and training time.

SETTING: A higher surgical orthopedic training program serving a single UK (Wales) Deanery.

PARTICIPANTS: Twenty-four consecutive higher T&O surgery trainees.

RESULTS: Median caseload to achieve level 4 competences ranged from 9 (interquartile range 6-12) for tension band wiring (olecranon or patella) to 101 (61-127) for arthroscopy, with significant variation between all 12 procedures ($p < 0.001$). Median number of PBAs to reach level 4 competences was 4 (2-6) with significant variation between procedures ($p < 0.001$). Median learning curve gradients to achieve level 4 competence for tension band wiring were 68.2° and 33.7° by caseload and training time respectively, compared with 12.2° and 45° for arthroscopy, with significant learning curve variation for all procedures related to caseload between first level 3 and first level 4 PBA ($p < 0.001$). Competence ratios were <1 (median 0.99, range 0.70-2.53) for 6 of the 12 indicative procedures.

CONCLUSIONS: Significant learning curve trajectory variance was observed, with discrepancies between indicative operative numbers and the point at which competence was judged achieved. Numbers of index operations to achieve certification of completion of training warrant further examination. (J Surg Ed 76:1569−1578. © 2019 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: surgical training, operative competence, trauma and orthopedic surgery, operative learning curve

COMPETENCIES: Practice-Based Learning and Improvement, Patient Care, Medical Knowledge

INTRODUCTION

Seldom before have surgical education, training and curriculum development been under such intense scrutiny. The Intercollegiate Surgical Curriculum Programme (ISCP)[1] allied with the General Medical Council[2] has driven change focused on a competency-based approach, requiring clinical accountability and objective quantifiable educational outcomes and performance. Moreover, in 2013, the Joint Committee on Surgical Training (JCST) published specific competency-based guidelines[3] for the award of Certificate of Completion of Training (CCT). These stipulate a minimum total operative caseload, completion of sufficient procedure-based assessments (PBAs), a validated work-based assessment tool facilitating

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objective assessment of technical ability to demonstrate competence. Craft-based specialties are thus faced with unique challenges. Working time legislation has reduced the exposure that surgical trainees receive,[4] while the work-based assessments developed to assess operative competence, PBAs have been criticized by both trainers and trainee alike.[5-8]

In order to be awarded a CCT, Trauma & Orthopedic (T&O) Higher Surgical Trainees (HSTs) must achieve a minimum total of 1800 cases over 6 years of training.[3] Included are 12 index procedures, each of which has a set minimum indicative number of cases to be completed, with evidence of competence supported by appropriate PBAs. The current PBA has a scale of competence measured from 1 to 4, with each level divided in 2 to create 8 levels of competence (Table 1). The level of competence expected for CCT is level 4.

Learning curves are often referred to in the context of medical education, although their trajectories and natures are contentious. Serial evaluation of operation-specific outcomes can plot a surgeon's position on a curve, with competence deemed to be the point at which the curve trajectory reaches an inflection point or plateau phase, consistent with satisfactory quality.[9] Curve trajectory or gradient equates to the rate of improvement of performance. The aim of this study was to evaluate the trajectory or gradient of incline between performance levels for T&O surgery curricular index procedures related to both operative experience, indicative numbers, and time within a training program, for higher T&O surgical trainees within a UK deanery.

TABLE 1. Definition of Procedure-Based Assessment (PBA) Scores. Intercollegiate Surgical Curriculum Programme, Version 10

PBA Level	Definition
0	Insufficient evidence observed to support a summary judgement
1a	Able to assist with guidance (was not familiar with all steps of procedure)
1b	Able to assist without guidance (knew all steps of procedure and anticipated next move)
2a	Guidance required for most/all of the procedure (or part performed)
2b	Guidance or intervention required for key steps only
3a	Procedure performed with minimal guidance or intervention (needed occasional help)
3b	Procedure performed competently without guidance or intervention but lacked confidence
4a	Procedure performed confidently to a high standard without any guidance or intervention
4b	As 4a and was able to anticipate, avoid and/or deal with common problems/complications

