Journal of Medical Radiation Sciences

Open Access

ORIGINAL ARTICLE

VERT, a virtual clinical environment, enhances understanding of radiation therapy planning concepts

Aidan Leong, MHealSc,[1,2] Patries Herst, PhD,[1] & Paul Kane, MHealSc (Clinical Ed)[1]

[1]Department of Radiation Therapy, University of Otago, Wellington, New Zealand
[2]Wellington Blood and Cancer Centre, Wellington, New Zealand

Keywords
Dosimetry, medical education, radiation therapy, simulation, treatment planning, VERT, virtual reality

Correspondence
Aidan Leong, Department of Radiation Therapy, University of Otago, PO Box 7343, Newtown, Wellington 6242, New Zealand.
Tel: Phone: +64 4 385 5475; Fax: +64 4 389 5725; E-mail: aidan.leong@otago.ac.nz

Received: 14 September 2017; Accepted: 2 February 2018

J Med Radiat Sci **65** (2018) 97–105.

doi: 10.1002/jmrs.272

Abstract

Introduction: The ability to understand treatment plan dosimetry and apply this understanding clinically is fundamental to the role of the radiation therapist. This study evaluates whether or not the Virtual Environment for Radiotherapy Training (VERT) contributes to teaching treatment planning concepts to a cohort of first-year radiation therapy students. **Methods:** We directly compared a custom-developed VERT teaching module with a standard teaching module with respect to the understanding of treatment planning concepts using a cross-over design. Students self-reported their understanding of specific concepts before and after delivery of the VERT and standard teaching modules and evaluated aspects of VERT as a learning experience. In addition, teaching staff participated in a semi-structured interview discussing the modules from an educational perspective. **Results:** Both the standard teaching module and VERT teaching module enhanced conceptual understanding and level of confidence in the student cohort after both teaching periods. The proportion of students reporting a perceived increase in knowledge/confidence was similar for the VERT teaching module for all but two scenarios. We propose that an integrated approach, providing a strong theoretical conceptual framework, followed by VERT to situate this framework in the (simulated) clinical environment combines the best of both teaching approaches. **Conclusion:** This study has established for the first time a clear role for a tailored VERT teaching module in teaching RT planning concepts because of its ability to visualise conceptual information within a simulated clinical environment.

Introduction

During their education, radiation therapists must acquire a comprehensive range of theoretical and practical competencies to meet the demands of safe clinical practice. In New Zealand, a radiation therapist's scope of practice includes the generation of treatment plans in addition to pre-treatment simulation and treatment delivery. Whilst this scope is not consistent globally, it is internationally recognised that an understanding of plan dosimetry, and the ability to apply this understanding clinically, is essential for all radiation therapy (RT) practitioners.[1]

The Bachelor of Radiation Therapy (BRT) offered by the University of Otago, Wellington (UOW) is New Zealand's sole RT education programme. BRT students are taught the principles and practice of treatment plan generation primarily using treatment planning software over the course of the 3 year curriculum.[2] During the first year, students are taught the fundamental concepts of dosimetry and treatment planning. Application of conceptual knowledge to the generation of basic plans is developed in the second year. The third year focuses on more complex plan generation and critical evaluation. Educating students in treatment planning concepts and practice has traditionally relied on a commercially available treatment planning system. In 2013, UOW acquired the Virtual Environment for Radiation Therapy Training (VERT) system. Utilising a 3D projection system, VERT software simulates an RT treatment room,

allows interactive operation of a virtual linear accelerator, and can visualise imported patient CT scans and treatment plans.[3–5] The basis for the development of this system was to enable students to use a linear accelerator without occupying clinical resources.[4] Numerous studies have since shown VERT to improve student psychomotor skills in operating a linear accelerator.[4,6,7] However, VERT's value in facilitating understanding of RT treatment planning concepts has only been reported anecdotally, with limited detail regarding the structure and outcomes of such teaching sessions.[6–9]

A limitation of VERT is the inability to compare and contrast multiple treatment plans simultaneously. We developed a workaround to this limitation and created a structured VERT-based teaching module that interactively compares the technical and dosimetric features of conventional and intensity modulated RT modalities. In this study we aimed to evaluate whether or not this VERT-based module enhances students' perceived understanding of treatment planning concepts. To achieve this, a custom-developed VERT teaching module was compared with a pre-existing standard treatment planning teaching module using a cross-over study design. Students self-reported their understanding and confidence with specific concepts before and after delivery of the individual teaching modules, and provided feedback on the VERT module as a learning experience. In addition, teaching staff participated in a semi-structured interview discussing the modules from an educator's perspective.

