International Journal of Technology Assessment in Health Care, **25:3** (2009), 383–390.

doi:10.1017/S0266462309990195

The effects of technological developments on nuclear medicine technologist productivity: A systematic review

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Objectives: Nuclear medicine has changed rapidly as a result of technological developments. Very little is reported on the effects these developments may have on technologist productivity. This study aims to determine whether advances have created a workplace where more patient studies can be performed with fewer technologists. The level of change in automation or time taken to perform a routine task by the nuclear medicine technologist as a result of technological development over the past decade is reported.
Methods: A systematic review was conducted using Embase.com, Medline, INSPEC, and Cinahl. Two authors reviewed each article for eligibility. Technological developments in routine areas over the past decade were reviewed. The resultant automation or time effects on data acquisition, data processing, and image processing were summarized.
Results: Sixteen articles were included in the areas of myocardial perfusion, information technology, and positron emission tomography (PET). Gamma camera design has halved the acquisition time for myocardial perfusion studies, automated analysis requires little manual intervention and information technologies and filmless departments are more efficient. Developments in PET have reduced acquisition to almost one-fifth of the time.
Conclusions: Substantial efficiencies have occurred over the decade thereby increasing productivity, but whether staffing levels are appropriate for safe, high quality practice is unclear. Future staffing adequacy is of concern given the anticipated increasing service needs.

Keywords: Nuclear medicine, Gamma camera, Positron emission tomography, Nuclear medicine technologist

Technological change has influenced medical imaging dramatically over the past 50 years (15). Computing developments have increased speed and automation of tasks (37) and have taken over many skills previously required by technologists in medical imaging (16).

Nuclear medicine (NM) uses radiotracers to diagnose and treat disease and in many countries is a subspecialty of radiology. The two primary diagnostic imaging methods are single photon imaging and positron emission tomography (PET) (29).

The nuclear medicine technologist (NMT) or radiologic technologist performs patient preparation, data acquisition, data processing, and image processing. Over the past decade, worldwide NMT shortages have been reported (7;8;35;41;42;50).

In Australia, the workforce size increased between the years 1996 to 2001 by 19.8 percent (3) but then decreased from 2001 to 2006 by 4.9 percent (6). Service provision, however, continued to increase, with growth of 26.3 percent from 1996 to 2001(3) and 14.2 percent from 2001 to 2006 (31). A comparison with radiography found the workforce in the 2001 to 2006 period grew by 9 percent and service provision by 14.7 percent. Hence, similar service provision growth is exhibited between the disciplines but a substantially different workforce outcome appears.

An American survey (24) reports that the average volume of studies performed by a full time equivalent (FTE) NMT in 1995 was 988, was 1,392 in 2000, and was 1,390 in 2004. Although not a direct comparison to Australia, it would appear that in the United States there was a rise in service provision per full time worker from 1995 to 2000, but after that it leveled off. The shrinking workforce in Australia with rising service provision from 2001 to 2006 indicates that more is being done with less staff. In addition, an increase in demand for these services has been predicted in the United States (49) and Australia (9).

Several quality review papers addressing technological developments in NM have been published but limited research has been conducted on how developments in technology have affected NMT practice and its workforce. This study aims to determine whether advances in technology have enabled the NM workplace to conduct more patient studies with fewer technologists. A systematic review quantifying the level of change in automation or time taken to perform a routine task by the NMT as a result of technological development over the past decade was undertaken. The outcomes measured are the degree of simplification of the task because of automation, the increased speed of the task, and increased speed of acquisition. The review is limited to data acquisition, data processing, and image processing in single photon (gamma camera) and PET imaging systems. Radiopharmaceutical preparation is excluded because it is less affected by technological change.

METHOD

Literature Search

The search strategy was limited to the English language, peer-reviewed journals, the years 1998–2008 and articles with abstracts. The electronic databases Embase.com, Medline by means of Ovid SP (1950 to present), INSPEC by means of Ovid SP (1969 to present), and Cinahl by means of Ovid SP (1982 to present) were used. The keywords used are displayed in Supplementary Table 1, which can be viewed online at www.journals.cambridge.org/thc. Keywords in parts A, B, C, D were used without quotes using the Boolean operator "and" or "or". Each part was focused on terms that related to specific aspects of NM.

The Cochrane Database of Systematic Reviews was searched using the keywords but returned zero results. A search of full text theses was conducted using the keywords "nuclear medicine" with none in the past decade. Hand searching was conducted by scanning the reference lists. The search strategy is displayed in Figure 1 and was completed June 2008.

