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Original Article

The use of a laser scanning digitiser to assess the accuracy of immobilisation masks

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Abstract

The accuracy of a range of immobilisation systems for head and neck radiotherapy has been measured. Two types of vacuum-formed shells, and eight thermoplastic systems have been evaluated. For each system, a mask was made for the same volunteer. A non-invasive optical system, using a scanning laser digitiser, was used to measure the displacement of a fiducial marker. The volunteer was asked to move a maximum comfortable distance in each of the superior, inferior, left and right directions, and a scan was taken at each location. Standard deviations, calculated from the maximum range of movements, were in the range of 1.7–2.9 mm in the right–left direction, and 0.9–3.0 mm in the superior–inferior direction. The smallest movements were measured for the Medtec S-frame, with nine-point fixation. A laser-scanning camera can assess the movement potential for a subject inside an immobilisation device with good accuracy and precision. Because ionising radiation is not used as part of the imaging process, the same subject can be used for several mask systems to assess which is the best one.

Keywords

Immobilisation; head-and-neck; thermoplastic; setup; shell; mask

INTRODUCTION

Patients having radiotherapy to the head and neck are frequently immobilised using masks. Two forms of immobilisation mask are in common use: clear hard plastic shells made by vacuum-forming over a plaster cast of the patient, and thermoplastic material moulded directly over the patient. No patient mask can be made as a perfect tight fit, as patients need not only accurate, but also comfortable treatment setup. Therefore there is always a tolerance of movement associated with any immobilisation device. The task of the manufacturers is to minimise this error while retaining patient comfort.

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There have been many studies to evaluate the positioning reproducibility of patient mask immobilisation devices.[1–4] However, very few have evaluated more than one or two forms of mask simultaneously. Many of the studies use portal imaging of patient treatments to assess day-to-day variability of setup. While this provides retrospective data on how patients have been setting up, it provides no theoretical framework for establishing maximum limits on tolerances. The measuring of patient setup also typically involves using portal images compared against gold-standard imaging such as digitally reconstructed radiographs (DRRs) generated from CT data. Not only does this require registering the portal image to the DRR, which may involve errors of over 1.5 mm,[5–7] but the pixel size of portal images ranges from 0.25 mm to over 1 mm, with a typical size of 0.5 mm.[8–10] Thus, the accuracy of results from such evaluations may be poor. Patients may also change size due to such factors as steroid intake associated with their treatment or reaction to radiation – both swelling of the irradiated area and shrinkage as the tumour recedes. These changes can affect how well a patient fits their immobilisation mask as their treatment progresses.

The work presented here evaluates the setup reproducibility of several head and neck immobilisation masks from several different manufacturers. The results will be compared against various other systems published in the literature. This setup study is performed on a healthy volunteer who can report feelings inside the mask in an articulate way and can also respond to instructions when inside the masks. The use of a healthy volunteer who is not undergoing treatment is important for maintaining accuracy, as many patients, used in other studies of immobilisation, undergo severe weight loss during the course of their treatment.[11]

MATERIALS AND METHODS

The subject

The subject was a healthy male, of slim build, aged 25, with short hair. The weight of the subject varied from 64.8 to 66.8 kg over the course of the study. The possibility of movement due to compression of the hair was therefore small, and the effects of changing anatomical shape were minimal. Only one subject was used in order to reduce costs of material, as ten different immobilisation mask methods were used and many of the systems used were trials from manufacturers. The study was carried out over several months as different materials became available.

The masks

Two plaster-cast PETG shells were made:

1. Impression was taken with the subject's shoulders relaxed.
2. Impression was taken with the shoulders pushed towards the feet using fixator[12] detachable pads on the table top.

Eight thermoplastic masks were made, of varying material and number of fixation points:

3. Orfit[13] five-point mask covering the head, neck and shoulder tops.
4. Addisilk[14] three-point mask covering the head only.
5. Imotek[15] five-point mask covering head, neck and shoulder tops.
6. Imotek four-point mask covering head, neck and shoulder tops, but not the top of the head or the forehead.
7. Medtec[12] S-Type five-point frame, covering only the head. The mesh had four strengthening bars – starting from just above the bridge of the nose, the bars run to the left and right of the patient and at 60° and 120° angles towards the top of the head.
8. Medtec S-Type five-point frame covering the head only. The mesh has three strengthening bars, running left, right and superiorly from the top of the bridge of the nose.
9. Aquaplast[16] nine-point frame covering the head, neck and shoulders.
10. Medtec S-Type nine-point frame covering the head, neck and shoulders. The mesh used three strengthening bars across the forehead plus wider bars across each shoulder.