Methods

Context

The positioning and perspective of the researcher influences the approach to data collection, analysis and interpretation of qualitative methodologies in particular, and should be clarified as such.[10] At the time of the study one author (AL) was a post-graduate student who developed the VERT module while employed as a clinical radiation therapist educator in Switzerland. Two authors (PH and PK) were supervisors and academic staff employed in the department the study was conducted in. Neither were involved in the teaching of treatment planning, however, staff members who taught treatment planning in the same department were interviewed.

Study design

This study employed a mixed method cross-over design to provide a broad insight into staff and student perceptions of VERT in the teaching of treatment planning concepts. All students enrolled in the first year RT treatment planning course (RADT117: Radiation Therapy Planning Concepts I) and the two staff members who co-taught the course were invited by email to participate. The two staff members were both recruited into the study after giving informed consent. Students were provided with information on the study and made aware that completion of online questionnaires was deemed to constitute the provision of informed consent. Both teaching and evaluation were carried out during October 2013. This study received ethical approval from the University of Otago Human Ethics Committee (protocol reference D13/355).

Teaching modules

The purpose of the two teaching modules was to introduce students to the principles of intensity modulated treatment techniques in comparison to conventional 3D conformal RT (3DCRT). The students had received no formal teaching regarding intensity modulated treatment techniques prior to completing the teaching modules and had only experienced a two-week introductory clinical rotation. Both modules were co-taught by the same two teaching staff.

The standard teaching module used Eclipse treatment planning system (Varian Medical Systems, USA) to demonstrate a 3DCRT plan for a sample prostate cancer patient. Clinical, technical and dosimetric aspects of the plan were discussed with the students. Isodose levels were demonstrated primarily on transverse CT slices in relation to beam arrangement, target volume coverage and dose to organs at risk. 'Beams eye views' were used to illustrate concepts of conformity to the Planning Target Volume (PTV). Following this, examples of both Intensity Modulated Radiation Therapy (IMRT) and Volumetric Arc Therapy (VMAT) plans for the same patient were demonstrated and the same aspects discussed.

A novel VERT-based teaching module was developed specifically for this research project. A CT dataset of a prostate cancer patient with similar characteristics to that shown in the standard teaching module was used to develop a consolidated sum plan containing treatment fields and isodose volumes of three separate 3DCRT, IMRT and VMAT plans (Figures S1 and S2). This consolidated sum plan was then imported into VERT and the integrated Virtual Presenter function used to prepare and save a sequence of scenes in four sections to structure the teaching module. The first section uses sequential scenes to explore the patient's anatomy by assigning colours and transparencies to each contoured structure (Fig. 1). Rendered anatomical volumes are also shown in conjunction with cross-sectional CT anatomy to

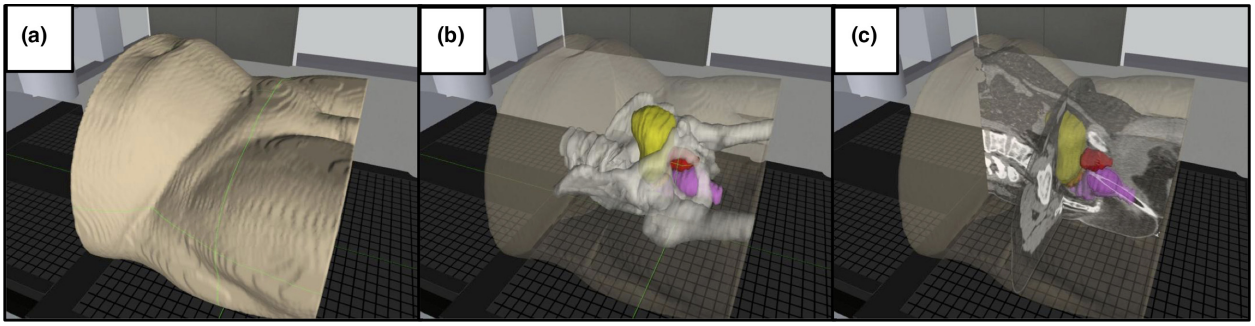

Figure 1. Section one VERT module. A clinical perspective of the patient's skin surface is first shown as well as alignment of reference marks with positioning lasers (A). Contoured internal anatomy is then shown including the PTV (red), bladder (yellow), rectum (pink) and bones (white) (B). Contoured structures are also shown in relation to 2D planar CT anatomy (C).

