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Who PACS a Punch? The Role of the Picture Archiving and Communication System/Radiology Information System (PACS/RIS) in Quantifying Experiential Learning in Radiology Residency

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Abstract
The clinical logbook is the currently accepted tool for evaluating experiential learning (EL) in postgraduate radiology training programs internationally. The role of the picture archiving and communication system/radiology information system (PACS/RIS) in defining the complete EL portfolio of radiology residents has not been explored. To conduct a PACS/RIS-based analysis of the comprehensive clinical outputs of radiology residents, and to correlate outputs with residency recruitment criteria and exit examination performance. Retrospective, customized searches of the institutional PACS/RIS were conducted to determine the clinical outputs of radiology residents completing a standardized 4-year training program at a single institution in a middle-income country. The association between outputs and prior-to-residency radiology experience, prior-to residency completion of the primary examination, and performance in the exit examination were determined. Fifteen residents were included. Average clinical output was 8286 cases, with a wide range (6268-10460). Total output was not associated with first-time exit examination success (p=0.16). Residents with prior radiology experience tended to greater success at first exit examination attempt (10/11, 91% versus 2/4, 50%; p=0.09), despite lower average outputs (8138 versus 8695). Outputs were not associated with prior completion of the radiology primary examination (8263 versus 8378; p=0.87). This first PACS/RIS-based analysis of the complete clinical outputs of any radiology residency training program provides important baseline educational data, with the potential to inform discourses on specialty training internationally. It demonstrates the potential for the modern PACS/RIS to supersede the traditional logbook and to serve as a comprehensive EL portfolio for radiology residents.

Keywords PACS/RIS · Logbook · Radiology residency · Experiential learning · Clinical output

Introduction

The logbook is a time-honored method of recording the experiential learning (EL) component of training programs in a broad range of disciplines, including clinical medicine. Internationally, the logbook is accepted as an important evaluation tool in postgraduate radiology training, being used by the Royal Australian and New Zealand College of Radiologists (RANZCR), the North American Accreditation Council for Graduate Medical Education (ACGME), the Royal College of Radiologists (RCR), the European Society of Radiology (ESR), the College of Radiologists of the Colleges of Medicine of South Africa (CMSA), and Councils in South-east Asia [1–9]. Radiology residents are required to provide evidence of EL by recording their individual clinical involvement in a broad range of imaging examinations and procedures.

Logbooks are traditionally submitted in hardcopy and contain only a selective record of clinical exposure in defined aspects of the radiology curriculum. Furthermore, despite international acknowledgement of the role of the logbook, no radiology accreditation authority has drafted comprehensive

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minimum EL requirements. The RANZCR has compiled the most detailed criteria to date, specifying targets in plain film, breast, vascular/interventional, obstetric/gynecology, nuclear medicine, magnetic resonance (MR), and pediatric imaging. The ACGME has defined requirements for only mammography and nuclear medicine. Additionally, even where targets have been specified, the rationale for such thresholds has not been provided [1, 2]. It has also been shown that traditional logbooks have limitations in capturing the full scope of a student's EL [10]. Thus, despite the logbook being widely used in postgraduate radiology training programs internationally, its role remains poorly defined.

Developments in information technology over the last half century have paralleled those of diagnostic imaging equipment, transforming the modern radiology department into a fully digital, filmless, and paperless environment [11–14]. Evolution of the integrated picture archiving and communication system (PACS) and the radiology information system (RIS) in the 1980s enhanced radiological workflow, facilitating the processing, display, storage, and dissemination of digital images (PACS), while managing the imaging environment (RIS). Numerous studies have documented the clinical benefits of the integrated PACS/RIS in healthcare delivery, most notably the substantially higher productivity and efficiency, with lower consumable costs [15–19].

Furthermore, the capacity of digital platforms to transform and inform educational methods is increasingly acknowledged, with emergence of a wide range of e-learning initiatives across the academic disciplines, including radiology [20–25]. However, educational literature in the radiological domain has largely highlighted the impact of web-based and electronic resources on teaching and learning [26, 27]. There has been relatively little work on the role of the digital platform in assessing the scope of radiology training. Additionally, although some national radiology accreditation authorities have recently introduced electronic logbooks to reflect EL, captured clinical outputs remain selective, rather than comprehensive.

