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Innovation in education: computer simulation in physics training

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Abstract. Interest in the application of Computer Simulation within Medical training continues to grow and the use of the VERT (Virtual Environment for Radiotherapy Training) system in radiotherapy training equally so. Herein we explore the use of the VERT system to understand, illustrate and experience the process required to calibrate an ion chamber and use it to obtain an accurate output measurement on a high energy Linac. The VERT system provides a detailed and accurate simulation of conventional Linacs and has a variety of physics activities that mirror the tasks medical physicists are required to become familiar with during their training. One such activity has been implemented to follow the steps defined by the IAEA TRS398 protocol. All activities on the virtual Linac can be undertaken with deliberate errors having been introduced to explore their consequences. The system was used to make the necessary ‘measurements’ to determine the various calibration factors required to correct the raw electrometer reading for ion recombination, polarity, temperature/pressure. Likewise, the Quality Index of the Linac’s 6MV beam was determined to enable the correction of the Absorbed Dose to Water factor measured in the reference Quality. The VERT system provides a simulation environment for training and enhancing the trainees understanding of radiotherapy concepts and practices. Dosimetry practice can be experienced and explored in the classroom during standard working hours rather than waiting until a clinical Linac is available. Random and systematic errors can be introduced, however, the virtual machine can be used without risk of leaving it in a mis-calibrated or unsafe condition.

1. Introduction
We have developed an education tool for Radiotherapy that uses virtual reality to provide a computer simulation environment that enables students and trainees to gain experiential learning or practical experience in the classroom. Over the ten years that it has been commercially available the use of the VERT system (Virtual Environment for Radiotherapy Training) has become established in 28 countries with some 140 installations, in Universities, Community Colleges, Hospitals and Standards Labs; eight of which are primarily used for Physics training programmes.

The VERT system has previously been described elsewhere [1-3] as has its origins [4, 5]. In summary, it was developed as a training tool for radiographers with a philosophy to bring an interactive, ‘fully’ functional, Linac into the classroom. Whereas the virtual Linac has full articulation and is faithfully and accurately modelled to resemble its real-world counterpart, it does not (of course) produce ionizing radiation. The immediate benefit to trainee and trainer being that the learning environment is
therefore safe, without electrical, radiation, mechanical crush risk and the virtual patients cannot be harmed in any manner, nor can the career of the trainee! The similarity to the flight simulators used by trainee pilots and astronauts has led to the VERT system being described as ‘the flight simulator for radiotherapy’.

In recent years there has been an increasing interest in the use of computer simulation training for medical physics applications. The concept and rationale being the same as for radiographer or therapist training, that practical experience can be gained, safely, at any time of the day without having to wait for a clinical unit to be taken out of clinical service. A common theme in the use of virtual reality is that we can learn from the experience of making mistakes. Therefore, not only can procedures and scenarios be repeatedly explored without delaying the return to use of clinical equipment, it can be done without impacting the integrity of its safety.

To explore this opportunity, the ‘physics tools’ in VERT have been expanded in order to make them more applicable to a wider audience and to add functionality. Previous implementations have been reported [6-8], however here we present a new feature aimed at expanding the understanding of dosimetric concepts and to broaden the systems applicability.

2. Materials

A variety of conventional Linacs produced by the two major manufacturers are available in VERT. In addition a Varian ProBeam Proton therapy system has recently been introduced and plans exist for similar systems from other manufacturers. They are controlled using the authentic hand control pendants or simple menu controls. Virtual patients are created using information taken from DICOM descriptions of treatment plans which can be sourced from any commercial treatment planning system and the radiation characteristics of the Linac are modelled via comprehensive beam models. All aspects of the treatment delivery and image verification are simulated within the system allowing trainees to explore concepts, techniques and related processes.

A Physics module is available that has previously been reported [8] which was essentially designed to make some of the ‘physics concepts’ more accessible to ‘other’ staff groups. However, one of the activities therein allowed the process of calibrating an ion chamber against a reference class chamber to be simulated was implemented. This was designed with the IPEM code of practice [9] in mind. To make this activity more universal a workflow that follows the IAEA TRS398 [10] has since been introduced.

The IAEA TRS398 activity guides the user through using the published protocol by simulation of the relevant equipment and process. The simulation provides a scanning water phantom with which to make the necessary measurements, see Figure 1. The system has a touchscreen interface that hosts a worksheet which is used to work through the process in conjunction with the published protocol. The worksheet also contains a virtual electrometer which is used to measure output for a configurable bias voltage.