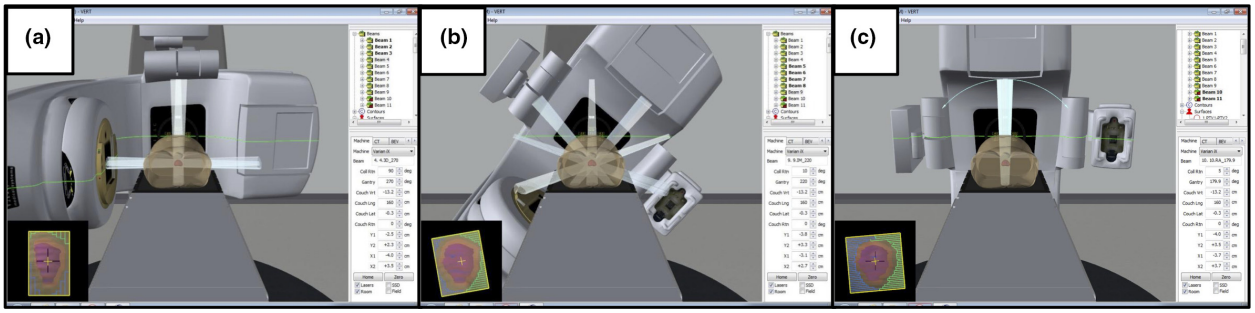

Figure 2. Section two of the VERT module. Technical aspects of three different treatment techniques are compared: 3DCRT (A), IMRT (B) and VMAT (C). Consecutive segments of IMRT fields and VMAT arcs can be individually visualised. Fields belonging to each specific plan are shown sequentially (as they would be administered in a real treatment environment), and then concurrently to emphasis the cumulative effect of their dose contribution (as is typically seen when using a treatment planning system).

reinforce the link between 3D anatomy and its representation on 2D imaging planes. The second section demonstrates technical aspects regarding the delivery of each of the three plans. Illuminated beam paths are used to illustrate the conformity of 3DCRT field aperture to the PTV contour, dynamic motion of the multi-leaf collimator for IMRT and VMAT in real-time, as well as motion of the gantry for VMAT (Fig. 2). The third section compares the dose distributions of the three plans as represented by isodose volumes generated previously within the treatment planning system (Fig. 3). The fourth module section shows imported screenshots (loaded as images within the same Virtual Presenter sequence) of plan comparison DVHs for the PTV, rectum and bladder.

Timing of the delivery and assessment of the cross-over study

As per standard practice in the BRT programme, the class was divided into two cohorts (A and B) for smaller group teaching. These subunits were used for the cross-over study (Fig. 4). During teaching period one, cohort A completed the standard teaching module and cohort B completed the VERT teaching module. Student cohorts were then crossed-over to complete the alternative teaching module 3 days later during teaching period two. Content of the modules did not change regardless of the order they were delivered in. Cross-over design also ensured that the learning opportunities for both student cohorts were not compromised.

End of year examinations were scheduled in the days immediately following teaching period two. To avoid adding additional summative assessments to an already challenging examination schedule, student evaluation was primarily limited to self-reporting of understanding and confidence.

Self-reporting by students

Likert-scale questionnaires were administered at three different time points: 3 days prior to completing the teaching modules (baseline: Q-BL); following the first teaching module (Q-PM1); and following the second

