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Image and isocentre management in the paperless age: an automated decision making model

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Abstract *Purpose:* The introduction of sophisticated imaging and image analysis tools into daily radiotherapy has made it feasible to undertake image guided radiation therapy (IGRT) on a daily basis. The aim of this paper is to outline that the introduction of a paperless automated decision making model to assess systematic trends in field placement can enhance the efficiency of a treating radiotherapy team. *Methods:* Automated custom reports were written using Infomaker (Sybase, Dublin, California, USA) to integrate with the ARIA (Varian, Palo Alto, California, USA) patient information system. This allowed automated systematic trend identification in treatment field set-up. The efficiency and accuracy of an automated approach was then compared to manual field placement analysis and a statistical model (Newcastle model). *Results:* The automated decision making model has been shown to reduce the amount of time taken to analyse images and systematic trend analysis, when compared to manual methods, significantly ($P < 0.001$). In addition to the enhanced efficiency there is no trade off in accuracy with the automated decision making model. *Discussion:* An automated approach to trend analysis allows the treating radiotherapy team to manage field placement in a highly efficient manner, which is paramount in the era of increased image data. A paperless approach to image analysis and field placement trend analysis places the responsibility of accurate field placement on the radiation therapist and represents a vital link in the management of an IGRT protocol. *Conclusion:* In the era of IGRT with increased imaging data, efficient methods must be found to analyse and manage systematic trends. An automated decision making model represents an increase in efficiency with no trade off in accuracy.

Keywords: image guided radiation therapy (IGRT), paperless, set-up error, trend analysis.

Introduction

With the advent of sophisticated image guided radiation therapy (IGRT) hardware and software it is now feasible to undertake IGRT for every patient undergoing radiotherapy for every treatment fraction. The introduction of online verification has introduced new levels of accuracy and precision to treatment delivery.[1,2,3,4,5,6] With appropriate training, equipment and highly sophisticated automated tools, radiation therapy teams can be assured of field placement accuracy on a daily basis, with management of both systematic and random set-up error.[7,8,9,10,11] This level of online verification, however, leads to enormous amounts of image data that must be analysed in both the online and offline environments. Since the clinical inception of Radiation Oncology Queensland (ROQ) in May 2007, over 25,000 MV or kV verification images have been taken. This equates to roughly 9.5 gigabytes (GB) of data. In order to maintain management of such an amount of data, treating radiotherapy teams must have the capacity to efficiently manage images and isocentre positions without trading treatment accuracy.

In order to maintain efficiency of an IGRT protocol, the issue of systematic isocentre trends and correction must be addressed. It is detrimental to workflow to continually set-up to an original isocentre which has experienced a systematic shift, and thus would require a move each day. An online intervention protocol ensures accuracy and effectively manages both components of set-up error, however, an understanding of systematic moves is required to ensure treatment efficiency. An essential part of any IGRT program is the capacity to identify, analyse and manage systematic trends in such a way that it can be easily carried out by radiation therapists.[7] This is of tremendous importance, with daily IGRT providing endless image data which needs to be assessed to ensure treatment accuracy. In order for a treating radiation therapy team to deal with this enormous volume of image data, electronic automated solutions must be found.

ROQ operates in a paperless environment utilising the Varian ARIA™ (Palo Alto, California) patient information system. One of the major challenges of a paperless radiation oncology setting is how to manage both images and isocentric moves. A scientific approach is required to monitor and address potential systematic isocentre moves, and present them in a straightforward common-sense approach. Importantly, all of this needs to be done utilising the one patient information database in a truly digital setting.