The philosophy behind the simulation is that the protocol can be followed and measurements can be made using VERT as if using a clinical system. The trainee is required to understand the protocol which can be achieved through self-study or via traditional didactic class teaching. The VERT system can then be used, again individually or as a demonstration by the instructor, to follow the process of taking appropriate measurements and calculating component correction factors of the chamber calibration factor, in a manner that mirrors the actual workflow. The true benefit is gained by the trainee using the system themselves whilst systematically following the protocol.

As required by the protocol, measurements can be made for the appropriate field size with the chamber at the appropriate depth of water and distance from the target, and with selection of an appropriate bias voltage for the chamber. Once the chamber has set up readings can be captured and recorded via interaction with a worksheet Fig 2. Repeated acquisitions yield values that demonstrate random measurement uncertainty, the magnitude of which can be configured. The temperature and pressure within the virtual treatment room is varied each time the software is used to ensure the trainee is required to calculate and correctly apply the associated correction factors.
3. User Case scenario: TRS398

In this section we illustrate the use of the simulation. Fig 2 shows the worksheet associated with the TRS398 ion chamber calibration activity which is presented as a touchscreen interface. On the left side of the panel we note that it displays the beam quality, field size, depth of chamber and SSD. The measurement configuration and conditions may be altered by the user; the Linac settings may be altered using the Pendant or via menus in the software GUI and the depth of the chamber using a menu in the GUI. When the ‘Measure’ button is depressed a reading commensurate to the current configuration, number of monitor units delivered and beam quality selected, is captured. The value produced is a function of the ‘assigned’ chamber calibration factor, the expected dose at the measurement point, the defined output (systematic) uncertainty and the measurement (random) uncertainty.
Figure 2. The worksheet associated with the TRS398 activity.

Assuming the trainee is familiar with the TRS398 protocol, the worksheet is intended to make the workflow of the activity / exercise very intuitive. The layout of the righthand side of the worksheet groups measurement steps and factor generation/look up and uses nomenclature from the protocol. The equations are presented as a reminder for which factors are used to correct the raw electrometer measurement and then how the calibration factor is converted to the clinical quality and deployed.

| Measurements                        |                                                                 |
|-------------------------------------|------------------------------------------------------------------|
| M_e                                 | Electrometer reading                                             |
| M_{20cm} / M_{10cm}                 | Reading at (20cm/ 10cm) depth                                    |
| TPR_{20/10}                         | Tissue Phantom Ratio for 20cm to 20 cm depth                      |
| |M_1| / |M_2|                                  | Reading with negative/positive polarising voltage                |
| V_1 / V_2                           | Polarising Voltage (1/2)                                         |
| **Individual (correction) factors** |                                                                 |
| k_{Q,o}                             | Quality correction factor                                        |
| k_{pol}                             | Polarity correction factor                                       |
| k_s                                 | Ion recombination factor                                         |
| k_{T,P}                             | Pressure and Temperature correction factor                       |
| k_e                                 | Electrometer factor                                               |
| N_{D,w,Q}                           | Absorbed dose to water factor calibrated in reference Quality     |
| **Calculation terms**               |                                                                 |
| M_0                                 | Corrected electrometer reading made in Quality Q                 |
| D_{w,Q}                             | Calibrated dose to water for Quality Q                           |

Table 1. Summary of the nomenclature used in the worksheet.
Where individual factors are assumed \((k_e\text{ and } N_{D(w,Q)})\) then default values are assigned in the simulation software. Whereas these are ‘blind’ to the trainee, the system administrator is able to update the default values should they have preferred ‘local’ values. When the corresponding button is depressed the value box to its right is populated by the assigned value.

Where individual factors are taken from the protocol \((k_{Q,Q_o})\), depressing the appropriate ‘factor’ button populates the value box with the value looked up from the protocol for an appropriate Chamber type. This value is a function of the TPR\(_{20/10}\) ratio which is calculated when the button is depressed.

Where individual factors are calculated \((k_{pol}, k_s, k_{T,P})\) then depressing the appropriate factor button will populate the associated value box with a value derived using the appropriate formulae (and any required parameters) from the TRS398 protocol.

Alternatively, for all classes of individual factors, the user can type values into the ‘value box’ to the right of each factor button and those values will be used in the subsequent calculation of dose.

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**Figure 3.** Worked example, having made all appropriate measurements and created the individual correction factors. The Dose at 5 cm in water for a 10 x 10 field for a measurement of 95 cm SSD is calculated from the uncorrected electrometer reading and the various factors. Note: a variety of information was captured by the user for evidence to be submitted for their training records.

