Abstract

Aim

Simulation forms an increasingly vital component of clinical skills development in a wide range of professional disciplines. Simulation of clinical techniques and equipment is designed to better prepare students for placement by providing an opportunity to learn technical skills in a “safe” academic environment. In radiotherapy training over the last decade or so this has predominantly comprised treatment planning software and small ancillary equipment such as mould room apparatus. Recent virtual reality developments have dramatically changed this approach. Innovative new simulation applications and file processing and interrogation software have helped to fill in the gaps to provide a streamlined virtual workflow solution. This paper outlines the innovations that have enabled this, along with an evaluation of the impact on students and educators.

Method

Virtual reality software and workflow applications have been developed to enable the following steps of radiation therapy to be simulated in an academic environment: CT scanning using a 3D virtual CT scanner simulation; batch CT duplication; treatment planning; 3D plan evaluation using a virtual linear accelerator; quantitative plan assessment, patient setup with lasers; and image guided radiotherapy software.

Results

Evaluation of the impact of the virtual reality workflow system highlighted substantial time saving for academic staff as well as positive feedback from students relating to preparation for clinical placements. Students valued practice in the “safe” environment and the opportunity to understand the clinical workflow ahead of clinical department experience.

Conclusion

Simulation of most of the radiation therapy workflow and tasks is feasible using a raft of virtual reality simulation applications and supporting software. Benefits of this approach include time-saving, embedding of a case-study based approach, increased student confidence, and optimal use of the clinical environment. Ongoing work seeks to determine the impact of simulation on clinical skills.

Introduction

Radiotherapy education, as in other health professions, aims to equip students with a combination of essential knowledge and understanding, clinical professional skills and clinical technical competencies. Traditionally, academic teaching blocks have provided the underpinning theoretical understanding while clinical placements have facilitated integration of theory into clinical skills development. At **** students undertake 6 separate placements at a variety of clinical sites spending a total of 32 weeks in radiotherapy departments over the 3 year Course. During these placements students are expected to develop a wide range of technical and interpersonal skills. The variety of sites provides students with exposure to a range of equipment and techniques. While this has great value in terms of providing a wide educational experience, it can lead to challenges when students are faced with learning to handle different situations. Students also need to maximize their patient-care skills, and concentrating on equipment skills can distract them from this.

Simulation forms an increasingly vital component of clinical skills development in a wide range of professional disciplines including medicine[2], surgery[1], physiotherapy[3], podiatry[4], pharmacy[5], chiropractice[6], paramedicine[7], psychiatry[8] and nursing[9]. Simulation of clinical techniques and equipment is designed to better prepare students for clinical placement by providing an opportunity to learn technical skills in a “safe” academic environment. Fear of making an error or inconveniencing clinical staff and patients is removed, allowing students to learn at their own pace. By familiarising students with complex equipment or processes before arrival in clinical departments, students are able to make optimal use of this valuable time and concentrate their efforts on patient care and applying their technical skills in a professional manner.

In radiotherapy training over the last decade or so, clinical simulation has predominantly comprised treatment planning software and small ancillary equipment such as mould room apparatus. The large and expensive nature of treatment delivery systems has until recently made their use in an academic training environment unfeasible. With the advent of the Virtual Environment for Radiotherapy Training (VERT), however, the potential for treatment simulation has increased. Published studies highlight the value of VERT for pre-clinical skills development[10,11] although it is only capable of simulating a couple of components of the radiotherapy workflow. Over the past 12 months at ****, an initiative to develop and integrate new simulation applications, Digital Imaging and Communications in Medicine (DICOM)[12] processing, and interrogation software has aimed to fill in the gaps left in the existing simulation solutions to provide a streamlined virtual workflow solution. This paper outlines the innovations that have enabled this, along with an evaluation of the potential benefits for students, educators and patients.

Materials and Methods

A series of new simulation applications and software solutions were developed to link existing simulation equipment and provide students with a continuous patient journey simulation. Table 1 illustrates how the various stages of a patient's radiotherapy course can be simulated using these tools. Although space prevents a detailed description of each tool an overview of each follows.