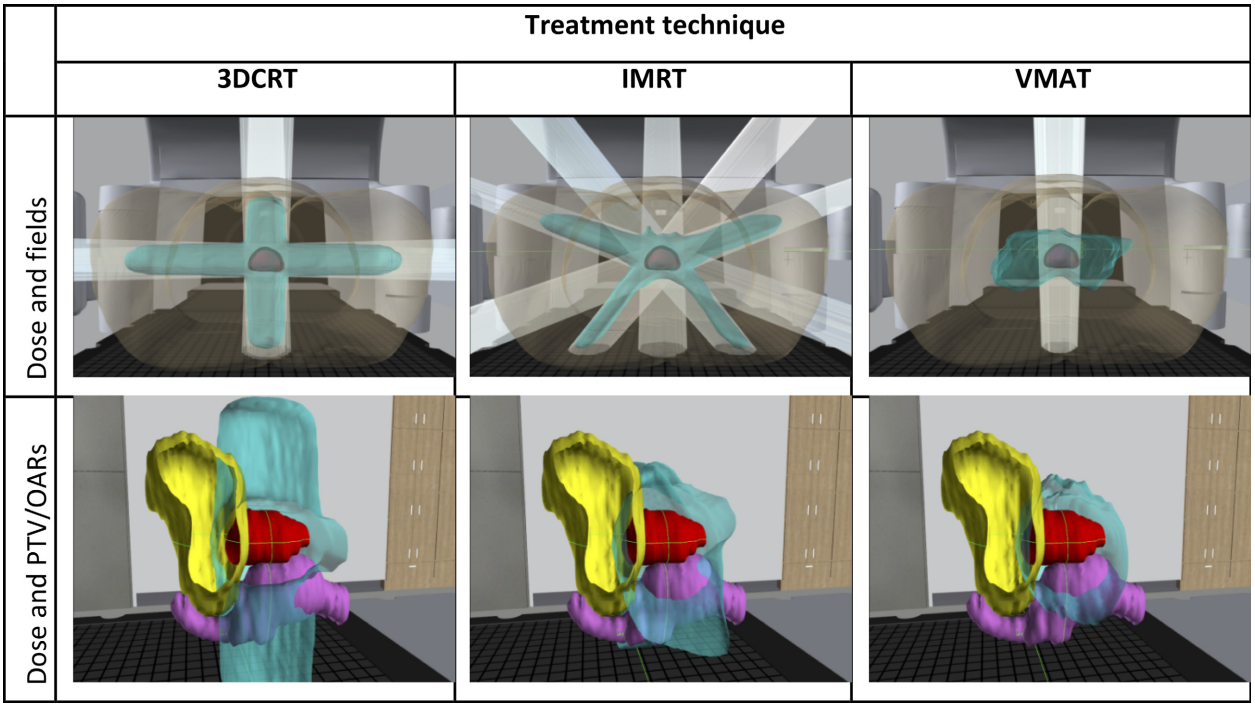

Figure 3. Section three of the VERT module. Dose distributions of the three different treatment techniques are compared. Upper row: previously generated isodose volumes corresponding with the fields of each plan are shown sequentially to demonstrate relative size and conformity to the PTV (red) (only the 25 Gy isodose volume in cyan is shown here for demonstrative purposes). Lower row: the same isodose volumes are shown in relation to the PTV (red), bladder (yellow) and rectum (pink).

teaching module (Q-PM2) (Fig. 4). Q-BL began by asking students to report which RT techniques they had seen either in planning or treatment rotations during their first-semester 2-week clinical placement. This was followed by six core questions that featured in all three questionnaires (Table 1). The first four questions asked students to self-report on their perceived understanding of 3DCRT, IMRT, VMAT and the comparative differences between the techniques. The final two questions rated their confidence at assessing DVHs and planning CT scans for the purposes of treatment planning. In an effort to control for the possibility that participants may have over- or under-estimated their understanding at baseline,[11] post-module questionnaires (Q-PM1 and Q-PM2) additionally asked participants to retrospectively report what they considered their understanding and confidence was prior to the module. Students also completed a separate questionnaire (Q-VERT) after the completion of both teaching modules rating three specific aspects of the VERT teaching module: 3D visualisation, complexity of module content and their ability to relate VERT content to their recently completed 2-week clinical rotations. Q-VERT also asked which of the teaching modules they felt provided a better understanding of dosimetry and to qualify their answer with supporting statements. Finally students were asked for feedback on how the VERT module could be improved and whether or not they would like to have further VERT-based lectures in the future.

Interview with teaching staff

The two staff members who co-taught both teaching modules took part in a single, semi-structured interview to explore their experience using the VERT teaching module and their perceptions of its effect on student understanding. The interview was conducted by an interviewer experienced in health practitioner education but independent of the Department of Radiation Therapy. The interviewer was provided with an overview of the project and given a series of suggested questions and prompts to guide the interview. The interviewer was instructed to explore unanticipated topics raised by the interviewees, provided they did not deviate significantly from the study's aims. The two lecturers were interviewed together to accommodate the interplay of reported perceptions. Both lecturers had similar levels of clinical and teaching expertise and had co-taught treatment

planning together for several years. Audio of the interview was recorded digitally and then transcribed verbatim for subsequent analysis.

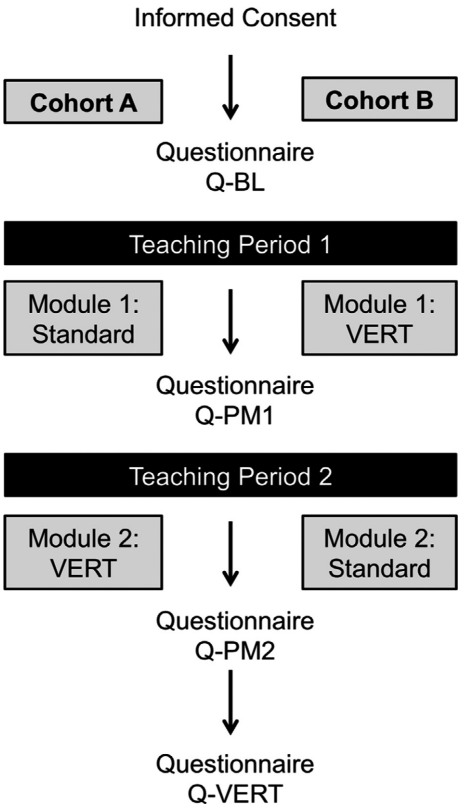

Figure 4. Study overview of teaching module delivery and student assessment. Students were divided into cohorts A and B. During teaching period one, cohorts A and B completed the standard and VERT modules respectively. The cohorts were then crossed-over to complete the alternate module during teaching period two. Questionnaires Q-BL, Q-PM1 and Q-PM2 were administered prior to the teaching period one, following teaching period one and following teaching period two respectively. Questionnaire Q-VERT was administered simultaneously with Q-PM2.