METHODS

National training number holding T&O HSTs within a single UK deanery who were ST6 or above were identified using the ISCP and anonymized. HSTs in the final 3 years of their training, between August 2016 and July 2018, were chosen as it was considered that they would be more likely to have achieved level 4 competencies in index operations. Formal permission under the ISCP Data Governance Structure was not required because the study was in keeping with service evaluation. Individual HST reports were created using the Head of School report function (ISCP version 10) with reference to PBA assessment dates and competency levels for each of the 12 index operations: carpal tunnel decompression, arthroscopy, total knee replacement, first ray (foot) surgery, total hip replacement, compression hip screw, hemiarthroplasty for neck of femur fracture, application of limb external fixator, operative fixation of ankle fracture, tension band wiring of olecranon or patella, intramedullary nailing of femur or tibia, and tendon repair. Access to trainee e-logbooks was obtained through the Head of School Director's page, and individual index operation reports were created to match with the specified date on which each competence level was achieved. PBA levels were plotted against caseload and time, creating learning curves for each index operation. Axes were universalized to allow direct graphical comparison. All trainees were assumed to be at level 1 competence at the start of the HST program. Learning curve gradients related to PBA levels (first level 2 competence to first level 3 competence, and first level 3 competence to first level 4 competence) were calculated using trigonometric techniques (inverse function of tan) to allow arbitrary, objective comparison between index procedures, caseload and time.

Statistical Analysis

Statistical analysis appropriate for nonparametric data (Kruskal-Wallis and Mann-Whitney U tests) was performed using IBM SPSS Statistics 25 (IBM, Armonk, NY). A p value of <0.05 was considered significant.

RESULTS

Twenty-four consecutive T&O HSTs were included in the analysis. All had achieved a level 4 competence in at least one of the index procedures (Table 2), and the

TABLE 2. Total Number of Level 4 Competence Procedure-Based Assessments Achieved for Each Index Operation by Surgical Trainee Grade

	ST3	ST4	ST5	ST6	ST7	ST8	Total
Carpal tunnel decompression	5	6	6	3	4	0	24
Arthroscopy	4	6	2	2	5	3	22
Total knee replacement	0	2	1	7	5	4	19
First ray operations	0	2	4	7	4	3	20
Total hip replacement	1	1	1	2	7	4	16
Compression hip screw	3	8	5	7	0	1	24
Hemiarthroplasty for neck of femur fracture	4	4	7	4	4	0	23
Application of limb external fixator	0	0	4	7	2	6	19
Operative fixation of ankle fracture	2	6	5	6	2	2	23
Tension band wiring of patella or olecranon	0	1	0	8	8	4	21
Intramedullary nailing of femur or tibia	1	5	4	9	3	1	23
Tendon repair	1	1	2	4	2	5	15

cohort had attained 249 level 4 competencies in total. There was significant variation related to training grade regarding the point when this was reached ($p < 0.001$). The median (interquartile range, IQR) number of PBAs required to reach level 4 competence was 4 (2-6), with significant variation in the number of PBAs related to index procedure ($p < 0.001$). Median (IQR) caseload to achieve level 4 competence was 26 (12-43), but the caseload varied according to specific index procedures (Table 3, $p < 0.001$).

Learning curves for the 12 index operations relating competence (PBA level) to both caseload and time are shown in Figures 1 to 3. The indicative number lay within or to the right of the IQR for all index operations except for arthroscopy and application of limb external fixator, implying that competence for these procedures may not be achieved within the current indicative number guidance.

Table 3 also shows the ratio of the median number of operations when level 4 competence was reached related to CCT operative target-defined competence ratio. A ratio of <1 implied that competence was achieved within the JCST target. This was achieved for 6 of the index procedures; compression hip screw, hemiarthroplasty for neck of femur fracture, operative fixation of ankle fracture, tension band wiring of patella or olecranon, intramedullary nailing of femur or tibia, and tendon repair. In the case of arthroscopy and application of external limb fixator, the operative experience required to reach CCT competence was double the set target.

Across the 12 index procedures, a wide variety of learning curve gradients were observed. The maximum median gradient measured was 90° and was observed related to time for carpal tunnel decompression, arthroscopy, total knee replacement, first-ray surgery, hemiarthroplasty for fractured neck of femur, and tension band wiring of the olecranon or patella. This implies that better competence levels were achieved in consecutive training years. Learning curve trajectories related to caseload between first level 3 and first level 4 competence for arthroplasty demonstrated the minimum median gradient (10.9°). This suggests that this procedure required the most cases to achieve

TABLE 3. Number of PBAs and Caseload Required to Reach Level 4 Competences and Competence Ratio. PBAs and Caseload are Expressed as Median (IQR)