The methodology for conducting systematic reviews as described in the Cochrane Handbook was used.

Study Selection

Articles were included if reporting a quantitative finding where the technological development had an impact on the automation or speed of a task that the NMT commonly undertakes, in data acquisition, data processing, or image processing. Only human patient imaging devices and procedures performed regularly in the developed nations of the world were used. Methodology must be clearly described and rigorous. One study where simulated patient conditions were obtained was included because it used commercial software for a routine clinical procedure, but in general, only studies including some findings in human patients or technologist workload in an NM department were included. The main reasons for inclusion were gamma or PET camera hardware or software developments that increased the speed or simplified the data acquisition and processing tasks, or information technology developments that affected the speed or automation of data or film processing.

Exclusion criteria are displayed in Figure 1. Inclusion and exclusion decisions were resolved by consensus. Given the scope of the review aims, a broad range of study designs was acceptable although some relevant papers were excluded because they provided limited methodological information. Prospective, retrospective, pre and post, comparative studies, and one survey were included. The survey was a large national survey with information directly related to NMT workflow. The outcome measures of this systematic review were more often secondary findings of the studies used.

Data Extraction

Data were extracted by one reviewer and confirmed by the second. Data extraction included study demographics and characteristics, the area of NM practice, and outcome measures. The outcome measures of automation or time were placed under three categories—myocardial perfusion imaging, information technology, and PET. Myocardial perfusion imaging was further defined with outcomes listed under acquisition or processing. Personal communication was made with two Australian NM product managers in November 2008 to add to understanding.

The diversity of data and dissimilarities in the outcome measures for this systematic review meant that no further analysis of the data was performed.

RESULTS

Systematic Review

Of the 1,233 titles and abstracts reviewed after duplicates were removed, 16 full text articles were accepted in the systematic review. Six studies reported on myocardial perfusion (2;11;14;19;43;53), two studies in information technology (36;37) and eight studies in PET (10;18;23;28;30;34;44;52). Supplementary Table 2, which can be viewed online at