Data analysis

Questionnaires were conducted anonymously online using the website Survey Monkey. Likert-scale responses were coded and analysed using Microsoft Excel (v14.3.9; Redmond Campus, Redmond, Washington, USA). Likert scores of 1–5 were assigned to each of the six core questions used across Q-BL, Q-PM1 and Q-PM2 (Table 1).

Improvement in understanding or confidence for each individual student was determined on the basis of their pre- and post-module responses contained within both Q-PM1 and Q-PM2. Fisher's exact test (two-sided) was used to determine the statistical significance of differences in frequency of reported improvement between student cohorts for Q-PM1 and Q-PM2 (IBM SPSS Statistics for Windows v22, Armonk, New York, USA).

Qualitative data from the semi-structured interview of teaching staff were analysed using directed content analysis. Directed content analysis is a specific approach to content analysis that can be used to validate or extend conceptually a pre-existing theoretical framework or theory.[12] Briefly, excerpts of text were identified that might be relevant with regard to the VERT module and any perceived teaching and learning value. These were then coded based on the perceptions considered to underlie each excerpt. Secondary coding was performed to consolidate the identified perceptions into more consistent patterns that might have been expressed over the course of the interview. Finally, the refined codes were assembled into structured themes to give a coherent synopsis of the interview's findings. The term 'theme' is used here to describe a recurrent phenomenon of the transcript dataset.[13] Transcript analysis was carried out by AL and reviewed by PH and PK.[14]

Likert-response data from Q-VERT were coded and analysed as for Q-BL. Text-based responses from Q-

Table 1. Likert scales for the six core questions.

	Likert-scale				
Core questions	1	2	3	4	5
Q1. How would you rate your understanding of 3DCRT?	Very Limited	Limited	OK	Good	Excellent
Q2. How would you rate your understanding of IMRT?	Very Limited	Limited	OK	Good	Excellent
Q3. How would you rate your understanding of VMAT?	Very Limited	Limited	OK	Good	Excellent
Q4. How would you rate your understanding of the comparative benefits/limitations of each technique?	Very Limited	Limited	OK	Good	Excellent
Q5. How confident are you using dose volume histograms (DVH) to assess target volume coverage and dose to organs at risk?	Not at all	Hardly	Somewhat	Very	Extremely
Q6. How confident are you recommending one treatment over another from looking only at a planning CT and the contoured target volume/organs at risk?	Not at all	Hardly	Somewhat	Very	Extremely

VERT were analysed using a modified form of directed content analysis. Successive coding was not required as the data were generated from more prescriptive questions. Responses for each question were grouped together and frequently expressed perceptions were synthesised to form a summary reflective of the entire cohort's response.

Results

Of a total first year group of 29 students, 20 students gave consent and took part in Q-BL (69% response rate). Within student cohort A, seven students completed Q-PM1 and Q-PM2 following the standard and VERT teaching module respectively. Within student cohort B, eight students completed Q-PM1 following the VERT teaching module, whereas seven students completed Q-PM2 following the standard teaching module (Fig. 4).

Students' experience and perceived understanding prior to teaching

The majority of students reported seeing 3DCRT both on treatment and in planning (85% and 70% respectively) during their mid-year clinical rotations. IMRT was also widely seen in treatment delivery (80%), though fewer participants had seen its use during planning (20%). VMAT was the least familiar treatment technique with only 5% of students having seen its use in planning, and 50% in treatment delivery. Perceived understanding of 3DCRT was ranked highest with two-thirds of students reporting an understanding they ranked as 'OK' or better. Perceived understanding of both modulated treatment techniques was more limited with 80% and 85% of students reporting limited to very limited understanding of IMRT and VMAT respectively. None of the students perceived their understanding of VMAT to be better than 'OK'. Student understanding of the comparative benefits and limitations of the different treatment techniques was low, 65% reporting they perceived their understanding as limited to very limited.

Students' improvement in perceived understanding

To determine whether or not the VERT teaching module increased students' perceived understanding and confidence in RT planning concepts, we calculated and compared the frequency of students who reported any increase in understanding/confidence after completion of each teaching module for both teaching periods (Table 2). Results from teaching period one showed both modules improved students' perceived understanding of RT planning concepts to a similar extent. Improvements in understanding were reported more frequently in IMRT, VMAT and treatment technique comparison, relative to 3DCRT. Student's confidence in DVH assessment improved more frequently on completion of the VERT module (38%) compared to the standard module within teaching period one (38% and 14% respectively), however, this difference was not statistically significant. Within the same teaching period, the standard module improved students' perceived confidence at assessing planning CT scan more frequently than the VERT module (100% and 38%, respectively, $P = 0.026$, Fisher's exact test).