All ten setups used a hard plastic headrest to extend the neck and tilt the chin back. This is a common technique used at Addenbrooke's for head and neck patients as it moves the jaw away from the neck to spare it from irradiation and also allows access to the neck area with electron applicators. The headrest used was a selected from a set of manufacturer-supplied ones, and chosen to provide the best anatomical fit to the patient's neck.

All of the shells and masks were made by the same mould room staff team, who have several years of experience using both thermoplastic and plaster-cast methods.

The measurements

Measurement of the setup reproducibility was performed using a Minolta[17] Vivid VI-700 non-contact 3D digitiser. This system uses a scanning laser line and camera to record a 3D point model of an object in its field of view. The system saves data files to a memory card which are then read into the manufacturer-supplied software on a PC. The software then exports all of the measured

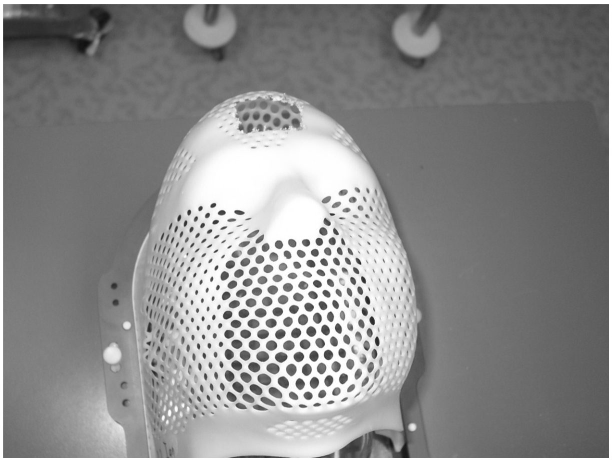

Figure 1. Thermoplastic head mask showing the cut-out used for the fiducial marker. The strengthening bars of solid material can be seen running across the brow and either side of the cut-out.

points in the original file as an ASCII point-cloud file, consisting of the 3D Cartesian co-ordinates of each point. This file was read into the MATLAB[18] programming environment using a script created by the author for this project. The (x, y, z) co-ordinate triples were displayed and measured interactively using the display routines within the MATLAB software.

The masks were fitted to the subject on each occasion by the same physicist. Measurements were made by imaging the subject on a linac treatment couch with a fiducial marker attached to his forehead, the marker protruding past the mask through a $3 \times 3\,cm^2$ window cut in the mask, as shown in Figure 1. Multiple sections larger than this are frequently removed from patient masks to reduce build-up of radiation at the skin, so it was not anticipated that a single window would cause structural weakening of the masks. As the coordinate system of the digitiser is relative to its own position, a fiducial marker was also fixed to the treatment couch in the field of view of the camera. All measurements of the subject's position were taken from the tip of this marker, thus showing the position of the subject relative to the treatment couch.

The accuracy of the laser scanning camera was established without the subject present by repeated images of fixed objects and by moving one fiducial marker by known distances.

For the measurements of setup, the subject was asked to move a maximum comfortable distance in each of the superior, inferior, left and right directions, and a scan was taken at each location. Anterior and posterior movements were not measured for this study as it was felt that movements in this direction are more affected by how the patient lies in the mask in terms of nervous tension in the neck and shoulders than how well the mask fits and prevents movement. Although there is likely to be anterior–posterior movement of patients in immobilisation masks, as shown by previous studies, the magnitude of the movements are harder to quantify with a single subject.

Two baseline scans were taken of a 'central' position at the beginning and end of the measurement sequence with the subject asked to position himself in what felt to be the most central comfortable position. The set of six measurements were then repeated after the subject had been removed from the mask, allowed to walk around the room and then refitted into the same mask. The baseline scans were performed to ensure that the co-ordinate system of the camera was constant, and also to check the constancy of the central position of the subject. Movements in each of the four directions will be quoted relative to the average position of the baseline scans.