Virtual CT-Scanner

With support from a Health Workforce Australia grant, a 3D virtual environment was developed to simulate a CT-scanner. Although primarily developed as a medical imaging simulation, it has demonstrated clear value for radiation therapy teaching. Students are able to “position” a patient on the couch and use the CT controls to set the correct parameters for their chosen radiotherapy planning scan. The application reinforces the importance of selecting correct scan limits, scan thickness and patient position. A gaming environment and realistic patient and equipment visualization along with 3D glasses engenders a genuine and high fidelity experience. Full class teaching using a PC laboratory can enable 40 students to undertake a rudimentary CT experience concurrently.

Batch CT Handler

The planning of multiple treatments on copies of a single CT dataset is an ideal teaching opportunity as students’ solutions and skills can be directly compared. This can be problematic since clinical DICOM systems do not allow simultaneous user access, there is greater potential for data loss through human error, and file access can be slower. To overcome these problems a new tool was developed, the DICOM CT Duplicator, allowing the automated production of duplicate CT datasets with unique identifiers. The user is able to specify override values for the Study ID, Patient ID and Patient Name DICOM attributes, such that files can be more easily organised in the planning system and beyond. This enables multiple students to plan the same dataset while retaining individual identification for each plan and thus allowing plan export and evaluation in all DICOM environments. The software was developed in the C# programming language and uses the Fellow Oak DICOM for .NET library.

Radiotherapy Information Management System

The MOSAIQ patient management software is used clinically to administrate patient schedules, connect planning and treatment software, and record and verify treatment-unit parameters. The system allows for easy transfer of data between the planning system and the VERT virtual linear accelerator, while students can gain valuable and clinically relevant experience with data input and checking procedures.

Treatment Planning System

The Pinnacle planning system (Philips Healthcare, Fitchburg) is used at **** to provide students with a range of planning opportunities from simple phantom dosimetry to IMRT using clinical software. Teaching is conducted in a specialist simulation IT lab to enable whole-class teaching, tutoring input from multiple clinical experts and proximity to additional simulation equipment. Broadcast software allows students’ work to be shared with the class and for live plan evaluations to be conducted. Although Pinnacle is tolerant of duplicate DICOM headers, other planning systems and DICOM tools refuse to distinguish between different copies of the same CT datasets. A case-study based approach provides students with genuine clinical details including diagnostic, IGRT and follow-up information to engender a holistic approach to each patient’s radiation therapy workflow.

VERT plan evaluation

VERT is a radiotherapy-specific virtual reality application utilising a large-screen and 3D shutter glasses to provide a high level of realism and presence[13]. It offers the user the opportunity to control a virtual linear accelerator with a genuine hand control system, displays CT and plan data in 3D and is rapidly becoming an integral component of radiotherapy training globally. Since VERT's implementation in Australia in 2011 it has been mainly used for pre-clinical skills practice, demonstration of techniques and 3D plan evaluation. The latter facility allows student-created dosimetry plans to be imported and displayed in immersive 3D using 3D shutter glasses and large screen rear projection. At **** all students have an opportunity to view their plans in 3D with at-elbow evaluation from a clinical tutor. With the ability to view the relative dose to target and critical structures; students can be informed of their plan development and provided with guidance as to how improvements may be made.

Batch Plan Comparison

The Treatment and Dose Assessor (TADA) software allows the batch analysis of dosimetric quality for treatment plans exported as DICOM files. Data exported to spreadsheets include student identification information (via the study ID), planning parameters and dose volume metrics. The software allows the specification of planning objectives and reports on whether they have been successfully met. These features can allow efficient evaluation of student performance with respect to assessment criteria. The software has previously been used for retrospective dose quality evaluations in a clinical environment [14] and the study of the relationship between plan complexity and treatment deliverability. [15]

Lasers

The recent acquisition of a laser positioning system further enhances the student's ability to practice core clinical tasks. The set up incorporates a ceiling mounted fixed sagittal laser in conjunction with two side-mounted lateral lasers, simulating the configuration of a standard radiotherapy bunker. This allows students to straighten and level within the scope of patient case studies, making the current VERT environment more clinically realistic to clinical practice. These clinical skills form the foundation of radiotherapy practice and it is of pivotal importance to provide students with the facilities and the time to become proficient at these central tasks outside the scope of a busy, rushed and often intimidating clinical setting.

VERT room setup

VERT's primary function is to prepare students for clinical practice in a safe environment. Students are able to use the hand pendant to control the various parameters as they would prior to a real patient treatment. They are not only able to gain experience at using the complex control systems but also understanding of treatment fundamentals and techniques. Furthermore, in the training of students VERT provides the flexibility to enhance learning or address 'at-risk' students where tailored instruction on techniques and processes can be delivered without calling on already pressured clinical resources.