Table 2. Percentage of students reporting an improvement in perceived understanding or confidence following the two teaching periods.

	Teaching period 1		Teaching period 2	
	VERT module	Standard module	VERT module	Standard module
Improvement in perceived understanding				
3DCRT	63%	57%	71%	43%
IMRT	100%	86%	100%	86%
VMAT	100%	100%	71%	86%
Comparison	88%	86%	86%	86%
Improvement in perceived confidence				
DVH assessment	38%	14%	29%	14%
CT assessment	38%*	100%*	57%	57%

*$P < 0.05$ (two-sided Fisher's exact test for significance).

Results from teaching period two showed students' perceived understanding to continue to improve after either teaching module to a similar extent. Perceived understanding of VMAT was seen to improve less frequently during teaching period two relative to teaching period one. The VERT module continued to improve students' perceived confidence at DVH assessment more frequently than the standard module within teaching period two, though again this difference was not statistically significant. Of note, students' perceived confidence at assessing planning CT scans improved identically from either teaching module after teaching period two.

Students' perceptions of specific aspects of the VERT teaching module

Complete student responses to Q-VERT are shown in Table 3. Students largely found the 3D aspect of the VERT module beneficial (71%) though one participant did report it to be distracting. More than half of the participants (57%) found the content of the VERT module well-balanced, with a further 36% reporting it to be somewhat simple and 7% somewhat complex.

Table 3. Q-VERT Likert scales and responses.

Scale	Very beneficial	Beneficial	Neutral	Unnecessary	Unnecessary and distracting
Q1: How did you find the 3D aspect of the VERT module? (In comparison to the same module in 2D without glasses).					
Response	21%	50%	14%	7%	7%
Q2: How did you find the depth of the VERT module's content?					
Scale	Too simple	Somewhat simple	Well-balanced	Somewhat complex	Too complex
Response	0%	36%	57%	7%	0%
Q3: How well were you able to relate the treatment examples shown within the VERT module to your experiences in the clinical environment?					
Scale	Very well	Well	Moderately	Somewhat	Not at all
Response	7%	36%	21%	36%	0%
Q4: Which of the teaching modules do you feel gave you a better understanding of the dosimetry concepts addressed?					
Scale	VERT module alone	Mostly the VERT module with some of the standard module	Both equally	Mostly the standard module with some of the VERT module	Standard module alone
Response	7%	50%	36%	0%	7%
Q5: Would you be interested in further sessions utilising the VERT system?					
Scale	Yes	No			
Response	93%	7%			

Sixty-four percent of students found that the clinical examples used within the VERT module could be related to their limited experience of clinical practice 'moderately' to 'very well'. When asked about their preferred teaching module 86% of students expressed a preference for a combination of both, with 36% preferring an equal combination, and 50% preferring a combination weighted more heavily towards VERT content. All but one student (93%) indicated an interest in further VERT-based lectures.

When asked to explain their answers to Q-VERT questions four and five (Table 3), students commented on how the VERT teaching module allowed them to visualise technical aspects of treatment techniques in a simulated clinical context. The standard module was valued for the core information it provided, with VERT offering a more practical and clinically applied perspective on the content. Additionally, the standard module was valued for its basis within a treatment planning system familiar to students that they would continue to use in both educational and clinical contexts to generate treatment plans. Students expressed an interest in having more frequent and longer sessions with VERT.

> *'VERT is helpful to see how techniques/theories are applied clinically which helps aids in my overall understanding' (student #6)*

> *'I feel like the different modules complemented one another. Neither was the best but it was best to have both as they developed on one another' (student #5)*

> *'VERT was very helpful, especially with visualising the dose. However, the standard one helped cement the content from VERT as I am used to working on Eclipse [treatment planning system]. . .' (student #7)*

Teaching staff's perceptions of the VERT teaching module

Analysis of the semi-structured interview with the two lecturers who taught both the VERT and standard teaching modules revealed their enthusiasm for the VERT module and its implications for their approach to teaching RT planning. The VERT module offered them a novel educational tool that they had been unable to generate themselves.

> *'. . .it is exactly how we attempted to teach before we had VERT, but quite unsuccessfully because of the limitations of the equipment we had. . .' (participant #1)*

Both lecturers highly valued the ability of VERT to visualise the conceptual content of the module within a simulated clinical environment. While the content itself was not novel, they felt that VERT allowed them to connect different technical levels of planning information (such as contoured structures and a planning CT scan) with the reality of the treatment room. In addition, VERT could demonstrate the motion of linear accelerator components for the different treatment techniques.