The modern PACS/RIS allows comprehensive electronic monitoring of a resident's entire clinical training experience. The PACS/RIS captures an individual's complete reporting portfolio, including examination descriptors, patient demographics, clinical details, radiological findings, the supervising radiologist, and the procedure date and time.

The PACS/RIS thus represents a comprehensive, objective, digital repository of residency outputs, providing unique insights into the extent of clinical exposure. Furthermore, these data can be extracted on a simple spreadsheet, facilitating easy analysis and stratification by modality or time period. The PACS/RIS thus has the potential to make a substantial contribution to an individual's EL learning portfolio.

To the best of our knowledge, there are no published data on the overall clinical experience afforded by any radiology training program. Such data are pivotal to the accurate documentation of EL. A comprehensive record of clinical outputs during radiology residency affords important insights into program structure and content while providing benchmark data for future training and assessment initiatives.

Additionally, there has been no analysis of the association between residency outputs and training outcomes, specifically success in the final specialist examination. There has also been no work on the impact on outputs of prior clinical experience in diagnostic imaging or completion of the radiology primary examination prior to residency. Such knowledge is important if one is to gain deeper insights into the determinants of success in postgraduate radiology training.

This study therefore conducted a PACS/RIS-based analysis of the comprehensive clinical outputs of radiology residents on a uniform, 4-year training program at a single institution, and correlated outputs with residency recruitment criteria and exit examination performance.

Material and Methods

This retrospective study was conducted from 1 July 2009 to 31 July 2017 in the radiology department of Tygerberg Hospital (TBH), the 1386-bed tertiary level teaching hospital of the Faculty of Medicine and Health Sciences of Stellenbosch University, in Cape Town, South Africa. TBH commissioned a fully digital radiology department, including an integrated PACS/RIS, in June 2009. During the study period, the department performed an average of 180,000 examinations annually, of which approximately 100,000 (55%) were plain radiographs, had a 22-resident, 4-year specialist training program, and a faculty of 8 attending radiologists. All residents underwent the same structured program, commencing with an initial 29-month rotation through all major imaging modalities, including plain radiography (2 months), fluoroscopy (3 months), ultrasound (3 months), computed tomography (CT) (6 months), interventional radiology (2 months), mammography (4 months), MR (4 months), nuclear medicine (2 months), and pediatric imaging (3 months). In the final 19 months of training, residents gained additional clinical radiology experience by assuming greater responsibility in all modalities, and rotating through the various stations on a weekly basis. Formal, formative, end-of-block assessments were conducted by way of reporting sessions, individual patient examinations (IPX), or directly observed procedure skills (DOPS) for all residents. In addition, there were six-monthly director of training (DOT) assessments, which included a detailed appraisal of the trainee's PACS/RIS-based clinical outputs during the preceding 6 months.

Sequential, customized searches of the TBH PACS/RIS were conducted to extract the comprehensive 4-year clinical outputs of each resident completing the full program on the TBH digital radiology platform. All data were captured on a

customized Microsoft Excel spreadsheet and reflected as total and modality-specific clinical outputs for each resident. The records of the Division of Radiodiagnosis of the Faculty of Medicine and Health Sciences of Stellenbosch University were reviewed, to identify residents who had been successful in the first attempt at the final fellowship examination, those who had prior-to-residency experience as Medical Officers in a radiology department, and those who had completed the radiology primary examination prior to residency.

The term Medical Officer refers to a public-sector medical doctor who has completed 6 years of undergraduate medical training, 2 years of compulsory internship (PGY-1 and PGY-2) and 1 year of compulsory community service (PGY-3). Medical Officers are typically employed in the radiology departments of peripheral South African hospitals, working under supervision of a specialist radiologist until the commencement of resident training. Experience as a Medical Officer in radiology is not a prerequisite for resident training. Some doctors start their residency without such clinical exposure to the field of radiology.

The average clinical outputs between different groupings were compared using the one-way analysis of variance (ANOVA) *F*-test. Normality and homogeneity-of-variance were found to be in order in all instances. Previous radiology experience was compared using cross tabulation and the chi-square test. A 5% significance level ($p < 0.05$) was used as a guideline for evaluating significant differences. However, due to the small sample size, trends where the p values were significant at 10% ($p < 0.1$) or slightly higher were reported as such.