IGRT Software

With the advent of electronic portal imaging in the 1990s, and even more so with the more recent development of Intensity Modulated Radiation Therapy (IMRT) and Image Guided Radiation Therapy

(IGRT), treatment field verification using imaging prior to beaming on has taken a prominent place in the routine delivery of radiation. Whether by the use of electronically captured MV portal images, orthogonal kV iso-check films, or the ever-increasing application of Cone Beam Computed Tomography (CBCT), daily treatment field verification prior to beaming on is now more often performed than not in a growing number of departments.

Equipping students for this task involves not only instruction on the use of equipment for acquiring and assessing images, but also in the often subtle art of making ‘on the spot’ clinical decisions based on their assessment. As for any art, this latter skill is best developed with experience; in this case in the busy clinical environment. Unfortunately, acute time constraints during real world treatment delivery mean that the procedures of IGRT are often denied the student on clinical placement, leading to a shortfall in an essential clinical skill. Clinically relevant IGRT software is used in conjunction with case-studies created from real de-identified patients to provide a set of simulated situations in which students are introduced to the challenge of evaluating images and making treatment decisions. This can be done with a gradual increase of time pressure to practice decision making under gradually more realistic circumstances.

Workflow Evaluation

Student feedback was gathered from all students across all 3 years relating to several key aspects of the workflow simulation as part of an ongoing Course Development and Evaluation project. Different aspects of the workflow were used by different year groups as seen in Table 2. All feedback was anonymous and provided voluntarily via a simple tool utilizing both Likert-style and open question formats. Ethical approval for data collection was provided by the University Human Research Ethics Committee. Descriptive statistical analysis of the Likert responses and thematic analysis of the open questions was performed.

Results and Discussion

Time Saving

Tutorials using the virtual CT scanner and VERT for pre-clinical preparation have replaced previous introductory visits to a clinical department. This was traditionally run in small groups and demanded hours of clinical resource and personnel time. Replacing this initial experience with virtual simulation aims to reduce this burden on clinical resources. Figure 1 shows the substantial time-reduction that whole-class simulation-based teaching can facilitate. It should be acknowledged that virtual simulations only aim to replace the introductory group teaching, and are not seen as a replacement for clinical experience gained on individual placements.

In addition to savings on clinical time the workflow tools have enabled additional administrative time-saving. Copying of identical CT datasets can now be performed with automatic generation of user-determined identification codes including Unit Code, tumour site and student ID codes that overwrite even to “StudyID” level. This enables batch upload of multiple copies of the same patient with different IDs. For academic purposes this is very useful as it provides good parity for assessment as well as facilitating whole class teaching. Previously, anonymisation and plan copying was performed manually in a laborious and time-consuming manner as seen in Figure 1. Since the deep anonymisation allows multiple copies to be uniquely identified in patient information systems, automated transfer between the planning system and VERT can be facilitated. Previously plans had to be transferred via USB, as batch export failed when identical Study UIDs were picked up by DICOM servers.

This means that students can evaluate plans in VERT to identify potential improvements and then action the changes immediately. An advantage of whole-class planning of identical patient datasets is that students can be assessed with parity. A software tool has been created that provides quantitative assessment of student performance against PTV and OAR doses. Although this is only 1 component of plan assessment, it does provide a useful indication of the extent to which individual students have achieved their targets compared to class performance. Figure 2 illustrates typical results from this with comparative PTV coverage statistics for a Year 2 cohort of 29 students; it can be seen that Students 2, 20 and 25 have under-dosed their target volumes compared to the rest of the class.

When combined with whole class teaching and practice on the same patient dataset, this allows students to gauge their performance against the “gold standard” generated from their peers. Although existing software allows generation of contouring gold standards for teaching purposes,[16] these have yet to extend to plan evaluation. This has great formative value as optimal solutions can be rapidly identified and used to illustrate possible solutions to the rest of the class.