	PBA	Caseload	Competence Ratio
Carpal tunnel decompression	3 (2-4)	33 (9-56)	1.10
Arthroscopy	7 (3-11)	101 (61-127)	2.53
Total knee replacement	10 (5-13)	54 (32-67)	1.35
First ray operations	5 (3-7)	25 (17-30)	1.25
Total hip replacement	9 (5-12)	41 (23-62)	1.03
Compression hip screw	3 (2-6)	28 (17-38)	0.70
Hemiarthroplasty for neck of femur fracture	4 (2-6)	30 (21-48)	0.75
Application of limb external fixator	1 (1-4)	10 (5-15)	2.00
Operative fixation of ankle fracture	3 (1-5)	28 (13-44)	0.70
Tension band wiring of patella or olecranon	2 (1-3)	9 (6-12)	0.90
Intramedullary nailing of femur or tibia	5 (3-8)	25 (14-31)	0.83
Tendon repair	2 (2-4)	19 (14-25)	0.95

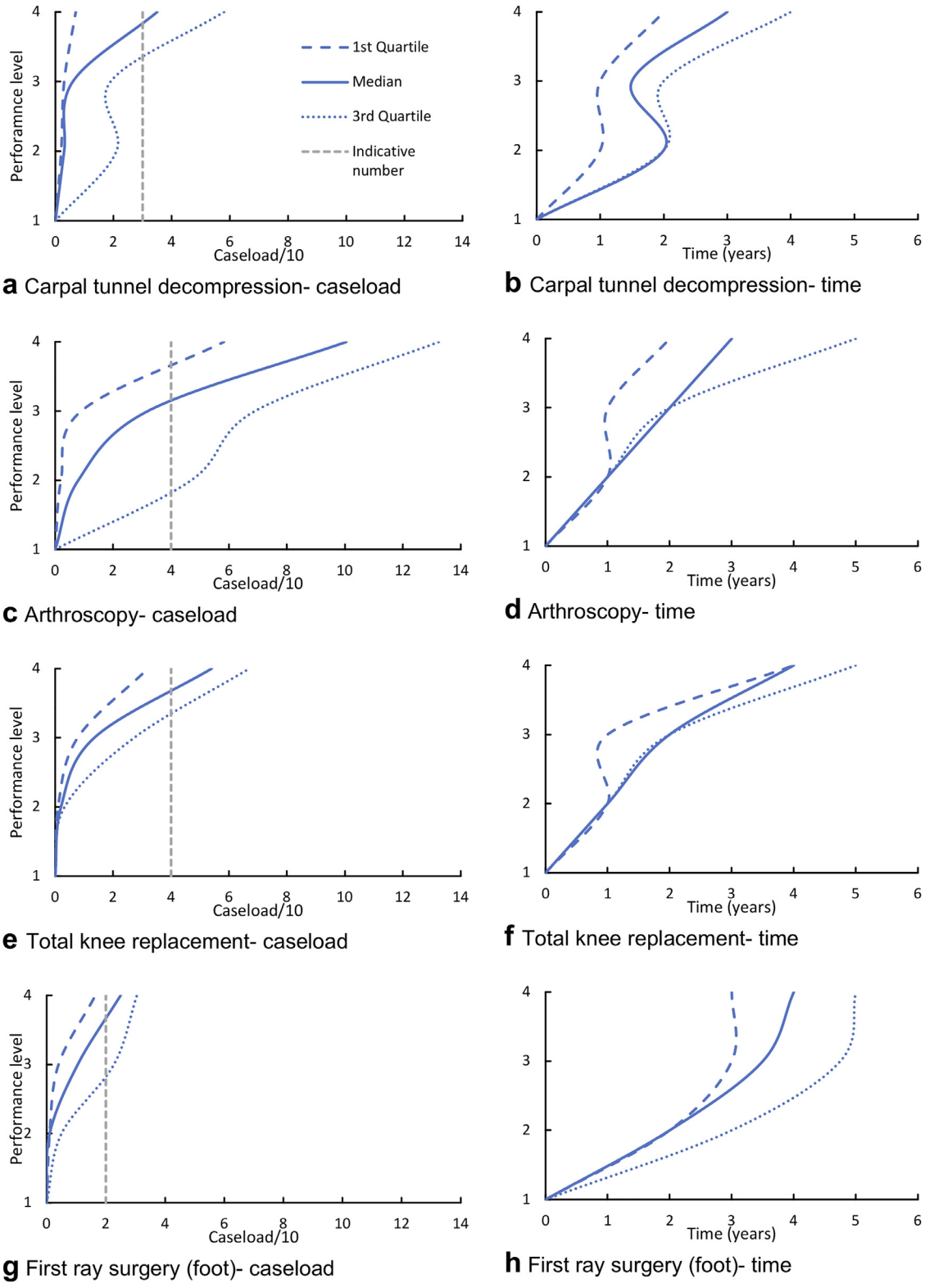
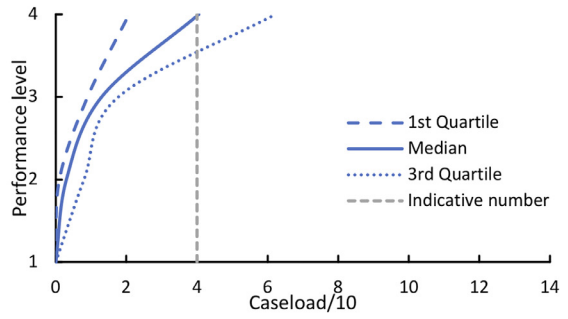
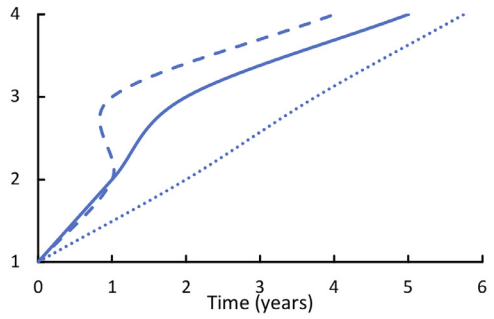