Incorporating this level of sophistication into image analysis has been proposed by several different methods.[12,13,14,15,16,17,18] These methods include the Amsterdam or Quebec approaches.[16,17] However this has often entailed complex statistical analysis incorporating prior knowledge, and as such cannot be introduced into the daily imaging regime of most departments.[6,17,19,20] This prior knowledge includes individual machine characteristics, characteristics of particular set-up solutions and so on. In other words the processes are too complex or cumbersome to become part of a daily imaging protocol, they are not real time and rely on complex post-treatment statistical analysis. In order to become part of a daily imaging regime a simpler solution must be found. It is for

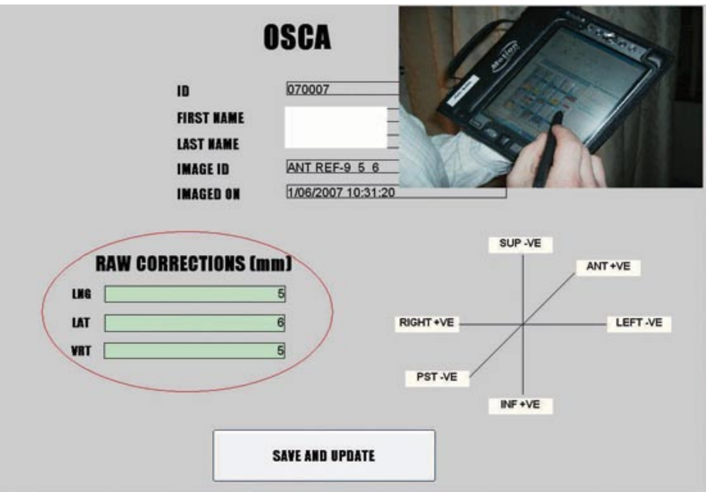

Figure 1: Online recording of raw match data.

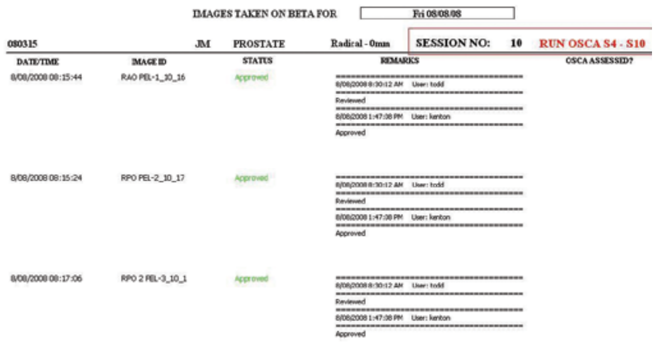

Figure 2a: Daily image running list prompting at specific sessions when to run trend analysis tool.

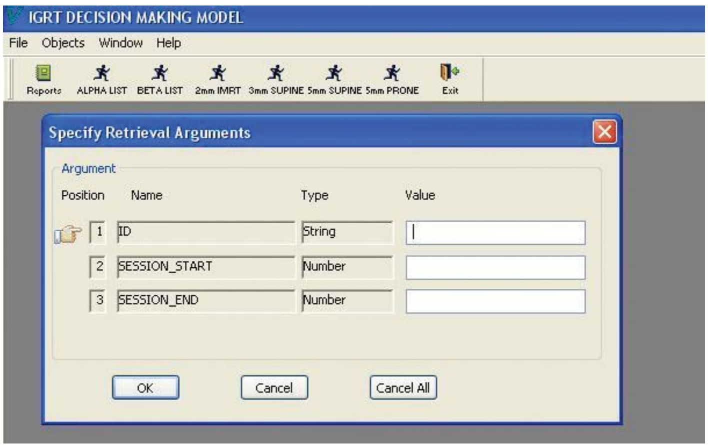

Figure 2b: Run trend analysis tool with patient ID and prompted session numbers.