Improved pre-clinical preparation

One of the criticisms of simulation-based education is that it usually focuses on a single “high-stakes” procedure and fails to replicate the full workflow of processes. This has led to the concept of integrated simulation[17] where radiotherapy students have the opportunity to “scan”, plan, evaluate, QA check, “treat” and verify their own patient in a simulated yet integrated manner. The software solutions offer students the closest experience possible to clinical practice in a virtual environment. This has the benefit of not only better preparing students for clinical practice but also integrating it more completely and closing the theory-practice gap.[18]

Students can be made aware of the cumulative effect of errors as well as the importance of viewing each step of the patient journey as part of an interlinked continuum. Table 3 contains typical comments related to the benefits of simulation reported by Year 1 students. The comments highlight the value of their prior exposure to the simulated radiation therapy environment. It can be seen that students felt better prepared for placement and in particular understood the workflow processes. This should allow students to concentrate more on patient interaction skills, and ongoing evaluation seeks to determine the extent to which this was achieved. It was particularly interesting to see students citing a firmer link between academic theory and clinical practice.

Safe learning environment

The major advantage of simulating the whole RT workflow is that students can be allowed to experiment and start to gain valuable clinical skills that only come with hard earned experience. While the best forum for this is the clinical environment, the provision of a safe environment for learning purports to promote a range of skills stemming from simple motor control to high-level clinical decision making but with reduced pressure and risk. Table 3 highlights typical feedback comments concerning the benefits of learning in a safe environment. The introduction of VERT for pre-clinical skills training has already been demonstrated[10] to relieve the heavy burden that exists in meeting teaching and training needs of students whilst still doing the best by an unyielding patient waiting list. This is reflected in positive informal feedback from clinical educators and students in their identification of being ‘better prepared’ for clinic.

With the integration of additional software solutions, simulation of the radiation therapy workflow in a safe learning environment not only equips students for clinical placement but also frees up valuable clinical resources and time and allows students to make the most of the rich clinical learning environment.

Simulation Limitations

It was reassuring to see that the students identified the key limitation of the workflow simulation as being the lack of patient interaction. Comments acknowledged that real patients would move, would be more challenging to position and would require constant use of interpersonal skills. This is unsurprising as the stated aim of the simulation was to provide foundation technical skills in order to help students focus more on patient skills when out on clinical placement. Some of the students also reported limitations from the hardware requirements and difficulty with the control systems.

Resource Implications

Clearly some of these resources required substantial initial development while some draw on existing commercial products. Ongoing use of these innovations, however, promises to bring significant efficiency gains to the academic workload. Batch processing software reduces time taken to prepare a class (n=40) CT datasets by around 80%. Use of a virtual reality CT environment enables whole class experience that would require multiple consecutive small group bookings in a real imaging suite. For a class size of 40 this would replace 10 hours of clinical seminars with a single hour in a PC lab. Investment In staff training with software is important to ensure efficient and effective use of resources but overall the time gains outweigh this initial outlay.

Future Directions

It is hoped to further develop the plan assessment tool to generate a quantitative “score” for plans to complement qualitative plan feedback and assessment. In addition, the ability to quickly compare treatment plan "quality" for different students could enable the construction of a database of results for experience-based course design. This in turn would enable identification of areas of systematic deficiency in the plans that could inform future teaching.

More longitudinal evaluation will seek to determine student perspectives on the workflow simulation initiative. Additionally, in-depth and ongoing evaluation of the individual components of the workflow simulation is necessary to determine the value in practical skills preparation for students and impact on clinical performance. As with so many clinical skills training projects, however, the multitude of factors impacting on student performance in the clinical environment threatens to frustrate attempts to quantify the specific impact of a single intervention.

Conclusions

A series of existing and newly developed simulation applications have been integrated to successfully and efficiently simulate the workflow of a radiation therapy department in an academic environment. Student feedback suggests that this better prepares them for clinical placement, ensures that they understand the relevant processes and allows them to learn in a safe environment with minimal impact on clinical resources. Additionally, developed DICOM software tools allow for substantial time-saving while facilitating whole class teaching, comparative automated assessment and streamlined case preparation. The virtual workflow simulation supports a clinical case-study based approach to radiotherapy education. Ongoing evaluation seeks to determine the specific impact of simulation on students' clinical skills.