RESULTS

The data in the camera's data file is given with 0.01 mm precision in each of the three Cartesian axes. It is not known if these values are obtained by truncation or rounding, but the precision of the values is much greater than the anticipated accuracy of measurement, and the rounding error is therefore ignored. The known movements of the objects used in the assessment of the measurement accuracy could be measured only to the nearest 0.25 mm. The measurements of the locations of these objects from the digitised images were within 0.25 mm of the expected positions, and therefore the precision of the 3D coordinates exported from the digitiser is taken to be ± 0.25 mm (which equates to a standard deviation of 0.14 mm).

The results of the subject's measured movements are presented in Table 1, showing movement in

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Table 1. Results of the measurements on the mask types listed

Mask	Movements, mm				Standard deviation, mm				Baseline difference 3D
	Right	Left	Superior	Inferior	Right	Left	Superior	Inferior	
Imotek four-point	4.75	5.25	5.00	1.75	2.7	3.0	2.9	1.0	0.3
Imotek five-point	3.75	4.75	3.75	2.00	2.2	2.7	2.2	1.2	0.4
Addisilk three-point	4.50	3.75	4.00	2.75	2.6	2.2	2.3	1.6	0.3
Orfit five-point	4.25	3.50	3.75	3.50	2.5	2.0	2.2	2.0	0.4
Medtec three-bar	4.25	3.75	3.75	3.75	2.5	2.2	2.2	2.2	0.3
Medtec four-bar	4.00	3.25	2.75	3.50	2.3	1.9	1.6	2.0	0.4
Medtec nine-point	3.25	3.00	2.50	1.50	1.9	1.7	1.4	0.9	0.2
Aquaplast nine-point	3.25	3.50	3.50	3.00	1.9	2.0	2.0	1.7	0.4
PETG shell	5.00	4.75	5.25	4.00	2.9	2.7	3.0	2.3	0.5
PETG shell + shoulder retractors	4.50	4.25	3.25	3.25	2.6	2.5	1.9	1.9	0.5

The movements (in mm) are the average of two sets of measurements, taken as distances from the average of the baseline images. Standard deviations are taken as movements divided by √3, as discussed in the text. The difference between the baseline images is also shown as a 3D vector distance.

each of the four directions (right, left, superior, inferior). The standard deviation of the four baseline scans is shown. The results show the average of the two sets of readings taken, rounded to the nearest 0.25 mm.

Harrison and McKenzie[19] show that the standard deviation of a top-hat function of half-width a is equal to $a/\sqrt{3}$. The second group of columns of Table 1 therefore shows the measured values divided by $\sqrt{3}$ to give a standard deviation. This then presents the results of this study in the same format as those from other studies in the literature (Table 2), which are all quoted to 1 SD.

DISCUSSION

The results from measurements taken for this study show that all systems gave positioning of better than 5.25 mm from the central location, with the standard deviation calculated as <3.0 mm for all systems. This agrees well with previously published studies presented in table 2, which show a maximum standard deviation of 3.1 mm.

The measurements show a wide variation in the immobilisation of the subject, standard deviations varying from <1 mm for the inferior movement with some systems, to as much as 3 mm for others. Table 1 shows that with the exception of the Medtec five-point system with four strengthening bars, the inferior movement was the smallest of the four directions. The largest movements were recorded mainly for the left or right directions. When examined without the subject, the thermoplastic masks showed greatest flexibility in the left and right directions, with excellent rigidity in the superior–inferior directions. The left–right flexibility accounts for most of the measured movement, as in general the masks fitted well to the sides of the head. In contrast, the inferior movements for most masks was good, primarily due to good contact between the mask and vertical surfaces of the subject such as below the chin and the base of the nose, both of which prevent significant inferior motion. The Imotek masks, in particular, have a cut-out in the material for the nose, such that it protrudes through. There is little stretching of the material around the nose area, and there is therefore a hard edge to the material around the nose cut-out. This hard edge made it uncomfortable for the subject to move in the inferior direction, and this is reflected in the measurements. The Medtec nine-point system had a small hard ridge at the base of the nose which also made inferior movement uncomfortable.