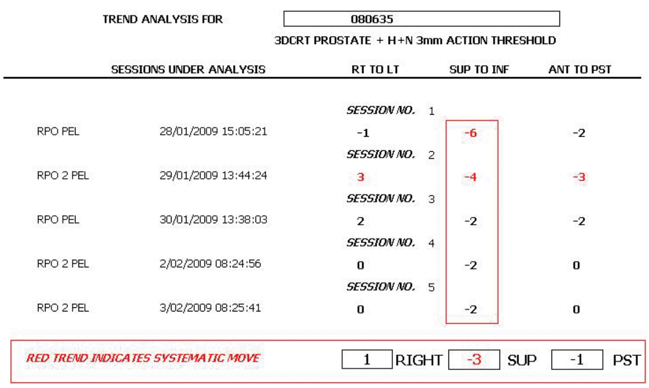

Figure 2c: Trend analysis tool indicating presence of systematic trend.

this reason that the Newcastle model has been used for analysis in this paper, as it represents a model that *could* become part of a daily IGRT program.

The aim of this paper is to illustrate the advantages of an objective automated decision making model, operating in a paper-less environment, over the subjective process of manual image and field placement trend analysis. Of course, with any image analysis process there is subjectivity but the automated decision-making model removes this via electronic notification of systematic trends. Included in the analysis is a time study of both methods, and the accuracy offered by both the diagnosis and prediction of systematic trends. Additionally, the predicted systematic isocentre moves calculated both by the automated decision making model and the manual method were also compared to a previously published statistical decision making model of port film analysis, the Newcastle model.[15,22] The automated decision making model allows presentation of potential systematic trends present in a time zone that the treating radiation therapist has been instructed to analyse. It is based on online image mismatch data and presents a systematic trend automatically. The manual method represents analysis of images in the offline environment and systematic trends identified by the user, i.e. continual set-up error in the left to right direction, and a decision made on its magnitude. The Newcastle model is a robust statistical method of analysing field placement. Importantly, it does not analyse shifts separately but as a group, requiring four or more images to reach a decision. The efficiencies gained by operating in a truly digital environment and the ability to accurately manage large levels of image data will also be highlighted.

Methods

Ethics approval

This study received low risk ethics approval from Toowoomba and Darling Downs Health Services District (TDDHSD) Human Research Ethics Committee (HREC) on the 23rd February 2009.

Online and offline image assessments

For the purposes of this study, an online correction is made in real-time while the patient is on the treatment couch. Pre-treatment orthogonal images are taken, assessed and an online intervention made if required. It is this online image mismatch data that is used by the automated decision making model.

An offline image assessment is retrospective and can be done anytime after the patient has received treatment. It involves analysing the image mismatch data in an offline environment, and it is these data that the manual method described in this study uses.

Technique and equipment

It is important to note that an online verification process has dealt with the set-up error on a daily basis, thus assuring accuracy and recognition of random errors, however, it is still necessary from a workflow perspective to identify and manage systematic trends. Five radical prostate patients were chosen randomly to be assessed retrospectively in this study. All patients who had undergone IGRT with intraprostatic fiducials were extracted from the ARIA database, with five chosen at random by the extraction tool. Importantly, no variation was made to a standard course of prostate radiotherapy at ROQ. Each of these patients underwent a daily online intervention protocol (daily pre-treatment orthogonal images), with corrections made to intraprostatic fiducials, giving rise to image data from each fraction of a 78 Gy in a 39 fraction course. The patient set-up was an indexed pelvic board, individualised indexed vac-fix bag and two square sponges under the head.

The Varian 4DTC™ match and correct tool was used for online image analysis in conjunction with several in-house Infomaker™ reports and forms.

Decision making models

Automated decision making model

The raw image mismatch data from the Varian 4DTC was entered directly into the ARIA database via a wireless tablet PC as shown in Figure 1. It is important to note that this is truly online data, match results from the treatment console showing *online* field placement data. The data were later used for statistical analysis of any systematic trends. Used in conjunction with Varian's Offline Review 8.1™ was a daily image running list, illustrating images taken and their status. Inclusive of this is the automated decision making model, instructing staff of when to assess systematic trends. When the radiation therapist is instructed to assess systematic trends, they run a custom report which extracts the online image data for the time zone analysed and presents a systematic trend if identified. This is illustrated in Figures 2a, 2b and 2c. Figure 2a shows the daily image running list, what session the image is associated with and at specific sessions instructs the user to run the trend analysis tool. The trend analysis tool is then accessed as per Figure 2b by entering the patient's identification number and the session numbers flagged by the image running list. Figure 2c represents trend analysis of these sessions and associated images. Importantly the automated decision making model will represent the mean error in each of the orthogonal planes for that time zone.