The study was approved by the Health Research Ethics Committee of the Faculty of Medicine and Health Sciences of Stellenbosch University and TBH Management. Written informed consent was obtained from all participating residents, whose anonymity was assured through the use of unique study identifiers, known only to the principal investigator.

Results

Sixteen residents completed training in the study period; one declined participation. Fifteen residents ($n = 15$) were thus included in this analysis. Twelve (12/15; 80%) were successful on first attempt at the final fellowship examination of the College of Radiologists of the Colleges of Medicine of South Africa. Eleven (73%) residents had a median of 24 months experience as Medical Officers in radiology; 12 (80%) had passed the radiology primary examination prior to commencement of training.

The average total clinical output was 8286 cases. Computed tomography (CT) and plain radiography were the most commonly reported modalities, averaging 3252 and 2499 cases, respectively, and together constituting almost 70% of all clinical work. On average, fluoroscopy, mammography, and MR each accounted for approximately 5%, and interventional radiology for approximately 2% of total outputs (Table 1).

The highest total clinical output (10460) was 67% more than the lowest (6268). Discrepancy in outputs was most marked in plain radiography reporting, where the highest (3758) exceeded the lowest (908) by a factor of more than four. The most consistent outputs were in CT (Table 1).

Higher total outputs were not associated with first-time exit examination success ($p = 0.16$) (Table 2). With the exception of interventional procedures, where successful candidates tended to higher outputs ($p = 0.05$), there was no association between modality-specific outputs and examination success (Table 2).

Residents with prior radiology experience tended to greater success at first exit examination attempt (10/11, 91% versus 2/4, 50%; $p = 0.09$), despite lower average outputs (8138 versus 8695; $p = 0.38$). There was no significant difference in modality-specific outputs by prior radiology experience, although the 32% higher outputs in plain film reporting by those without prior experience ($n = 2306$ versus $n = 3032$; $p = 0.06$) approached significance (Table 3).

There was no significant difference in clinical output by prior-to-residency completion of the radiology primary examination (Table 4).

Discussion

This first PACS/RIS-based documentation of the comprehensive clinical outputs of any radiology training program provides important baseline educational data. It highlights the potential pivotal role of the modern PACS/RIS in facilitating a broad range of educational analyses in postgraduate radiology training. Despite the study being based at a single institution, it has the potential to inform discourses on specialty training at institutional, regional, national, and international level.

The study has yielded a number of salient findings. Firstly, it has demonstrated the wide range of clinical outputs amongst radiology residents on the same training program at a single institution. Such data have not been previously recorded. The limited available work on the productivity of qualified radiologists provides some insight into this wide range of outputs. There is evidence that individuals have an inherent "baseline" or "natural" reporting speed, and that accuracy is enhanced when maintaining one's baseline speed [28–30]. Although the determinants of resident outputs remain poorly understood, it is likely that differential baseline reporting speeds contribute to this range in outputs.

Secondly, although the study demonstrated a tendency to higher outputs amongst successful final examination candidates, the differential was not significant. This underscores the prevailing belief that quantity of clinical exposure per se does not ensure quality training.