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Figure 1: Time taken for tasks (hours for 40 students)

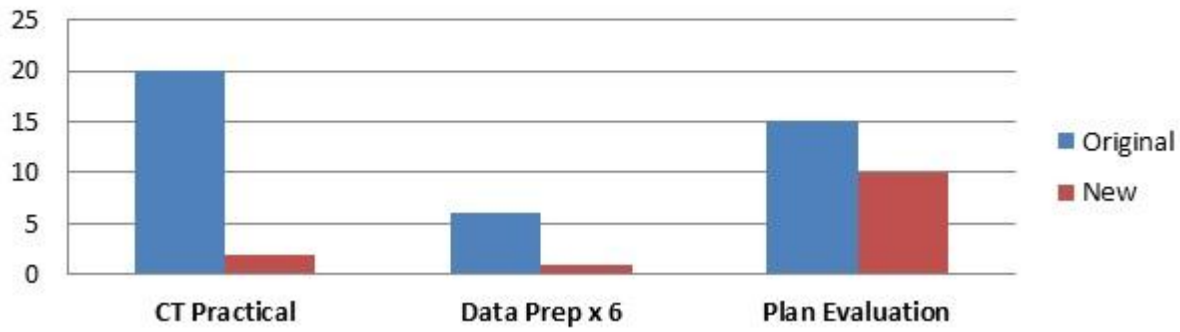

Figure 2: Cohort PTV dose comparison using TADA

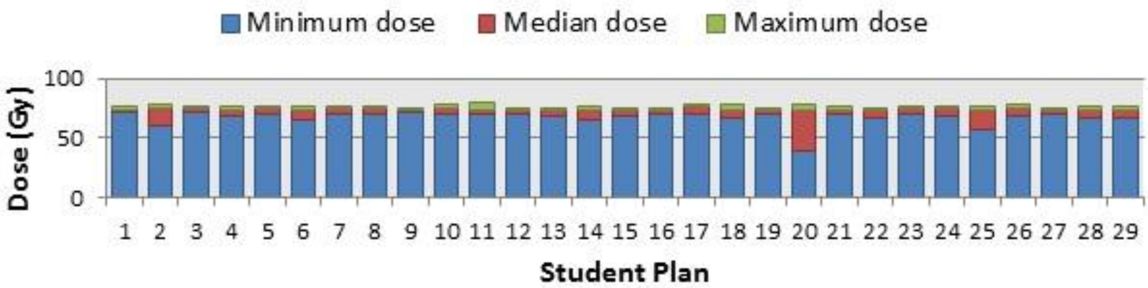

Table 1: Virtual Radiotherapy Workflow Solutions

Workflow Stage	Simulation / Solution
Patient imaging	Virtual CT-scanner
Image transfer	Batch CT Anonymisation, Copying and Labelling
Patient database preparation	Verification System
Radiotherapy planning	Treatment Planning System
Plan evaluation	Virtual Environment for Radiotherapy Training
Plan assessment	Batch Plan Comparison System
Patient setup	Patient Alignment Lasers
Room setup	Virtual Environment for Radiotherapy Training
Treatment verification	Image-Guided RT Software

Table 2: Teaching resource use and data collection

Resource	Student numbers	Evaluation method
Virtual CT Scanner	Year 1 (n=58)	Dedicated questionnaire
VERT plan evaluation	Year 2 (n=29)	Module feedback questionnaire
Lasers	Year 1 (n=58)	Module feedback questionnaire
VERT room setup	Year 1 (n=58)	Module feedback questionnaire
IGRT Software	Year 3 (n=24)	Module feedback questionnaire

Table 3: Benefits of Simulating Workflow

Theory-Practical Link
"Helped me link theory to practical to develop understanding." *"It allows you to learn practically as well as theoretically."* *"Apply theoretical knowledge into practical situations"*
Preparation
"Will know how to use machine for placement" *"Getting to have hands-on experience during semester made me more confident when attending placement and I felt I got the hang of the real life situations easier."* *"You were able to put into practice what you had learnt straight away rather than waiting for placement."* *"It was very useful to gain more knowledge on how to set up patients and the use of pendants."* *"It will help us to be more prepared towards future practicals"* *"Allow to build knowledge before placement"*
Workflow Understanding
" we could understand the relations between imaging and planning departments" *"It provided me with a better understanding of clinical treatment prior to my placement."* *"Experience in practical application before placement made me more aware of procedures."* *"It was good for placement as I was more aware of procedures."* *"Helpful to see and walk through the process"* *"Provides run through of steps in process"* *"Increasing familiarity with procedures"*
Safe Environment
"Can be useful to make mistakes" *"You can't kill the patient"* *"You can fiddle around and have a go with the buttons…without the patient being there"* *"Similar to actual set-ups without the pressure."* *"I was able to practice moving the bed without the pressure of a real patient set-up."* *"It was a good way to learn without the time constraint of a real patient scenario."*