The approach of ROQ has been to incorporate an automated decision making tool into its daily image analysis, and ensure that the decision making tool is not only accurate but easy to use. Approaches such as this puts the onus of field placement management on the treating radiation therapy staff.[7,21] This process works on time zones, with analysis of retrospective field placement data being analysed at specific points in time. In the case of a radical prostate patient, the time zones are as follows;

Fraction 5 – analysis of fractions 1–5.
Fraction 10 – analysis of fractions 6–10.
Fraction 15 – analysis of fractions 11–15.

The automated decision making model is a suite of Infomaker™ reports and forms. Infomaker is a database management tool, which interfaces directly with the ARIA database. Accessing the Varian database to utilise image and isocentre information has been previously noted.[21] This process continues for the duration of a 39 fraction prostate course of treatment.

Manual method

Image and field placement analysis for these five patients was then repeated without the inclusion of the automated decision making model. This involved using the Varian Offline Review to analyse all images, while identification of systematic trends was done manually from the image mismatch data presented by Offline Review. The Offline Review software is a package designed to allow organisation and analysis of treatment images taken during a course of treatment, inclusive of multiple image registration and analysis tools. This involved observing the image mismatch data in each orthogonal plane and then manually averaging the raw numbers over the same specific time periods used in the automated analysis. This can be designated as offline data. If a systematic trend was identified, it was manually related back to the treatment isocentre, and a potential new isocentre identified. Again the time taken to undertake this process was recorded, as well as the accuracy of the identified systematic trends presented by the manual process. Effectively an objective automated tool was used to analyse and identify systematic trends and compared to the method of looking at image mismatch data and subjectively pinpointing a systematic error or average trend.

Newcastle model

The sets of image mismatch data, both online and offline, were then analysed using the Newcastle model, comparing the objective systematic errors identified and the subjective systematic errors with a robust statistical model. The Newcastle model is based on a two dimensional evaluation of at least five treatment verification images. It identifies systematic trends by using a 95% confidence interval for different numbers of verification images.[15,22] In simple terms, an ellipse is plotted using raw mismatch data and if the origin of the co-ordinate system is not within the ellipse (95% confidence area), a systematic trend can be diagnosed. Additionally, the online mismatch data was then benchmarked to the offline data, assessing the level of consistency across the two imaging environments. This involved the use of a Microsoft Excel 2003 (Microsoft, Seattle, Washington, USA) program utilising the Newcastle model through which both online and offline data were processed.

Time study

The time taken to analyse image and field placement for this patient population was recorded, as well as the accuracy of the identified systematic trends, presented by both the automated and manual decision making model. In the case of the automated decision making model the time taken to perform a trend analysis can be defined as the time taken to run image running list, be instructed to run decision making model at a specific session or fraction number and be presented with a systematic trend if present. It is important to note that the automated decision making model uses field placement data collected in the online environment, and thus that data is ready for instant analysis. For all methods of analysis, be it automated or manual an image and trend analysis refers to the time take to match or register an image and then perform a trend analysis.

Analysis

Two-sided T-tests were performed for all time study analyses comparing the automated and manual times for task completion. These data are not independent and for analysis purposes were viewed as paired. In all cases a P value of 0.05 was taken to be statistically significant, and all analyses were performed on Excel 2003. This process was repeated benchmarking the online data to the Newcastle model, the offline data to the Newcastle model and the online data to the offline data.

Results

Time study

For the five patients, a total of 195 imaged fractions were available to analyse. The mean time taken to analyse both images and systematic trends for the automated decision making model was around 0.25 minutes, as compared to 1.5 minutes for the manual method (automated 0.25 minutes *vs* manual 1.5 minutes: P <0.001).