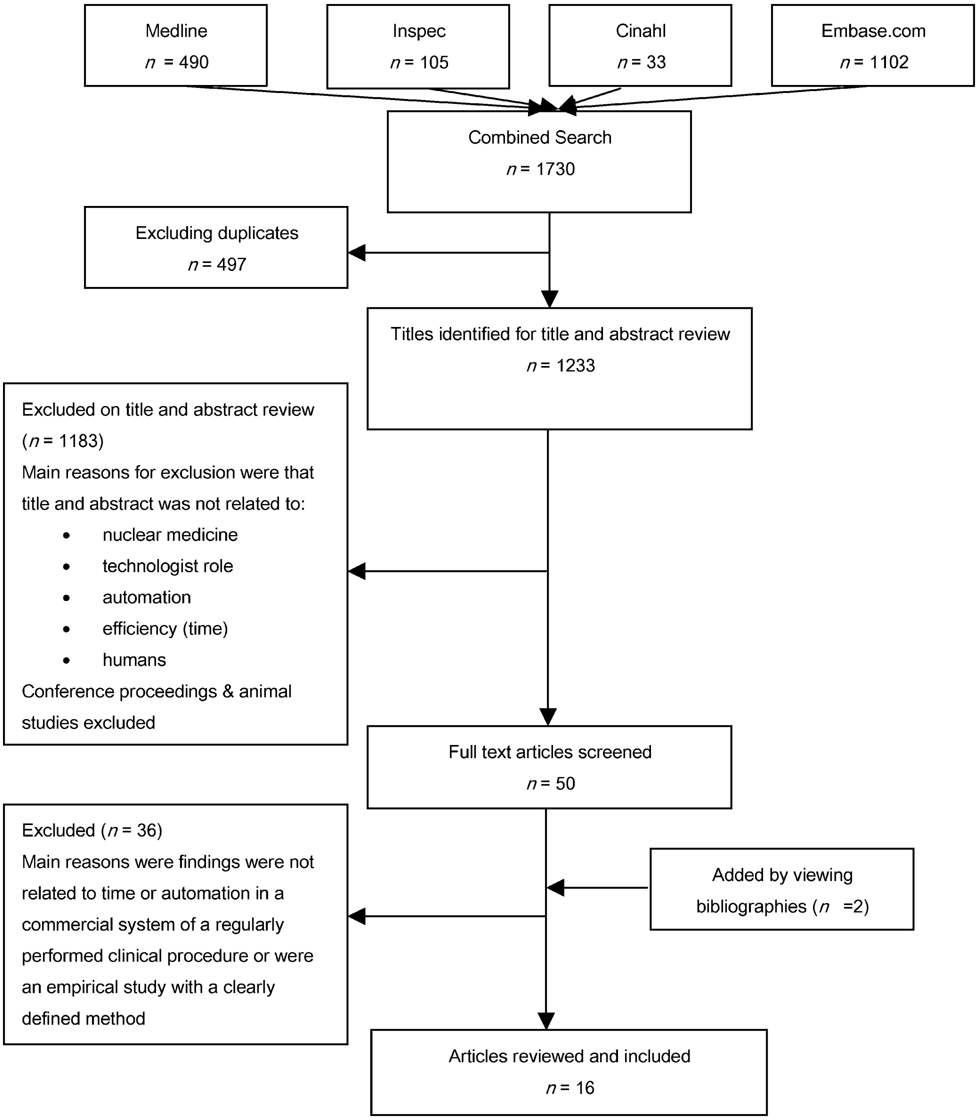

Figure 1. Flowchart of study selection.

www.journals.cambridge.org/thc, displays the study characteristics and outcomes.

MYOCARDIAL PERFUSION

Six studies relate to single photon emission computed tomography (SPECT) myocardial perfusion acquisition and/or its associated data processing. Results are categorized as data acquisition or data processing with subsections to identify if the developments relate more to time or automation. Specific technological developments are presented under headings.

Data Acquisition

Four studies (11;14;43;53) fully report the acquisition parameters and the gamma camera system used. One study (19) reports only partial information. All use a dual-detector system with one using a single-detector as well.

Time

Dual-Detector Gamma Cameras. Dual-detector systems acquire the study in almost half the time of single-detector systems if the same acquisition parameters are used. Acquisition time for dual-detector systems is reported by two authors (11;14) to be 21 minutes, whereas a single-detector system takes 43 minutes with the same acquisition time per projection and the same number of projections (11). The number of projections and time per projection will alter the total acquisition time. The reported acquisition times ranged from 20 to 50 seconds per slice (11;14;43;53). All papers effectively acquired 64 slices, leading to an overall time of 21–48 minutes.

Acquisition parameters are variable, and not all centers use a protocol that will halve the acquisition time of a single-detector but dual-detector systems set at right angles have the ability to save substantial acquisition time.

Data Processing

Findings relating to data processing of SPECT myocardial perfusion studies are presented under automation and time.

Automation

Five studies (2;14;19;43;53) evaluated the performance of automated commercial myocardial perfusion software. These papers described and quantified the success of processing. Limited manual intervention is possible in myocardial perfusion data processing.

Manual Reorientation of the Heart. After reconstruction of the automatically generated short axis slices, manual reorientation of the heart may be needed. Of the five studies, three (2;19;53) note the use of manual reorientation if required. Manual reorientation requires the user to move the settings until the correct left ventricular (LV) axis is defined (2).

Success of Automatically Generated Heart Regions. Epicardial and endocardial regions are created automatically in all programs with varying degrees of success. All programs in this systematic review include the ability to manually override the automated regions if the user considers them to be placed inappropriately. Four studies (14;19;43;53) report the rate where automatic contouring of the LV regions required no manual intervention. Two studies (14;19) report similar levels of automated success (76/79 and 75/77 patients) using the radiopharmaceutical technetium-99m and two different software programs. A third group using different software and radiopharmaceutical on 82 patients (43) reports less success with 60 percent (49/82) requiring manual intervention. In the most recent study (53) using technetium-99m and comparing three software programs on 328 patient datasets there was variable need for manual adjustment (4.1–43.9 percent). The accuracy of commercial software automatically creating accurate heart contours is variable and requires review with possible intervention.

Time

Two studies (2;43) report times for processing. The earlier one reports that automatic ejection fraction calculation could be inaccurate and requires manual intervention, which can take 10–15 minutes (2). Seven years later, manual intervention was much quicker with manual regions reported as typically taking 30–40 seconds per case, whereas the automatic contour was 2 seconds (43).

INFORMATION TECHNOLOGY

Two studies relate to the effects of information technology and image processing developments.

Task Analysis

A task analysis evaluated the workflow in all modalities of radiography and the effect of information technologies (36). A median of 63 percent of NMTs' time was spent performing procedures, 8 percent in patient preparation, image processing 10 percent, accessing data 5 percent, and 2 percent of the day in retrieval of old examinations.

Image Processing

Two studies (36;37) investigated the effect of filmless operation (digital images with no manual image processing) on technologist productivity in radiology, compared with film-based operation.