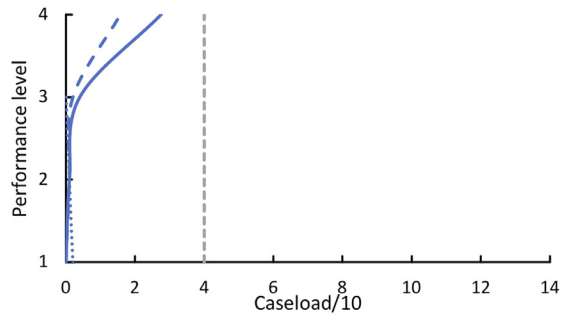
FIGURE 1. Operative learning curves for **a, b** carpal tunnel decompression, **c, d** arthroscopy, **e, f** total knee replacement, and **g, h** first ray surgery (foot) by caseload (a, c, e, g) and time (b, d, e, f).



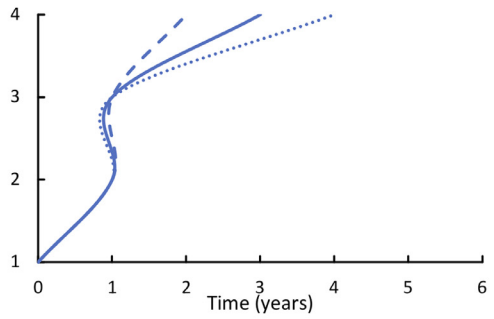
i Total hip replacement- caseload



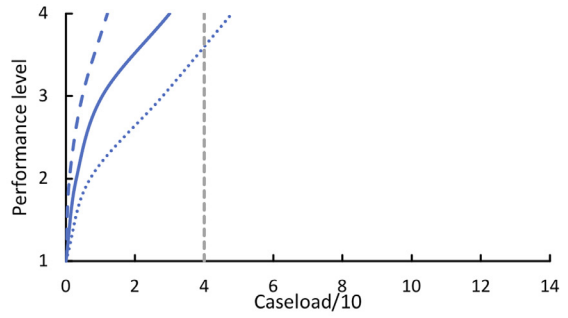
j Total hip replacement- time



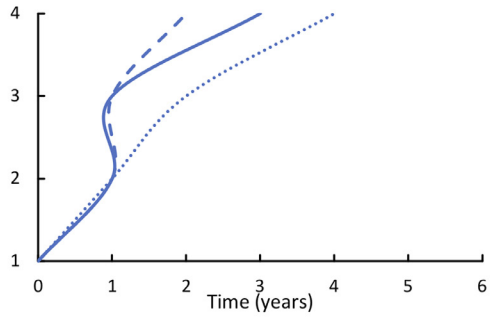
k Compression hip screw- caseload



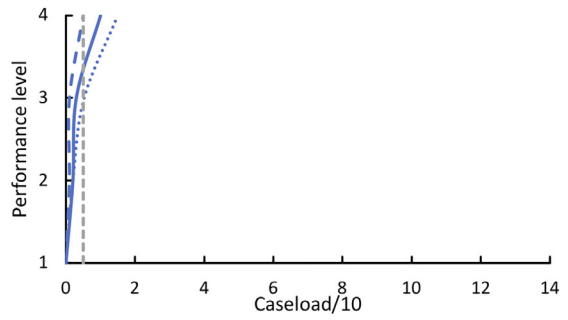
l Compression hip screw- time



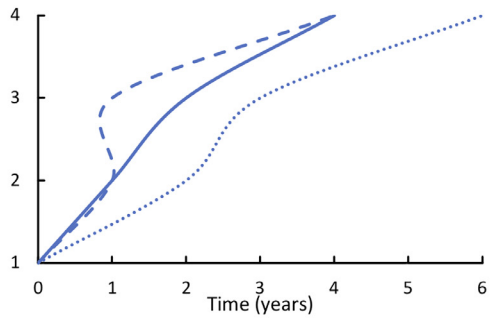
m Hemiarthroplasty for neck of femur fracture- caseload