Looking at only trend analysis the mean time for the automated decision making model was 0.5 minutes as compared to 3 minutes for the manual method (0.5 *vs.* 3 minutes: P < 0.001). Figure 3 illustrates the time taken for each session to analyse both images and systematic trends. The manual method presents a peak in time at the specific fractions when systematic trend analysis is carried out.

Table 1: Comparison of mean match data for automated online method versus Newcastle model and manual offline method versus Newcastle model (Two sample T Test)

Time zones	Online data automated (mm)			Online data Newcastle model (mm)			Offline data manual (mm)			Offline data Newcastle model (mm)		
	X (lat)	Y (lng)	Z (vrt)	X (lat)	Y (lng)	Z (vrt)	X (lat)	Y (lng)	Z (vrt)	X (lat)	Y (lng)	Z (vrt)
Zone 1 (#1–5)	-0.8	-2.2	3	-0.72	-2.28	2.72	-0.68	-2.28	2.6	-0.52	-2.2	3.32
Zone 2 (#6–10)	0.8	-0.2	-2.6	1.2	-0.44	-1.12	0.88	-0.4	-2.36	1.52	-0.8	-1.16
Zone 3 (#11–15)	1.2	0.2	-1.8	0.76	-0.16	-1.56	1.88	-0.72	-1.76	1.72	-0.6	-2.08
Zone 4 (#16–20)	0.4	-1.4	0	0.52	-1.64	0.04	0.72	-1.48	-0.12	1.44	-1.8	-0.2
Zone 5 (#21–25)	0.2	-1.8	0.2	0.4	-2.16	0.16	0.72	-2.48	-0.04	0.84	-2.6	-4.4E-17
Zone 6 (#26–30)	1.2	-1	1.2	1.52	-1.16	1.08	2.08	-1.4	0.48	2.08	-1.52	0.92
Zone 7 (#31–35)	1.2	-2.6	1.4	1.4	-2.64	1.64	1.2	-3.32	2.28	1.68	-3.32	1.36
Zone 8 (#36–39)	0.8	-1.4	0	1.12	-1.66	-0.06	1.54	-1.42	-0.16	1.54	-1.78	-0.12
	P value		X	Y	Z			*P* value	X	Y	Z	
			0.149	0.01	0.367				0.071	0.091	0.561	

Table 2: Comparison of mean match data for each time zone for online analysis versus offline analysis.

Time zones	Online data automated (mm)				Offline data manual (mm)		
	X (lat)	Y(lng)	Z(vrt)		X(lat)	Y(lng)	Z(vrt)
Zone 1 (#1–5)	-0.8	-2.2	3		-0.68	-2.28	2.6
Zone 2 (#6–10)	0.8	-0.2	-2.6		0.88	-0.4	-2.36
Zone 3 (#11–15)	1.2	0.2	-1.8		1.88	-0.72	-1.76
Zone 4 (#16–20)	0.4	-1.4	0		0.72	-1.48	-0.12
Zone (#21–25)	0.2	-1.8	0.2		0.72	-2.48	-0.04
Zone (#26–30)	1.2	-1	1.2		2.08	-1.4	0.48
Zone (#31–35)	1.2	-2.6	1.4		1.2	-3.32	2.28
Zone (#36–39)	0.8	-1.4	0		1.54	-1.42	-0.16
Raw mean difference (mm)			**X**	**Y**	**Z**		
			0.417	0.38	0.06		