> *'. . .[the VERT module] is a very graphic. . .[and]. . .rich way to be able to show the information that situates [sic] in a very real environment for the students' (participant #1).*

> *'. . .the content wasn't new, it was just the [. . ..] delivery' (participant #2)*

Both lecturers felt that the students were much more actively engaged in discussions and questioning during the VERT module sessions. This increased interaction resulted in students themselves extending the scope of the lesson to cover additional material not originally planned by staff.

> *'...it [the VERT module] did generate a few more discussions than just in the basic class...' (participant #1)*

> *'...you could see that they were a lot more engaged [than during the standard module]'. (participant #2)*

With respect to the sequence of module delivery, the lecturers thought that students benefited from receiving the basic information first in the form of the standard teaching module and then gain further insight from the perspective offered by the VERT teaching module.

> *'...the group who'd had the [...] normal teaching first and then had VERT, [...] a few lights went on, and we had a few more questions...' (participant #1)*

The lecturers also saw merit in dividing the current module into separate conceptual sections that could be introduced gradually throughout the year. They also expressed a desire to continue to develop and implement similarly styled VERT modules in the future across a broader range of RT planning topics.

Discussion

In this study we evaluated whether or not a virtual clinical environment could enhance the teaching of treatment planning concepts to a cohort of first year RT students. Over the last decade, simulating aspects of the clinical environment has seen increased use in medical education.[15] A recent systematic review evaluating the outcome of using technology enhanced simulation for health professional education identified 609 relevant studies.[16] Simulation was shown to be of significant benefit to domains relating to student knowledge, procedural skills and behaviours relating to patient care. A consistent limitation across the studies recognised by the authors was a lack of control groups against which simulation was evaluated. Rosen[17] similarly acknowledged validation as a key barrier to the progressive implementation of simulation within medical education. In order to directly compare a custom-designed VERT teaching module with a standard teaching module, using a treatment planning system, we used a cross-over study design, allowing all students to experience both modules sequentially.

RT training programs worldwide have been utilising the VERT system increasingly since its inception in 2007.[4] The system's value in training RT students to position a linear accelerator has been well established across several studies.[4,6,7] Beyond this role, Nisbet and Matthews[8] described the educational theory underpinning a VERT-based clinical workbook which included review of plan dosimetry. The authors note that VERT was used to compare the dose distributions of different techniques for the same treatment site, though limited detail on the content of these sessions is provided. Further anecdotal reports[6,7] have suggested a role for VERT in the teaching of RT planning concepts, but similarly without evaluation either alone or in comparison with pre-existing teaching methods.

Several limitations should, however, be recognised when interpreting the results of this study. The CT datasets and plans used within the standard and VERT modules were similar but not identical as the VERT module and the standard teaching modules were developed in different countries. Furthermore, staff may have altered their delivery of either teaching module slightly between teaching periods one and two. This is an unavoidable limitation of the cross-over study design and could potentially have influenced students' learning experiences and subsequent questionnaire responses.

Timing of the study precluded the use of formal pre- and post-module quantitative summative assessments because of the intense examination schedule at the end of the students' first academic year. Although this could be considered a limitation of the study, asking students to self-report their perceived understanding and confidence in various treatment planning concepts gave a useful initial insight into the merits of VERT as a teaching tool in this context.

Both the standard teaching module and VERT teaching module enhanced perceived conceptual understanding and perceived level of confidence in the student cohort after both teaching periods. The proportion of students reporting a perceived increase in knowledge/confidence was similar after either teaching module for all but one scenario. Notably, the proportion of students reporting an increase in perceived confidence in assessing a planning CT was significantly higher after completing the standard teaching module compared to the VERT module within teaching period one. Although this difference was not replicated during teaching period two, this may nonetheless represent a limitation of the VERT system relating to the teaching of actual treatment planning practice.

Students and staff both commented that a combination of both teaching modules would enhance students' conceptual knowledge and application of concepts. This is further evidenced by the continued improvement in students' perceived understanding and confidence from either teaching module within teaching period two, suggesting added value from the sequential delivery of both modules. Neither sequence was conclusively shown to be superior to the other. However, based on staff and student comments we propose that providing a strong conceptual framework using a treatment planning system, followed by VERT to situate this framework in the (simulated) clinical environment may offer the best of both teaching approaches.