Table 1 Breakdown of clinical outputs

Subject no.	MO time	First pass	Part I	CR, *n* (%)	CT, *n* (%)	MG, *n* (%)	MR, *n* (%)	RF, *n* (%)	US, *n* (%)	XA, *n* (%)	Total, *n*
1	No	Yes	Yes	3758 (39)	3683 (38)	394 (4)	399 (4)	259 (3)	1013 (11)	123 (1)	9629
2	Yes	Yes	Yes	2301 (31)	3385 (46)	320 (4)	295 (4)	341 (5)	551 (8)	128 (2)	7321
3	Yes	Yes	No	3268 (34)	3597 (38)	436 (5)	592 (6)	381 (4)	1029 (11)	183 (2)	9486
4	Yes	No	Yes	908 (15)	2962 (47)	469 (7)	220 (4)	459 (7)	1146 (18)	104 (2)	6268
5	Yes	Yes	No	2361 (30)	3174 (41)	293 (4)	427 (5)	401 (5)	1056 (13)	124 (2)	7836
6	Yes	Yes	No	2173 (28)	2783 (36)	338 (4)	623 (8)	411 (5)	1248 (16)	237 (3)	7813
7	Yes	Yes	Yes	2220 (26)	3738 (45)	411 (5)	363 (4)	456 (5)	967 (12)	218 (3)	8373
8	Yes	Yes	Yes	1954 (25)	3049 (40)	439 (6)	304 (4)	551 (7)	1191 (15)	260 (3)	7748
9	Yes	Yes	Yes	3084 (30)	3744 (36)	556 (5)	530 (5)	651 (6)	1684 (16)	211 (2)	10,460
10	No	No	Yes	2609 (33)	2984 (38)	511 (6)	312 (4)	322 (4)	1092 (14)	81 (1)	7911
11	No	Yes	Yes	3122 (35)	2995 (34)	377 (4)	403 (4)	604 (7)	1117 (13)	245 (3)	8863
12	No	No	Yes	2639 (32)	3542 (42)	371 (4)	493 (6)	291 (3)	897 (11)	144 (2)	8377
13	Yes	Yes	Yes	2206 (27)	3173 (39)	610 (8)	636 (8)	257 (3)	1033 (13)	130 (2)	8045
14	Yes	Yes	Yes	2214 (25)	3417 (39)	504 (6)	519 (6)	495 (6)	1292 (15)	219 (3)	8660
15	Yes	Yes	Yes	2675 (36)	2551 (34)	325 (4)	288 (4)	446 (6)	1011 (13)	207 (3)	7503
Average (%)				2499 (30)	3252 (40)	424 (5)	427 (5)	422 (5)	1088 (13)	174 (2)	8286
Median				2361	3174	411	403	411	1056	183	8045
IQR				2210–2880	2990–3570	355–487	308–525	332–477	1012–1169	126–219	7781–8762
Min (*n*)				908	2551	293	220	257	551	81	6268
Max (*n*)				3758	3744	610	636	651	1684	260	10,460
Min/max				1:4.1	1:1.5	1:2.1	1:2.9	1:2.5	1:3.1	1:3.2	1:1.7

CR plain radiographs, *CT* computed tomography, *IQR* interquartile range, *MG* diagnostic mammography, *MO* medical officer, *MR* magnetic resonance imaging, *n* total, *RF* fluoroscopy, *US* general ultrasound, *XA* interventional radiology

Thirdly, prior-to-residency experience in diagnostic imaging is a potential determinant of first-time exit examination success ($p = 0.09$). This finding is intuitive, since one would expect candidates with accrued time and clinical outputs in the discipline to be better examination candidates. However, the finding also makes an important contribution to current discourses on the optimal duration of specialist training in the discipline.

Our findings highlight the need for further analyses in this domain, with a view to defining evidence-based minimum EL clinical output requirements in radiology residency. The

Table 2 Association between output and success in final fellowship examination

Modality	First attempt pass	*n*	Mean	Standard deviation	*p* value
CR	Yes	12	2611	563	0.20
	No	3	2052	991	
CT	Yes	12	3274	388	0.66
	No	3	3163	329	
MG	Yes	12	417	98	0.59
	No	3	450	72	
MR	Yes	12	448	128	0.23
	No	3	342	139	
RF	Yes	12	438	124	0.32
	No	3	357	89	
US	Yes	12	1099	262	0.74
	No	3	1045	131	
XA	Yes	12	190	51	0.02
	No	3	110	32	
Total	Yes	12	8478	969	0.16
	No	3	7519	1108	

Table 3 Association between output and previous medical officer time

Modality	MO time	*n*	Mean	Standard deviation	*p* value
CR	Yes	11	2306	616	0.06
	No	4	3032	538	
CT	Yes	11	3234	386	0.77
	No	4	3301	364	
MG	Yes	11	427	103	0.80
	No	4	413	66	
MR	Yes	11	436	150	0.67
	No	4	402	74	
RF	Yes	11	441	105	0.32
	No	4	369	159	
US	Yes	11	1110	273	0.58
	No	4	1030	99	
XA	Yes	11	184	53	0.31
	No	4	148	70	
Total	Yes	11	8138	1116	0.38
	No	4	8695	734	

Table 4 Association between output and prior success in part I examinations

Modality	Prior success in part I	*n*	Mean	Standard deviation	*p* value
CR	Yes	12	2474	706	0.78
	No	3	2601	586	
CT	Yes	12	3269	375	0.74
	No	3	3185	407	
MG	Yes	12	441	91	0.16
	No	3	356	73	
MR	Yes	12	397	124	0.08
	No	3	547	105	
RF	Yes	12	428	134	0.71
	No	3	398	15	
US	Yes	12	1083	264	0.86
	No	3	1111	119	
XA	Yes	12	173	60	0.82
	No	3	181	57	
Total	Yes	12	8263	1092	0.87
	No	3	8378	959	

modern PACS/RIS is the ideal platform for such analyses, and the PACS/RIS data represent a rich seam of untapped evaluation resources in modern postgraduate radiology training programs.