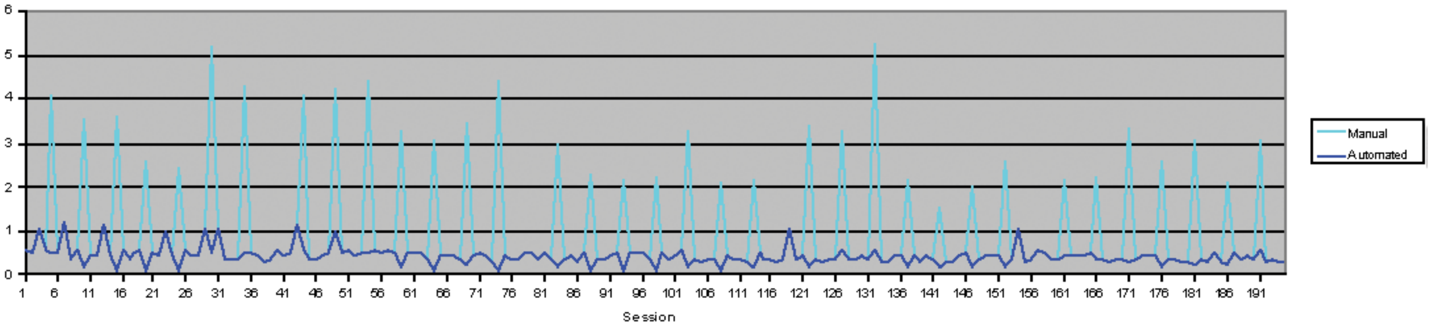

Figure 3: Mean time taken at each treatment session to undertake image analysis. Every fifth session involves trend and image analysis

Accuracy

Presented in Table 1 are the mean results for the total population over each time zone being analysed and this illustrates very small differences for each time zone under analysis. The online automated data compared to the data analysed with the Newcastle model showed a raw mean difference of 0.15mm for the lateral direction (X) (automated 0.62 mm *vs.* Newcastle model 0.77 mm: $P = 0.149$), 0.21 mm for the longitudinal direction (Y) (automated 1.31 mm *vs.* Newcastle model 1.51 mm: $P = 0.01$) and 0.18 mm for the vertical (Z) (automated 0.17 mm *vs.* Newcastle model 0.36mm: $P = 0.367$).

The offline manual data compared to the Newcastle model showed a raw mean difference of 0.24 mm for the X (manual 1.04 mm *vs.* Newcastle model 1.28 mm: $P = 0.071$), 0.14 mm for the Y (manual 1.68 mm *vs.* Newcastle model 1.82: $P = 0.091$) and 0.24 mm for the Z (manual 0.115 mm *vs,* Newcastle model 0.255 mm: $P = 0.561$).

Online *vs.* offline

Table 2 shows the differences between data analysed in the online and offline environments (the differences between the mean results for the total population over each time zone). The online environment was calculated using the automated decision making model and the offline environment with the manual method. The raw mean difference for the X was 0.417 mm, 0.38 mm for the Y and 0.06 mm for the Z.

Discussion

Time study

It is clear from the results presented that introducing an automated decision-making model into image analysis can significantly reduce the time taken to undertake these tasks. Using the automated method represented a halving of the total time taken to analyse both images and trends. This may seem small but when viewed in the context of increasing levels of image data to analyse, the reduction is enormous.

Looking at only the trend analysis aspect the reduction in time is significant with 3 minutes for the manual method being reduced to 30 seconds with the automated decision making model. This reduction in time is possible due to the automated decision making model using online data whereas the manual method involves matching the image again in the offline environment. Clearly this level of reduction in time is an enormous advantage as radiation therapists are faced with more and more treatment images to analyse and manage. Time taken in image and trend analysis in both paperless and paper-based environments has been benchmarked previously,[23] and the results presented here are consistent with those findings and are statistically significant.

Accuracy

Both the automated and manual methods of trend analysis showed great agreement with an established statistical decision making model. Importantly, both the automated online method and the manual offline method identified systematic trends in agreement with the Newcastle model. Use of a robust statistical package such as the Newcastle model is often undertaken in a retrospective manner and seen as a research tool. However the ever increasing role of IGRT has seen the need to identify and manage systematic trends in a more 'real time' approach. See, *et al.*[22] noted that an approach such as the Newcastle model would lend itself well to be incorporated into the major vendor's electronic portal imaging software, and this is the type of approach taken at ROQ. Although custom in approach the ROQ decision-making model interfaces with the ARIA patient information system and utilises one patient database. This represents a stepping-stone to having such a tool within the software itself.