In a comparison of film-based and filmless settings the mean percentage of time spent by NMTs conducting examinations increased (6 percent), but not significantly (36). In the other study, where a pre- and postretrospective study (37) was conducted in a filmless radiology center using a picture archival communication system (PACS), results were more striking. The overall technologist productivity (examinations per full time equivalent) rose by 25 percent when filmless as compared to film-based: 34 percent above the U.S. national norms. Unfortunately the results do not give NM only findings. Another interesting finding was in comparing the control site staffing levels and volume of studies to the center that went filmless. The control site had a 30 percent increase in FTE technologists and 18 percent increase in volume of studies, whereas the center that moved from film to filmless over the same period had a 13 percent increase in staff and 48 percent increase in volume of studies.

Information Technology

Only one study (36) quantified the impact of information technologies (radiology information systems, hospital information systems, modality worklist, and picture archival communication systems) on the productivity of the technologist. The authors note that a direct cause and effect relationship is not established. In this U.S. nationwide survey ($n = 112$ centers), the authors report that all medical imaging modalities with some form of information technologies had greater productivity. A statistically significant difference was found in NM with hospital information systems (mean 62 percent) versus those without (mean 46 percent).

POSITRON EMISSION TOMOGRAPHY

Eight studies relate to whole body PET imaging from the years 2001–2007. The total acquisition time for whole body PET studies has been affected by technological developments in PET systems and computing. All studies discuss some aspect/s of these developments and the impact on acquisition time. Findings are reported in chronological order to present developments over time. Four factors contributed to a decrease in acquisition time over these years: two-dimensional

(2D) versus 3D, type of detector used, CT attenuation correction and computing power. The studies are difficult to compare, because they all use a combination of some of these factors. In all cases, the mode of acquisition was documented. Three studies evaluated PET with CT attenuation correction (10;23;44), and one discussed computing power (35).

Acquisition Time

An unsuccessful attempt to make 2D faster (34) produced images unsuitable for routine use. However, this establishes a baseline of 30–50 minutes per patient for a standard 2D study.

The combination of lutetium oxyorthosilicate (LSO) detectors, large injected activities based on patient weight and acquisition in 3D mode should result in substantial reductions in acquisition time (18). However it showed acceptable images with a large dose and short acquisition time (30–35 minutes), but unacceptable patient radiation dose and cost.

A combination of weight-based dose, an LSO detector, 3D acquisition, and CT attenuation correction resulted in a range of 7–35 minutes to acquire, with 2,000 studies having a mean time of 14 minutes (23). Computed tomography attenuation correction acquisition took 80–110 seconds and removed the need to acquire a separate transmission acquisition, which occurs over 5–7 bed positions at a rate of 3–5 minutes each.

The feasibility of reducing scan time for whole body imaging in a PET system with a BGO detector using 3D mode acquisition as compared to 2D was investigated (52). Images were acceptable in 3D, but there was no significant reduction in overall scan time. On the other hand, a comparison of 2D versus 3D with a LSO detector (28) found a reduction of 33 percent scan time with 3D. A third detector type (GSO) (30) was evaluated with attenuation correction using a transmission source instead of CT, simultaneously with image acquisition. Image quality was acceptable, and studies were acquired in one third of the time of a current commercial scanner.

A research PET/CT system and a newly developed fully iterative reconstruction program resulting from improved computing power were used to determine if 3D acquisition was suitable for clinical use and provide greater patient throughput (44). Whole body CT attenuation correction took 12–18 seconds. The 2D (21 minutes) and 3D (10.5 minutes) data were acquired. Unfortunately poor interobserver correlation made statistical significance of findings for subjective image quality and lesion detection impossible. Objective analysis found significant differences in the standard uptake value of lesions with 2D outperforming 3D. The authors conclude that the new reconstruction method can be used reliably in the clinical environment and results in a scan time reduction of 50 percent without significant loss of lesion detectability.

A new 3D BGO PET/CT scanner was investigated by comparing 2D acquisition mode against 3D performance (10). In all conditions, the 3D acquisition mode resulted in superior quantitative and qualitative assessments as compared to 2D, in half the time.

DISCUSSION

Findings in this systematic review show that substantial technological developments in computing, camera design, and information technology over the past decade in NM have made acquisition, data processing, and image processing quicker and more automated. This has been strikingly evident in PET imaging. On the other hand, some developments have introduced new tasks such as systems incorporating a CT unit to either the single photon or PET camera.