For example, this study provides insights into the local TBH clinical environment, by demonstrating an institutional emphasis on the reporting of special radiological examinations. Although plain radiographs constitute approximately 55% of departmental workload, plain-film reporting represents only 30% of average resident outputs. Given prevailing South African public-sector resource constraints, departmental reporting outputs are determined by clinical imperative. While all special investigations are prioritized and reported under supervision, plain film reporting is largely initiated by clinician request. Such reporting is predominantly at a resident's own initiative, providing a measure of an individual's capacity for self-initiated EL.

Studies such as this also afford quality assurance and comparison of training programs regionally and internationally. To the best of our knowledge, the RANZCR is the only national accreditation body to have defined minimum plain radiograph EL requirements, specifying 7000 cases within the first 3 years, and 10,000 by completion of a 5-year program. However, the RANZCR permits inclusion of images seen in multidisciplinary meetings and group teaching sessions. Such criteria would have contributed approximately 40 additional cases per week for TBH residents. The average diagnostic mammography output of TBH residents ($n = 415$) meets the minimum published requirements of both the RANZCR ($n = 100$) and the ACGME ($n = 300$). Similarly, the average vascular and interventional output (165) would satisfy the sole published specifications in this domain (RANZCR, $n = 100$). However, the average TBH MR output ($n = 437$) over 4 years is below that specified by the RANZCR ($n = 600$) for an equivalent training period. This reflects institutional resource constraints, since TBH has a single 1.5 Tesla MR unit.

It is hoped that this report will stimulate similar PACS/RIS-based analyses from other centers, enhancing understanding of radiology training programs globally. The sharing of training data has been shown to foster international collaboration amongst institutions and statutory bodies across the medical disciplines [31–38]. Collaboration is assuming increasing importance as the radiological community embraces the challenges of globalization and equitable access to healthcare [39–42]. Advances in digital imaging and communication technology offer ever-increasing opportunities for the standardization of radiological training globally [43–45].

The study had a number of strengths. Subjects underwent the same training program, with no change to the syllabus, curriculum, resident rotations, or digital radiology platform during the study period. The integrity of the resident clinical outputs was assured through the continuous utilization of standard quality-assurance procedures applicable to all DICOM systems and commercial PACS/RIS installations.

Study limitations included a retrospective design and a purely quantitative analysis of outputs, which provided no insights into the quality of resident reporting. Of note, the latter limitation could be addressed in future studies by incorporating a qualitative component to the analysis of reporting outputs. This could be achieved by assessing discrepancies between the provisional resident and the final attendant report. Such discrepancy data is typically incorporated in the modern PACS/RIS.

A further limitation is the omission of obstetric ultrasound and nuclear medicine studies from the analysis, since these studies are not currently networked with the TBH radiology PACS/RIS. Additionally, since only PACS/RIS-based, formally reported clinical cases were included, the study did not incorporate an observational component. These latter factors contribute to under-reporting of institutional EL, particularly in the domain of plain-film reporting. Additionally, the

small sample size may be implicated in the failure to achieve statistical significance of results.

Conclusion

This first PACS/RIS-based analysis of the comprehensive clinical outputs of any radiology training program provides important baseline educational data, with the potential to inform discourses on specialty training at institutional, regional, national, and international level. It is hoped that this report will stimulate similar PACS/RIS-based analyses from other centers, enhancing understanding of radiology training programs globally. Furthermore, on the strength of this study, we suggest that the traditional, selective radiology logbook be superseded by comprehensive PACS/RIS-based data reflecting a resident's comprehensive clinical outputs throughout the training period.

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Compliance with Ethical Standards

The study was approved by the Health Research Ethics Committee of the Faculty of Medicine and Health Sciences of Stellenbosch University and TBH Management. Written informed consent was obtained from all participating residents, whose anonymity was assured through the use of unique study identifiers, known only to the principal investigator.

Conflict of Interest The authors declare that they have no conflict of interest.

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