PETG or PVC shells are often regarded as a gold standard for immobilisation, because the process is more established than the use of thermoplastics and because of the rigidity of the shell. It is interesting to note that the measurements recorded here show that one of the worst immobilisations in this study came from the PETG shell. With the PETG shell, the addition of shoulder retractors improved the movements in all four directions, especially to the superior. With the shoulders pulled towards the feet there was less

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Table 2. Results of mask setup studies previously published showing right–left (RL), superior–inferior (SI), anterior–posterior (AP) and 3D displacements

Mask	RL	SI	AP	3D	Reference
Orfit five-point	–	2.1	2.1	–	2
PETG shell	–	2.1	2.1	–	2
Posifix three-point[26]	–	–	–	3.1	3
Posifix four-point	–	–	–	2.4	3
Posifix five-point	–	–	–	2.4	3
Aquaplast	1.3	1.0	1.2	–	20
Orfit three-point	–	–	–	3.05	21
Mouthplate system	–	–	–	1.02	21
Mouthbite	3.1	2.5	2.7	3.1	22
PVC shell	0.6	0.5	–	–	23
Orfit Raycast (three-point)	0.74	0.93	0.75	1.59	24
UON precise-fit[27]	1.2	1.1	0.6	–	25
Medtec S-Type nine-point	0.3	1.1	0.8	–	25

Values (in mm) are quoted as the standard deviation about the mean.

scope for hunching of the shoulders and therefore a better fit of the shell later. The retraction of the shoulders also extended the neck, which made superior movements difficult. Without shoulder retraction the head can move superiorly without moving the shoulders by extension of the neck.

For a particular material, there is a trend towards better immobilisation for more fixation points. However, between materials, there is no such trend with the best three-point system outperforming the worst four-point system.

This study is unique among those previously published in terms of the number of different materials tested, with previous studies testing no more than three different masks. This study has allowed the use of a volunteer who could articulate what each mask is like in terms of the fit and the flexibility within it, whereas many patients, only having experience of one mask, cannot relate such information. Additionally, this study used one subject whose weight and size did not change significantly throughout the whole process. Many patients experience shape change due to steroid intake, swelling from radiosensitivity or weight loss during the course of their treatment. Thus previous studies have shown how patients reposition over a course of treatment when these effects are taken into account, whereas this study shows the immobilisation capabilities of the mask. Possible future work includes studies using articulate subjects with different characteristics to the one in this study.

This study has shown that a non-invasive method is possible for measuring the position of volunteers or patients in immobilisation masks. Laser-based systems such as the digitiser used here, can provide safe, repeatable measurements that could be used on a large patient set for measurement of population statistics. The benefit of this would be that the patients would require no extra portal imaging or radiation dose and scans could be repeated without health and safety or ethical issues. Measurement of object positions using a laser digitiser are also less prone to errors than the registration of portal images to DRR imaging, and is likely to be more precise and more accurate.

Treatment margins are calculated as the addition in quadrature of several potential errors. Therefore, provided that the setup error is not small compared to the other potential errors, reducing it will allow for the reduction of treatment margins. For example if the phantom transfer error is 2.9 mm,[19] then reducing the standard deviation of the systematic setup error from 3 to 1.4 mm gives a reduction in the combined error from 4.2 to 3.2 mm, and thus a reduction in the systematic component of the CTV–PTV margin by 2.5 mm. This will allow the reduction of the irradiated volume, which gives a reduction of normal tissue irradiation.

CONCLUSION

A method has been described to establish the setup accuracy of immobilisation devices without the use of ionising radiation. A laser-scanning camera can assess the movement potential for a subject inside an immobilisation device with good accuracy and precision. Because ionising radiation is not used as part of the imaging process, the same subject can be used for several mask systems to assess which is the best one. By selecting the best masks and with knowledge of the likely movements, improvements can be made in patient setup, which will lead to better accuracy in radiotherapy treatments and improvements in patient outcome.