Myocardial Perfusion

Myocardial perfusion studies have been one of the most commonly performed studies in NM over the past decade (21). Gamma camera developments with the advent of two or three detector systems, technetium-99m labeled radiopharmaceuticals and faster computing have changed myocardial acquisition. These changes have impacted on the speed and automation of routine tasks performed by the NMT.

Faster Acquisition. Dual-detector gamma cameras have made the routine use of SPECT for myocardial perfusion studies possible without long acquisition times (11;20). It is possible to decrease acquisition time to at least half that of a single-detector if the same acquisition parameters are used (11;14) but dual-detectors were not common to the vast majority of practices until after the year 2000. A multicenter trial in the United States published in 2000 showed 26 percent of cameras were dual detector systems (33). Two Australian product managers confirm that dual-detector sales in Australia overtook single-detectors in 1998 to 2000 (personal communication).

No studies relating to bone imaging were eligible for this systematic review, therefore, the effect of dual-detectors has not been reported, but Sarikaya et al. (38) report that bone SPECT is the second most frequently performed SPECT procedure. The impact of dual-detectors in this area should be considered, given that two projections can be acquired at the one time. It is acknowledged that other technological developments such as detector autocontouring and SPECT/CT may have impacted on automation and possibly time, but no studies in this systematic review related to these developments.

Faster and More Automated Processing. The introduction of routine SPECT acquisition to myocardial perfusion imaging, primarily as a result of new technetium-99m labeled radiopharmaceuticals (2), brought changes to processing methods that have developed over time to become faster, produce new quantitative results and with less operator intervention. Cedars Sinai brought out their first fully automated suite of myocardial perfusion SPECT software in the late 1990s (1;22).

Five of the systematic review articles evaluate the clinical utility of commercial automated software programs over the decade (2;14;19;43;53). Khalil et al. (26) report that, in the past decade, processing has gone “from simple methods to advanced three-dimensional modeling.” Increased computing speed has made this evolution for quick and fully automated cardiac processing possible (1;26).

Operator intervention is highly limited in these automated programs but not all patient anomalies can be managed by the software and, therefore, an operator is sometimes required to intervene (27). The need for intervention was found to be variable, but the latest and largest study used in this systematic review found that manual intervention ranged from 4.1 percent to 43.9 percent, depending upon the software in use.

The time taken for manual intervention has become much faster over the decade, although findings are very limited. Two Australian product managers report 1 minute for processing in current systems (personal communication).

In summary, myocardial perfusion imaging has become faster with dual detector systems; processing is far more automated with minimal manual intervention and is extremely quick.

Information Technology and Image Processing

The impact of technology related to hospital information systems and digital image processing and storage on the NMT workflow has had an effect on practice. Data relating to this area is very limited with the studies in this systematic review performed by only one group of authors in the United States.

Hospital information systems where bookings, results, and data pertaining to the patient are electronically managed are reported in one study to significantly increase NMT productivity (36). Advances in electronic storage such as PACS (37) or optical disk over the past decade may also have impacted on the technologist workload. Findings are limited but if, as reported, a median of 17 percent (36) of the NMT’s day is spent in image processing, accessing data, and retrieval of old examinations is generalizable, then time savings in these tasks will increase productivity.

The advent of digital image processing removed the need to manually process film, but findings (36;37) are again limited and it is difficult to know when this made substantial changes to NM departments.

PET Imaging

Since 1998, PET has had substantial technological developments and has grown in use (25;32). Dual SPECT/ PET systems were popular from 1995 but did not remain in use because of limited diagnostic quality (32), so are not included in this review.

The increased use of PET whole body studies in oncology today is recognized worldwide (44). Developments in detectors in the late 1990s (47), faster electronics and computing (45), and the use of CT for attenuation correction over the past decade have substantially reduced the time to acquire whole body PET studies. In 2001, acquisition was 30–50 minutes (34), and by 2007 it took approximately 10 minutes (10;44). This is supported by a 2003 published review of PET/CT developments (48) that notes acquisition time changed from 45–60 minutes to 10–20 minutes.

Developments in detectors and electronics, in conjunction with more powerful computing for reconstruction in the mid-2000s (10;28;44) have led to the clinical viability of 3D mode acquisition where higher count rates and shorter acquisition times make greater patient throughput possible.

The first commercial PET/CT system was introduced in 2001 (47). The CT is used for attenuation correction and takes only seconds to complete (44;47), which removes the need for a transmission scan, thereby substantially reducing overall scan time (5;47;48). By 2006, PET/CT was the most common PET system used (41).