n Hemiarthroplasty for neck of femur fracture- time

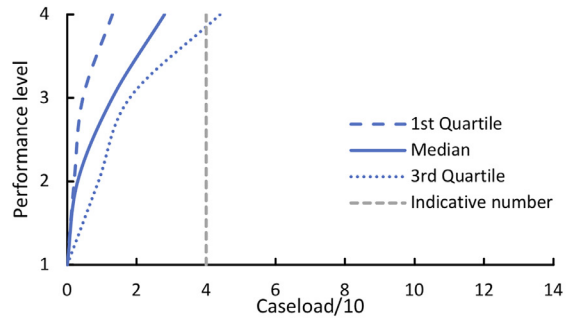


o Application of limb external fixator- caseload

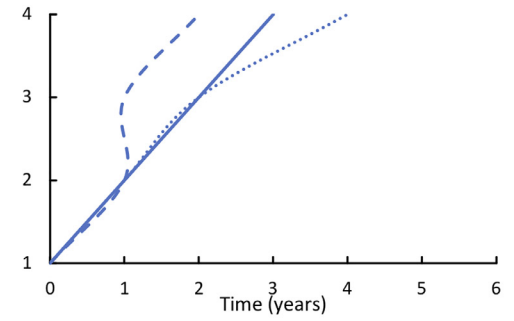


p Application of limb external fixator- time

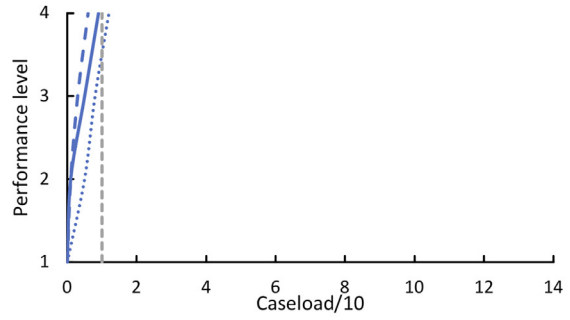
FIGURE 2. Operative learning curves for **i, j** total hip replacement, **k, l** compression hip screw, **m, n** hemiarthroplasty for neck of femur fracture and **o, p** application of limb external fixator by caseload (i, k, m, o) and time (j, l, n, p).



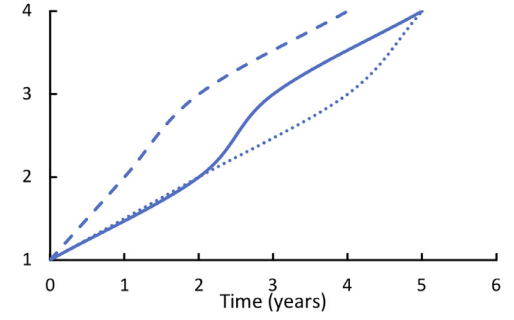
q Operative fixation of ankle fracture- caseload



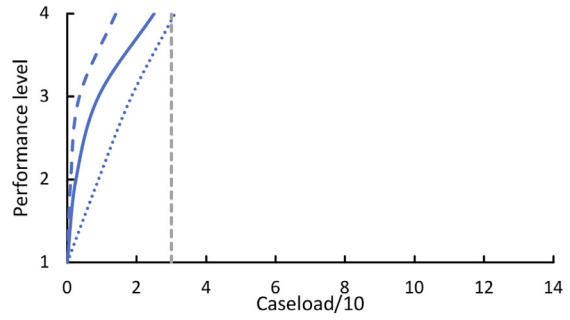
r Operative fixation of ankle fracture- time