Once a measurement is made and captured it is transferred to the ‘work area’ on the righthand side of the worksheet. For example, the measurement made under the conditions illustrated in figure 2 may be used in the calculation of the polarity factor. By depressing the button labelled \(|M -|\) the current reading would be used to populate the measurement value box to the right of that button. Next, the polarising voltage would be reset to +250V, the measurement captured and that reading be transferred to the appropriate field by depressing the button labelled \(|M +|\). The measurement reading obtained for the ‘reversed’ polarity bias voltage is reverse engineered using the default polarity correction factor defined in the user preferences of the system. Therefore, when the \(k_{pol}\) button is depressed, the correct value is recovered from a ‘forward’ calculation.

Figure 3 illustrates the completed activity. The various individual correction factors were generated as per the TRS398 protocol document. The Linac used in the simulation was calibrated to give 1 Gy per
100 MU at 5cm depth at isocentre for a 10 x 10 field. The uncorrected chamber/ electrometer reading was acquired under these conditions. This value was transferred to the ‘uncorrected reading’ box in the work area on the righthand side by depressing the button labelled M0. When the button labelled ‘Calculate’ is depressed the currently defined correction factors are applied to that value as described by the appropriate formulae in the protocol and reproduced on the worksheet to produce a corrected reading. In the example shown in figure 3 we see the expected (calibration) dose value is recovered.

The pencil icons on the right of the two columns capture pertinent information when depressed. This information is shown in the ‘scratch pad’ box on the lower right of the screen (as seen in fig 3) and can be ‘copy/pasted’ into word pad or similar to make a record of the trainee’s experience.

4. Discussion
There is a common theme of discussion across all professions that training and education is moving, or has moved, away from the ‘talk and chalk’ or purely didactic methods of the previous centuries. Computer simulation technologies have been adopted in various medical fields; within radiotherapy it is beginning to become a standard in Radiographer/ Therapist/ RTT/ Technologists training, along with emerging published evidence [11-13]. The VERT system has been an enabler of this approach and is becoming used for Physics training [14-16] of Radiographers, Dosimetrist and Physicists. The VERT system has proven useful for the Group learning or inverted classroom approaches that are becoming more common in contemporary education.

In this manuscript an activity within VERT to simulate the process for calibrating an ion chamber and subsequently making a calibrated measurement of the output of a Linac, following the IAEA TRS398 protocol is described. It has been kept very simple in order to demonstrate how the VERT system is used as a platform to illustrate or practice skills and methodologies in the safe and relaxed classroom environment. Computer simulation platforms are intended as additional tools to enhance the educational experience. For the trainee they are safe in the knowledge that, no matter how long they take, they are not holding up the return to service of any equipment nor could it be handed over incorrectly calibrated. For the trainer, they can concentrate on passing on their knowledge and experience without any distractions [17] that could lead to failing to catch an incorrectly calibrated piece of equipment [18], or by ensuring this is not the case, failing to provide a high quality of training.

A key benefit that computer simulation brings to training is the ability to explore errors and process failures in a safe and instructive environment [5]. In the training of Physicists or Physics technicians this concept can be expanded to fault finding [8]. The VERT system has a facility (known as Virtual Presenter) for the trainer to set up scenarios for the trainee to explore and therefore if fault conditions are incorporated then failed QC tests can be illustrated and the appropriate course of action followed to rectify the experienced problem. Anecdotally, it might take several years of traditional post-training clinical practice to experience all the typical mis-calibration errors that a medical physicist is expected to know how to identify or ‘capture’. Computer simulation allows them to be demonstrated or experienced during the training phase.

This scenario setting facility can be taken one step further and used for competency assessment or sign off of the trainee. Since the scenario can be reset countless times without restriction or deviation, every trainee in every training cohort can be given the exact same test. Clearly such an approach offers benefit from an educational ethics perspective. Furthermore, if the note/ record generation is used (as illustrated in figure 3) then evidence can be collected and provided to demonstrate competency.

5. Conclusion
The VERT system is a computer simulation training system that is offered commercially and at the time of writing is used at approximately 140 installations in 28 countries across the world. It was initially designed and promoted as a Radiographer training tool, however it has developed more broadly and has modules designed to assist ‘physics’ training. The physics tools enable activities such as calibration of ion chambers and measurement of Linac output to be introduced to trainees in the classroom environment with a blended learning approach that includes discussion of process and ‘hands on’
experiential learning. The physics activities in the VERT system are not limited to those discussed here and the scope of this computer simulation training environment continues to be developed.

6. References

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