Currently, only a small component of the total service provision is PET, but this has grown over the decade. A health technology assessment (25) reports that Australia, Switzerland, and Denmark each had fewer than five scanners in 1999. In 2003, there were eight government funded PET sites in Australia (39). In 2005 in the United States, only 5.2 percent of the workforce spent all their working time in PET/CT, whereas 74.6 percent were in single photon NM services (46). Although substantial technological developments have led to much faster scan times (approximately 1/5) and increased patient throughput, this development in itself could not account for the rise in service provision and decrease in staff numbers seen in Australia and the world staff shortages reported over the past decade.

Staffing Concerns

The comparison made in the introduction of radiography and NM technology from 2001 to 2006 in Australia raises staffing concerns. Similar increases in service provision (14.7 percent and 14.2 percent) occurred with substantial dissimilarities in workforce size (+9 percent and −4.9 percent). The effect of automation encountered in NM would be similar in radiography, particularly in CT and digital imaging, and yet in Australia NMTs appear to do more with fewer staff. The United States does not appear to have this dilemma, with the volume of studies per FTE remaining constant from 2000 to 2004 (24).

A survey (4) conducted in 2004 in Australia found a minimal FTE staffing ratio per gamma camera. Centers with two gamma cameras range from 1 to 5 staff, three gamma cameras from 2 to 9 staff, and 4 gamma cameras from 3.2 to 10.2. In some cases, therefore, there are more gamma cameras than FTE technologists. Does this have implications for the quality of images and patient care?

Although technology has increased productivity, the anticipated rise in service provision because of imaging needs for the growing ageing population and the capabilities of SPECT/CT and PET/CT will put a strain on the workforce. In PET, a greater staffing ratio is required because technologists incur higher radiation levels (40), so increasing use will require increased staffing.

CONCLUSION

Major technological developments have occurred over the past decade, bringing far more automation and speed to tasks performed by the NMT. Detector advances, faster computing and digital image processing have markedly reduced task times. Given the scope of developments, the limitations with some findings, and the difficulty in determining when the developments affected the majority of departments, it is difficult to make definitive conclusions regarding staffing levels and increased productivity. Current staffing levels will need to increase to meet the anticipated rise in demands and this more so in Australia, where the present workforce appears inadequate.

SUPPLEMENTARY MATERIALS

Supplementary Tables 1 and 2 (www.journals.cambridge.org/thc)

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REFERENCES

1. Abidov A, Germano G, Hachamovitch R, Berman DS. Gated SPECT in assessment of regional and global left ventricular function: Major tool of modern nuclear imaging. *J Nucl Cardiol.* 2006;13:261-279.
2. Achtert AD, King MA, Dahlberg ST, et al. An investigation of the estimation of ejection fractions and cardiac volumes by a quantitative gated SPECT software package in simulated gated SPECT images. *J Nucl Cardiol.* 1998;5:144-152.
3. Adams E, Cox J, Adamson B, Schofield D. A profile of Australian nuclear medicine technologist practice. *Nucl Med Commun.* 2008;29:83-90.
4. Adams E, Schofield D, Cox J, Adamson B. Will the Australian nuclear medicine technologist workforce meet anticipated health care demands? *Aust Health Rev*. 2008;32:282-291.
5. Alessio AM, Kinahan PE, Cheng PM, Vesselle H, Karp JS. PET/CT scanner instrumentation, challenges, and solutions. *Radiol Clin North Am*. 2004;42:1017-1032.
6. Australian Bureau of Statistics. *2006 census data*. http://www.abs.gov.au/websitedbs/D3310114.nsf/Home/Census+Data (accessed May 2008).
7. Australian Government Department of Employment and Workplace Relations. *Australian jobs update January 2005.* http://www.workplace.gov.au/workplace/Individual/Migrant/AustralianLabourMarketUpdate.htm (accessed May 2008).
8. Australian Government Department of Employment and Workplace Relations. *National Skills Shortage List, Jan 2004.* http://amwac.health.nsw.gov.au/ (accessed May 2008).
9. Australian Government Productivity Commission. 2005 *Impact of advances in medical technology in Australia*. http://www.pc.gov.au/projects/study/medicaltechnology/docs/finalreport/mediarelease (accessed May 2008).
10. Bettinardi V, Mancosu P, Danna M, et al. Two-dimensional vs three-dimensional imaging in whole body oncologic PET/CT: A Discovery-STE phantom and patient study. *Q J Nucl Med Mol Imaging.* 2007;51:214-223.
11. Bucerius J, Joe AY, Lindstaedt I, et al. Single- vs. dual-head SPECT for detection of myocardial ischemia and viability in a large study population. *Clin Imaging*. 2007;31:228-233.
12. Burbridge B, Bell C. The digital readiness of imaging facilities in Saskatchewan. *Can Assoc Radiol J*. 2004;55:311-314.
13. Chowdhury FU, Scarsbrook AF. The role of hybrid SPECT-CT in oncology: Current and emerging clinical applications. *Clin Radiol*. 2008;63:241-251.
14. Chua T, Yin LC, Thiang TH, et al. Accuracy of the automated assessment of left ventricular function with gated perfusion SPECT in the presence of perfusion defects and left ventricular dysfunction: Correlation with equilibrium radionuclide ventriculography and echocardiography. *J Nucl Cardiol*. 2000;7:301-311.
15. Doi K. Diagnostic imaging over the last 50 years: Research and development in medical imaging science and technology. *Phys Med Biol*. 2006;51:R5-R27.
16. Donahue K. *Radiologic technologists: Alienation and deskilling in a "high technology: Profession*. Santa Barbara: University of California; 1995:231.
17. Dwyer SJ, Templeton AW, Martin NL, et al. Cost of managing digital diagnostic images for a 614-bed hospital. *J Digit Imaging*. 2002;15:255-260.
18. Everaert H, Vanhove C, Lahoutte T, et al. Optimal dose of F-18-FDG required for whole-body PET using an LSO PET camera. *Eur J Nucl Med Mol Imaging*. 2003;30:1615-1619.
19. Faber TL, Cooke CD, Folks RD, et al. Left ventricular function and perfusion from gated SPECT perfusion images: An integrated method. *J Nucl Med*. 1999;40:650-659.
20. Freeman MR, Konstantinou C, Barr A, Greyson ND. Clinical comparison of 180-degree and 360-degree data collection of technetium 99m sestamibi SPECT for detection of coronary artery disease. *J Nucl Cardiol*. 1998;5:14-18.