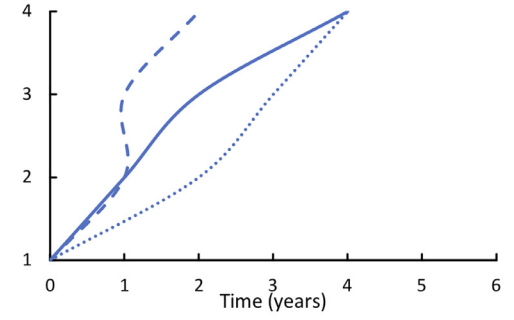
s Tension band wiring of olecranon or patella- caseload



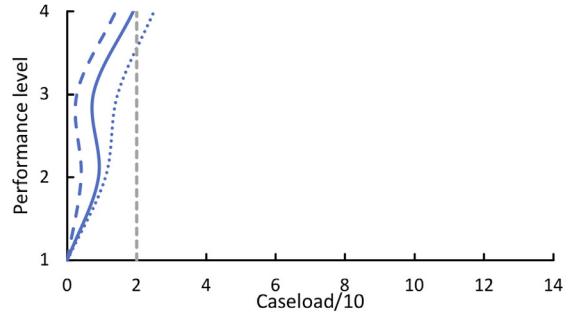
t Tension band wiring of olecranon or patella- time



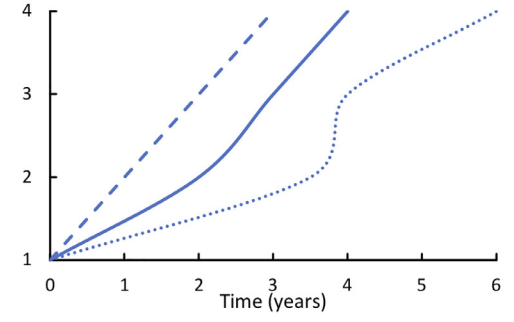
u Intramedullary nailing of femur or tibia- caseload



v Intramedullary nailing of femur or tibia- time



w Tendon repair- caseload



x Tendon repair- time

FIGURE 3. Operative learning curves for **q, r** operative fixation of ankle fracture, **s, t** tension band wiring of olecranon or patella, **u, v** intramedullary nailing of femur or tibia and **w, x** tendon repair by caseload (q, s, u, w) and time (r, t, v, x).

TABLE 4. Learning Curve Gradients Between First Procedure-Based Assessment at Level 2 Competence and First at Level 3 Competence, and Between Level 3 and Level 4 Competence. Values are Median (IQR)

	Trajectory (°)			
	PBA Level Versus Caseload		PBA Level Versus time	
	First L2 to L3	First L3 to L4	First L2 to L3	First L3 to L4
Carpal tunnel decompression	68.2 (51.3-78.7)	23.5 (16.0-55.0)	90.0 (90.0-90.0)	90.0 (18.4-90.0)
Arthroscopy	41.7 (16.9-68.2)	10.9 (7.7-35.9)	90.0 (45.0-90.0)	45.0 (18.4-90.0)
Total knee replacement	53.2 (35.1-76.0)	16.9 (10.3-33.7)	90.0 (45.0-90.0)	18.4 (14.0- 26.6)
First ray operations	55.2 (30.5-73.3)	46.5 (25.5-59.0)	45.0 (26.6-90.0)	90.0 (90.0-90.0)
Total hip replacement	51.3 (37.6- 63.4)	19.4 (12.5-36.6)	67.5 (45.0-90.0)	18.4 (14.0- 26.6)
Compression hip screw	56.2 (33.7-78.7)	24.0 (18.4-39.8)	67.5 (45.0-90.0)	35.8 (18.4-45.0)
Hemiarthroplasty for neck of femur fracture	63.4 (39.8-68.2)	30.5 (16.9-42.3)	90.0 (45.0-90.0)	26.6 (18.4-90.0)
Application of limb external fixator	73.4 (68.2-78.7)	53.2 (45.1-78.8)	45.0 (29.5-67.5)	22.5 (16.2-67.5)
Operative fixation of ankle fracture	51.3 (48.0-73.3)	23.1 (18.5-42.4)	45.0 (45.0-45.0)	26.6 (22.5-45.0)
Tension band wiring of patella or olecranon	73.3 (68.2-84.3)	55.0 (55.0-73.3)	90.0 (26.6-90.0)	18.4 (18.4-45.0)
Intramedullary nailing of femur or tibia	61.2 (48.0-78.7)	39.8 (27.8-61.2)	45.0 (45.0-90.0)	35.8 (26.6-90.0)
Tendon repair	58.1 (43.9-76.2)	57.0 (35.9-70.8)	26.6 (22.5-58.3)	35.8 (22.5-67.5)