Online *vs.* offline

Clearly, there is great consistency in the analysis of images and diagnosis of systematic trends across between the online environment and the offline environment. This is of great importance because online analysis is conducted under the duress of time constraints and by two radiation therapists. Of course, in the offline environment time constraints are more relaxed and input from colleagues is not limited. It is imperative that treating radiation therapist teams are just as effective in the online environment as the offline environment, and the results shown here illustrate that with appropriate training and knowledge, this can be achieved.

Summary

It is important to stress that the automated tool here does not look at field displacement data from separate fractions, it looks at a specific group within a designated time zone, and presents the mean error, or in other words the systematic component of set-up error. Daily online imaging has dealt with the random component. Also important to note are the limitations of the current study, which represents an analysis of only five patients. This study has shown that the automated decision making model is just as accurate as other methods in determining systematic trends, while also being highly efficient. In order to fully quantify this in statistical terms a larger patient population would obviously be required and potentially the inclusion of other anatomical sites, but the primary aim of this study was to show our group that this is a logical step forward. Expansion of the analysis of online versus offline images is an area of continuing work.

In both the online and offline environment at ROQ it is the treating radiation therapy staff who manage isocentre moves. It has previously been stated that the radiation therapists are the only group who are feasibly able to undertake daily image analysis,[7,21] and this is the approach of choice at ROQ. Inclusive of this is the necessity that the treating radiation therapists are able to pinpoint and act on systematic trends, thus ensuring treatment accuracy and efficiency. The time study data presented in this study illustrates that with the huge volume of image data now being assessed on a daily basis; now more than ever analysis methods have to be highly effective and efficient. It has been previously identified[12,15,24,25] that subjectivity can cause issues with image analysis with human observers having difficulty identifying errors under 5 mm, thus the need for automation and more objectivity[24] is both about accuracy and efficiency. Most vendors now have the capacity to perform automated matches in both the online and offline environments, however there is still a degree of manual matching done by the radiation therapists. For the purposes of this study all image matches were carried out by the radiation therapist, and thus subjectivity could be an area for further research.

The results from this study indicate that both in the online and offline environments there is great consistency in the diagnosis of systematic trends or errors. However, clearly an automated method has distinct advantages over manual or more retrospective statistical analysis. Very few information systems permit tracking of isocentre position over multiple fractions, and then combining this information into meaningful statistical data has required outside tools such as spreadsheets or hand-entered forms.[26] The use of one patient database to achieve these aims is imperative for process quality assurance and an area where significant infrastructure changes from the vendors could occur. While not the primary focus of this paper, a paperless approach in radiation oncology has many benefits. Clearly, issues of training, resource management and cost are paramount in order to make such a change. As shown by this study there are clear advantages of a paperless environment, however its introduction is a process that requires much thought, teamwork, commitment and careful analysis of workflow.

Conclusion

From the results presented in this study, it is clear that an automated decision-making model for field placement trend analysis can provide significant gains in efficiency, while maintaining the accuracy presented by manual methods and statistical packages. In the era of IGRT, enormous volumes of image data are now being captured and precise, effective management of that data is vital. The importance of daily imaging carried out by radiation therapists is well documented, however, the management of the data provided by daily imaging has not reached the same level of importance. An approach such as the automated decision making model presented in this study, can bring both daily online imaging and statistical analysis to their logical inclusion in imaging protocols. This in turn will allow treating radiation therapists to diagnose, analyse and intervene daily field placement corrections in a highly accurate and efficient manner, whilst also managing the consequential huge amount of imaging data. This enormous amount of image data demands a high level of image and isocentre management. An automated decision making model as outlined in this study can ensure that the treating radiation therapy team can not only manage these factors accurately but also with a large degree of efficiency.

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