21. Germano G. Technical aspects of myocardial SPECT imaging. *J Nucl Med.* 2001;42:1499-1507.
22. Germano G, Kavanagh PB, Berman DS. An automatic approach to the analysis, quantitation and review of perfusion and function from myocardial perfusion SPECT images. *Int J Cardiovasc Imaging*. 1997;13:337-346.
23. Halpern BS, Dahlbom M, Quon A, et al. Impact of patient weight and emission scan duration on PET/CT image quality and lesion detectability. *J Nucl Med.* 2004;45:797-801.
24. Hanwell L, Conway J. *New staff utilization survey. American Healthcare Radiology Administrators Radiology Management. 1996*. https://www.ahraonline.org/RM/RMResults.asp (accessed January 2009).
25. Institute for Clinical Evaluative Sciences. *Health technology assessment of positron emission tomography (PET)—a systematic review*. Institute for Clinical Evaluative Sciences. 2001. www.ices.on.ca (accessed July 2008).
26. Khalil MM, Elgazzar A, Khalil W. Evaluation of left ventricular ejection fraction by the quantitative algorithms QGS, ECTb, LMC and LVGTF using gated myocardial perfusion SPECT: Investigation of relative accuracy. *Nucl Med Commun*. 2006;27:321-332.
27. Lin GS, Hines HH, Grant G, Taylor K, Ryals C. Automated quantification of myocardial ischemia and wall motion defects by use of cardiac SPECT polar mapping and 4-dimensional surface rendering. *J Nucl Med Technol*. 2006;34:3-17.
28. Lodge MA, Badawi RD, Gilbert R, Dibos PE, Line BR. Comparison of 2-dimensional and 3-dimensional acquisition for F-18-FDG PET oncology studies performed on an LSO-based scanner. *J Nucl Med.* 2006;47:23-31.
29. Lopes MI, Chepel V. Detectors for medical radioisotope imaging: Demands and perspectives. *Radiat Phys Chem.* 2004;71:683-692.
30. Matsumoto K, Kitamura K, Mizuta T, et al. Performance characteristics of a new 3-dimensional continuous-emission and spiral-transmission high-sensitivity and high-resolution PET camera evaluated with the NEMA NU 2–2001 standard. *J Nucl Med*. 2006;47:83-90.
31. Medicare Australia. *Medical benefit schedule*. https://www.medicareaustralia.gov.au/statistics/mbs_item.shtml (accessed May 2008).
32. Muehllehner G, Karp JS. Positron emission tomography. *Phys Med Biol*. 2006;51:R117-R137.
33. O'Connor MK, Leong LK, Gibbons RJ. Assessment of infarct size and severity by quantitative myocardial SPECT: Results from a multicenter study using a cardiac phantom. *J Nucl Med.* 2000;41:1383-1390.
34. Paul AK, Tatsumi M, Fujino K, Hashikawa K, Nishimura T. Feasibility of a short acquisition protocol for whole-body positron emission tomography with fluorine-18 fluorodeoxyglucose. *Eur J Nucl Med Mol Imaging*. 2001;28:1697-1701.
35. Perkins AC, Gordon I, Read J, Ellis B. Training of staff for the delivery of PET/CT services in the UK. *Nucl Med Commun*. 2006;27:1005-1010.
36. Reiner B, Siegel E, Carrino JA. Workflow optimization: Current trends and future directions. *J Digit Imaging*. 2002;15:141-152.
37. Reiner B, Siegel E, Scanlon M. Changes in technologist productivity with implementation of an enterprisewide PACS. *J Digit Imaging*. 2002;15:22-26.