L2, level 2 competence; L3, level 3 competence; L4, level 4 competence.

competence. Learning curve trajectories and gradients for all index operations are shown in Table 4. There was significant variance in the gradients of the learning curves related to caseload between the first level 3, and first level 4 PBA ($p < 0.001$) but learning curve gradients related to caseload did not vary between the first level 2 and first level 3 PBA ($p = 0.297$). Learning curve gradients related to time between first level 3 and first level 4 PBA demonstrated variance ($p = 0.01$), but not for the period between first level 2 and first level 3 PBA ($p = 0.324$).

DISCUSSION

This is the first study to examine operative learning curve trajectories in a cohort of T&O HSTs. Significant learning curve trajectory variance was observed related to both caseload and time across all 12-index procedures, ranging from 10.9° (arthroscopy) to 57.0° (tendon repair). The median number of PBAs to demonstrate level 4 competence was 4 (range 1-22), with competence for all procedures except arthroscopy and application of external limb fixator, achieved within the expected operative experience. Learning curve trajectory variability and form (Figs. 1-3) likely reflects the fact that acquisition of technical competence for different procedures is not uniform. For commonly performed operations such as total knee replacement, the gradient tends to be gentler, implying more gradual skill acquisition. In contrast, less frequently performed operations such as application of external fixators, the gradient was steeper, suggesting that the technical skills required are easier to achieve. The underlying reasons for trajectory variation are also probably a reflection of specific operations' unique combination of technical demands. Without analyzing operations by their component stages, assessing such variance further is difficult, and certainly not feasible within the constraints of this study's methodology.

Performance analysis of clinicians is challenging. Measures of learning operative procedures can be broadly divided into 2 facets: technical processes and patient outcomes, and for surgeons in training, measures of technical process clearly represent the mainstay of assessment. Any relationship between experience and competence is controversial, indeed recent reports from the arena of General Surgery have questioned the utility of indicative numbers as a marker for competence.[10-12] For example, the operative achievements in the 2013 UK General Surgery CCT cohort varied widely, with two-thirds of applicants achieving elective targets, but only half the requisite emergency experience, and 5% nonoperative targets.[13] The caseload required to demonstrate level 4 competencies has been reported to vary over 4-fold, and as a result the concept of competence ratios has been developed (ratio of case number at which CCT competence awarded to indicative number). This ratio has ranged from 0.76 (emergency laparotomy) to 3.4 (Hartmann's procedure).[11] Similarly in this study the competence ratio varied over 3-fold ranging from 0.70 (compression hip screw) to 2.53 (arthroscopy), this raises concerns that half the indicative procedures in T&O surgery, competence cannot be obtained within the current set requirements.

Hypothetically a learning curve plot has 4 phases: commencement of training, followed by an ascending trajectory, with the gradient representing the rate at which performance is improving; a third phase is reached once the procedure can be performed

independently and competently[9]; at this point additional experience improves outcomes in smaller steps; a fourth, plateau phase is finally reached. Difficult procedures are often erroneously described as having a steep learning curve. When considering the gradient of a learning curve, a steep gradient might actually represent rapid acquisition of skill, more commonly seen in simpler procedures. It would therefore be expected that technically demanding procedures would have shallow learning curves with much greater experience required to achieve satisfactory competence.

In this present study, none of the learning curve plots by caseload or time had reached the plateau phase when level 4 competence was achieved. This would suggest that trainees at this level had not achieved the skills expected of a qualified surgeon despite this being adequate for certification. Concerns that this may be the case led to a revision in the certification guidance published in August 2018.[14] This changed the requirement to three level 4 competence PBAs for index procedures, similar to certification guidelines in General Surgery.[15] Whether this modification will be consistent with a learning curve inflection point or plateau phase remains unclear. Indeed, Brown et al.[12] reported that despite the requirement of three level 4 competence PBAs, General Surgery trainees' learning curves did not demonstrate a plateau phase.