Facilitating the application of conceptual knowledge to the clinical environment is a core focus of the BRT curriculum. This is particularly relevant in the periods

leading to students' 6-month clinical placements during the first and second semester of their second and third years, respectively. A growing body of educational research supports integrated medical curricula, whereby content is horizontally integrated across traditionally distinct subject streams, as well as vertically integrated from basic knowledge to clinical application.[18,19] The use of customised VERT modules such as that described in this study offers numerous opportunities to integrate a diverse scope of RT-related concepts (e.g. anatomy, treatment technology, dosimetry, radiobiology) within a virtual environment that facilitates clinical application.

In conclusion, this project has established for the first time a clear role for a custom-developed VERT teaching module in teaching RT planning concepts because of its ability to visualise conceptual information within a (simulated) clinical environment. Further investigation is necessary to validate these findings quantitatively with the use of pre- and post-teaching summative assessment of students.

Acknowledgements

The authors acknowledge the contributions of the students and lecturers who participated in this study. Components of the VERT teaching module were developed with support of the University Hospital Zurich, Switzerland. This study was supported by the Department of Radiation Therapy, University of Otago, Wellington, New Zealand.

Conflict of Interest

The author declares no conflict of interest.

References

1. Coffey MA, Mullaney L, Bojen A, Vaandering A, Vandevelde G. Recommended ESTRO Core Curriculum for RTTs (Radiation TherapisTs) [Internet], 3rd edn. ESTRO; 2011 [cited 2015 Aug 14]. Available from: https://www.estro.org/binaries/content/assets/estro/school/european-curricula/recommended_core_curriculum-radiationtherapists—3rd-edition-2011.pdf.
2. University of Otago. Bachelor of Radiation Therapy [Internet]; 2017 [citied 2017 Sept 1]. Available from: http://www.otago.ac.nz/courses/qualifications/brt.html.
3. Phillips R, Ward JW, Beavis AW. Immersive visualization training of radiotherapy treatment. *Stud Health Technol Inform* 2005; **111**: 390–6.
4. Bridge P, Appleyard RM, Ward JW, Philips R, Beavis AW. The development and evaluation of a virtual radiotherapy treatment machine using an immersive visualisation environment. *Comput Educ* 2007; **49**: 481–94.
5. Boejen A, Grau C. Virtual reality in radiation therapy training. *Surg Oncol* 2011; **20**: 185–8.
6. Society and College of Radiographers. VERT Final Project Report [Internet]; 2010 [cited 2015 Aug 14]. Available from https://www.sor.org/learning/document-library/vert-final-project-report.
7. Phillips R, Ward JW, Page L, et al. Virtual reality training for radiotherapy becomes a reality. *Stud Health Technol Inform* 2008; **132**: 366–71.
8. Nisbet H, Matthews S. The educational theory underpinning a clinical workbook for VERT. *Radiography* 2011; **17**: 72–5.
9. Bridge P, Crowe SB, Gibson G, Ellemor NJ, Hargrave C, Carmichael M. A virtual radiation therapy workflow training simulation. *Radiography* 2016; **22**: e59–63.
10. Koch T, Harrington A. Reconceptualizing rigour: The case for reflexivity. *J Adv Nurs* 1998; **28**: 882–90.
11. Pratt CC, McGuigan WM, Katzev AR. Measuring program outcomes: Using retrospective pretest methodology. *Am J Eval* 2000; **21**: 341–9.
12. Hsieh H-F, Shannon SE. Three approaches to qualitative content analysis. *Qual Health Res* 2005; **15**: 1277–88.
13. DeSantis L, Ugarriza DN. The concept of theme as used in qualitative nursing research. *West J Nurs Res* 2000; **22**: 351–72.
14. Lincoln YS, Guba EG. But is it rigorous? Trustworthiness and authenticity in naturalistic evaluation. *New Dir Eval* 1986; **1986**: 73–84.
15. Bradley P. The history of simulation in medical education and possible future directions. *Med Educ* 2006; **40**: 254–62.
16. Cook DA, Hatala R, Brydges R, et al. Technology-enhanced simulation for health professions education. *JAMA* 2011; **306**: 8–15.
17. Rosen KR. The history of medical simulation. *J Crit Care* 2008; **23**: 157–66.
18. Jones R, Higgs R, de Angelis C, Prideaux D. Changing face of medical curricula. *Lancet* 2001; **357**: 699–703.
19. Dahle LO, Brynhildsen J, Fallsberg MB, Rundquist I, Hammar M. Pros and cons of vertical integration between clinical medicine and basic science within a problem-based undergraduate medical curriculum: Examples and experiences from Linköping, Sweden. *Med Teach* 2002; **24**: 280–5.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Figure S1. Field arrangements and dose distributions of the three different treatment techniques compared: 3DCRT (A), IMRT (B) and VMAT (C).
Figure S2. Consolidated 'sum plan' showing the fusion of 3DCRT (fields 1–4), IMRT (fields 5–9) and VMAT (fields 10–11) plans to produce a single plan for export into VERT.