38. Sarikaya I, Sarikaya A, Holder LE. The role of single photon emission computed tomography in bone imaging. *Semin Nucl Med*. 2001;31:3-16.
39. Scott A, Rowe C, Allman K, et al. Australian Prospective multi-centre PET data collection project–Impact of FDG PET in oncology, epilepsy and cardiac patients. *J Nucl Med*. 2007;48(Suppl 2):185P.
40. Seierstad T, Stranden E, Bjering K, et al. Doses to nuclear technicians in a dedicated PET/CT centre utilising 18F fluorodeoxyglucose (FDG). *Radiat Prot Dosimetry*. 2007;123:246-249.
41. Shaw A. *Shortage of imaging technologists threatens healthcare, experts say. Canadian Healthcare Technology; 2003.* http://www.canhealth.com/oct03.html#anchor192108 (accessed November 2008).
42. Skillman S, Holly C, Andrilla A, et al. *Washington State hospitals: Results of 2003/04 workforce survey*. http://www.healthcarepersonnel.org/publications.htm (accessed November 2008).
43. Slomka PJ, Fieno D, Thomson L, et al. Automatic detection and size quantification of infarcts by myocardial perfusion SPECT: Clinical validation by delayed-enhancement MRI. *J Nucl Med.* 2005;46:728-735.
44. Strobel K, Rudy M, Treyer V, et al. Objective and subjective comparison of standard 2-D and fully 3-D reconstructed data on a PET/CT system. *Nucl Med Commun*. 2007;28:555-559.
45. Tarantola G, Zito F, Gerundini P. PET instrumentation and reconstruction algorithms in whole-body applications. *J Nucl Med*. 2003;44:756-769.
46. The Center for Health Workforce Studies School of Public Health University at Albany. *Nuclear medicine technologists in the U.S., findings from a 2005 survey. 2006.* http://interactive.snm.org/docs/Nuclear_Medicine_Technologist_Report_2005.pdf (accessed November 2006).
47. Townsend DW. Positron emission tomography/computed tomography. *Semin Nucl Med*. 2008;38:152-166.
48. Townsend DW, Beyer T, Blodgett TM. PET/CT scanners: A hardware approach to image fusion. *Semin Nucl Med.* 2003;33:193-204.
49. United States Department of Labor Bureau of Labor Statistics. *Occupational outlook handbook, 2008–09 edition. Nuclear medicine technologists*. http://www.bls.gov/oco/ocos104.htm (accessed December 2008).
50. University of Arkansas for Medical Sciences. *UAMS study shows health care workforce shortages in Arkansas will double by 2008.* http://www.uams.edu/today/2003/061203/workforceshortage.htm (accessed January 2009).
51. Vaccari G, Saccavini C. Radiology informatics and work flow redesign. *PsychNology J.* 2006;4:87-101.
52. Visvikis D, Griffiths D, Costa DC, Bomanji J, Ell PJ. Clinical evaluation of 2D versus 3D whole-body PET image quality using a dedicated BGO PET scanner. *Eur J Nucl Med Mol Imaging*. 2005;32:1050-1056.
53. Wolak A, Slomka PJ, Fish MB, et al. Quantitative myocardial-perfusion SPECT: Comparison of three state-of-the-art software packages. *J Nucl Cardiol*. 2008;15(1):27-34.
54. Yoshimura H, Inoue Y, Tanaka H, et al. Operating data and unsolved problems of the DICOM modality worklist: An indispensable tool in an electronic archiving environment. *Radiat Med.* 2003;21:68-73.