This study has a number of potential limitations. The data gathered and learning curve trajectories are strongly linked to trainee and trainer engagement. Particular reliance rests on the accuracy of the trainee's logbook entries, assessment timing, and PBA validation. If a trainee did not complete any assessments until they or their trainer considered they had achieved level 4 competence, then the inflection points recorded would be inaccurate. This could lead to learning curve gradients being artificially steep with the impression of earlier competence. Concerns about the utility of the PBA have led to changes to the grading system from a prior 0 to 4 scale, to the current version shown in Table 1. This work was carried out within T&O surgery,[16] suggesting that concerns may be greater in this specialty than in others. Once the curriculum-defined measure of competence was reached almost no trainee recorded further PBAs, which compounds the absence of a learning curve plateau phase, contrasting poorly with other professions with high-risk profiles such as aviation,[17] where ongoing skill assessment is mandatory. A possible solution to this would be to demand greater numbers of level 4 competence assessments before certification. This is the approach that has been taken in the new Vascular Surgery curriculum,[18] although it should be noted that the number of index procedures is considerably less in Vascular Surgery (5) compared with Trauma and Orthopedics (12). This increased number of assessments should also mitigate the risks associated with operative difficulty. A trainee who completes their single level 4 or three level 4 assessments with easier cases may not have the competence if faced with a more challenging one. All of the trainees in this cohort were from a single UK deanery, and the data should be interpreted with caution. All were appointed via a local deanery selection process as opposed to national selection, which could raise concerns regarding quality assurance of selection. Yet using another surrogate marker for training quality, FRCS examination pass rates, the deanery was ranked fourth out of 20 deaneries across the UK,[19] suggesting upper quartile performance across the spectrum of training assessments. Variability in trainer performance is also recognized, some trainers may be more lenient or stringent in their scoring. In this retrospective series, it is not possible to estimate this effect however it may be mitigated by the fact that all trainers must declare their competence and have received training on PBA completion. At present, formal assessment of consultant surgeon trainers in the UK does not occur, but it would be surprising if no differences were apparent between individual trainers related to their technical training skills. This study included all trainers who completed the relevant PBAs within a single UK deanery but does not address the quality of the assessments. While all trainees were part of a higher T&O training program, some will have developed subspecialty interests, and arguably this may have been associated with greater exposure to certain index procedures, possibly altering both the time and caseload to achieve competence. Yet, the requirements of competence in these 12 index operations are mandated for all UK T&O trainees, and it is therefore a JCST requirement for the deanery to provide suitable placements to facilitate this. Although hospital unit rotation will vary, the role of the T&O specialty surgical training committee is to regularly review and oversee trainees' experience during the Annual Review of Competence Progression to quality assure the process. Moreover, this has rigorous external oversight from the JCST Specialty Advisory Committee.

Despite concerns raised about the acquisition of operative competence since changes to medical training and working hours, it is probable that training time may be reduced further.[20] It is likely therefore that UK consultant surgeons will be appointed based on a number of learning curves short of the requisite experience to be considered experts. The acquisition of skill as opposed to experience should be the focus of training developments. Utilizing teaching methods and technologies such as simulation to allow improved competence despite lesser experience should be the priority. A limitation of procedure-specific learning curve trajectory is that it risks ignoring the assessment of global surgical

skill acquisition. Certainly, some procedures will share specific technical skills, and looking to the future, the index procedures chosen and methods of summative competence assessment should account for this. It is possible that most, if not all consultants will have broader competent operative, repertoires. At present, the use of skills laboratories and deliberate practice is not commonplace, despite evidence to suggest both trainees and trainers desire it.[21] Integration of simulation training to the orthopedic residency program in Toronto not only led to quicker technical and nontechnical skill acquisition, but was also cost effective.[22,23] While efforts are focused on the early years of surgical training,[24] higher surgical training programs will require continual upgrade and adjustment. Moreover, in parallel with these initiatives, post-CCT fellowships, senior mentors, and structured appraisal will remain key elements of continued professional development.

In conclusion, this study has demonstrated variance in the learning curve trajectory related to the attainment of operative competence in trainee orthopedic surgeons. It raises questions about the acquisition of technical skill and operative competence that will need to be addressed as the development of competency based medical curricula continues.

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SUPPLEMENTARY INFORMATION

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jsurg.2019.05.009.