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References

1. Hess CF, Kortmann RD, Jany R, Hamberger A, Bamberg M. Accuracy of field alignment in radiotherapy of head and neck-cancer utilizing individualized face mask immobilization – a retrospective analysis of clinical-practice. Radiother Oncol 1995; 34:69–72.
2. Weltens C, Kesteloot K, Vandevelde G, Van den Bogaert W. Comparison of plastic and Orfit® masks for patient head fixation during radiotherapy: Precision and costs. Int J Radiot Oncol Biol Phys 1995; 33:499–507.
3. Gilbeau L, Octave-Prignot M, Loncol T, Renard L, Scalliet P, Grégoire V. Comparison of setup accuracy of three different thermoplastic masks for the treatment of brain and head and neck tumours. Radiother Oncol 2001; 58:155–162.
4. Humphreys M, Urbano MTG, Mubata C, Mites E, Harrington KJ, Bidmead M, Nutting CM. Assessment of a customised immobilisation system for head and neck IMRT using electronic portal imaging. Radiother Oncol 2005; 77:39–44.
5. Hawkes DJ. Algorithms for radiological image registration and their clinical application. J Anat 1998; 193:347–361.
6. Jobse M, Davelaar J, Hendriks E, Kattevilder R, Reiber H, Stoel B. A new algorithm for the registration of portal images to planning images in the verification of radiotherapy, as validated in prostate treatments. Med Phys 2003; 30:2274–2281.
7. Gilhuijs K, van de Ven P, van Herk M. Automatic three-dimensional inspection of patient setup in radiation therapy using portal images, simulator images, and computed tomography data. Med Phys 1996; 23:389–399.
8. Langmack K. Portal Imaging. Br J Radiol 2001; 74:789–804.
9. Boyer AL, Antonuk L, Fenster A, van Herk M, Meetens H, Munro P, Reinstein L, Wong J. A review of electronic portal imaging devices (EPIDS). Med Phys 1992; 19:1–16.
10. Munro P. Portal imaging technology: past present and future. Semin Radiat Oncol 1995; 5:115–133.
11. Beaver M, Matheny K, Roberts D, Myers J. Predictors of weight loss during radiation therapy. Otolaryngol Head Neck Surg 2001; 125:645–648.
12. Medtec. Indiana, USA: Orange City.
13. Orfit Industries. Belgium: Wijnegen.
14. Oncology Imaging Syetems. UK: Uckfield.
15. Imotek Internatiional. UK: Somersham.
16. WFR/Aquaplast Corp. New Jersey, USA: Wyckoff.
17. KonicaMinolta. New Jersey, USA: Mahwah.
18. The Mathworks. Massachusetts, USA: Natick.
19. BIR. Geometric Uncertainties in Radiotherapy. Defining the Planning Target Volume. British Institute of Radiology Publishing, 2003.
20. Tsai J-S, Engler MJ, Ling MN, Wu JK, Kramer B, Dipetrillo T, Wazer DE. A non-invasive immobilization system and related quality assurance for dynamic intensity modulated radiation therapy of intracranial and head and neck disease. Int J Radiat Oncol Biol Phys 1999; 43:455–467.
21. Sweeney R, Bale R, Vogele M, Nevinny-Stickel M, Bluhm A, Auer T, Hessenberger G, Lukas P. Repositioning accuracy: comparison of a non-invasive head older with thermoplastic mask for fractionated radiotherapy and a case report. Int J Radiat Oncol Biol Phys 1998; 41:475–483.
22. Willner J, Hädinger U, Neumann M, Schwab FJ, Bratengeier K, Flentje M. Three dimensional variability in patient positioning using bite block immobilization in 3D-conformal radiation treatment for ENT-tumors. Radiother Oncol 1997; 43:315–321.
23. De Boer HCJ, van Sörnsen de Koste JR, Creutzberg CL, Visser AG, Levendag PC, Heijman BJM. Electronic portal image assisted reduction of systematic set-up errors in head and neck irradiation. Radiother Oncol 2001; 61: 299–308.
24. Fuss M, Salter BJ, Cheek D, Sadeghi A, Hevezi JM, Herman TS. Repositioning accuracy of a commercially available thermoplastic mask system. Radiother Oncol 2004; 71:339–345.
25. Prisciandaro JI, Frechette CM, Herman MG, Brown PD, Garces YI, Foote RL. A methodology to determine margins by EPID measurements of patient setup variation and motion as applied to immobilization devices. Med Phys 2004; 31:2978–2988.
26. Gammex rmi. Wisconsin: Middleton.
27. Nuclear Associates. New York.