ORIGINAL ARTICLE

Evaluation of low-cost computer monitors for the detection of cervical spine injuries in the emergency room: an observer confidence-based study

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Background: To compare the diagnostic value of low-cost computer monitors and a Picture Archiving and Communication System (PACS) workstation for the evaluation of cervical spine fractures in the emergency room.

Methods: Two groups of readers blinded to the diagnoses (2 radiologists and 3 orthopaedic surgeons) independently assessed–digital radiographs of the cervical spine (anterior–posterior, oblique and trans-oral-dens views). The radiographs of 57 patients who arrived consecutively to the emergency room in 2004 with clinical suspicion of a cervical spine injury were evaluated. The diagnostic values of these radiographs were scored on a 3-point scale (1 = diagnosis not possible/bad image quality, 2 = diagnosis uncertain, 3 = clear diagnosis of fracture or no fracture) on a PACS workstation and on two different liquid crystal display (LCD) personal computer monitors. The images were randomised to avoid memory effects. We used logistic mixed-effects models to determine the possible effects of monitor type on the evaluation of *x* ray images. To determine the overall effects of monitor type, this variable was used as a fixed effect, and the image number and reader group (radiologist or orthopaedic surgeon) were used as random effects on display quality. Group-specific effects were examined, with the reader group and additional fixed effects as terms. A significance level of 0.05 was established for assessing the contribution of each fixed effect to the model.

Results: Overall, the diagnostic score did not differ significantly between standard personal computer monitors and the PACS workstation (both p values were 0.78).

Conclusion: Low-cost LCD personal computer monitors may be useful in establishing a diagnosis of cervical spine fractures in the emergency room.

In recent years, healthcare expenditures have increased enormously in industrialised countries such as the UK, Germany and the USA. In 2002, the total healthcare expenditure in the UK accounted for 7.7% of the gross domestic product, and was even higher in the USA (15%) and Germany (11.5%) in 2003.[1] As healthcare costs increase, so does the need for economisation in hospitals. To cap or reduce expenditure, healthcare institutions face the reality of the need to lower spending in human, physical and technological resources, while ensuring the accuracy of clinical diagnoses and delivery of treatments.

This study examined whether commonly available computer monitors can be used in emergency departments for the evaluation of digital *x* ray films to diagnose cervical spine injuries in patients compared with specially designed, more expensive Picture Archiving and Communication System (PACS) monitors.

The incidence of adult severe cervical-spine injury due to blunt trauma is about 2%.[2] Patients at risk of such injury should undergo immediate neck immobilisation until the status of the cervical spine can be assured. Timely diagnosis and exclusion of these injuries in patients with multiple injuries have become critically important because of the disastrous consequences that result from spinal injury misdiagnosis. As part of the diagnostic evaluation, trauma patients undergo digital *x* rays of the cervical spine at the anterior–posterior, oblique and trans-oral-dens views.

In most hospitals, personal computer monitors are readily available, whereas more expensive PACS workstations are not. In the emergency room, where this study was conducted, a PACS workstation was not immediately available for diagnostic readouts, whereas ordinary personal computer monitors were readily available for initial, fast diagnostic decision. If a confirmed diagnostic decision can be made via personal computer monitors, the rationalisation of workflow between different hospital departments can be improved, because a fast and certain decision-making process is one of the most important keys in the further treatment of patients. We assessed whether the certainty of diagnosis of cervical spine fractures can be made on ordinary, low-cost personal computer monitors.

METHODS

This study was carried out in accordance with the regulations of the local institutional ethics committee and the Declaration of Helsinki.

Two groups of readers (two radiologists and three orthopaedic surgeons) participated in this study. The trauma or emergency department in our hospital is managed by a team of orthopaedic surgeons who are always available. When a trauma patient is admitted to the trauma emergency room, they consult anaesthetists and radiologists and, if required, further specialists for an optimal treatment plan. Each group consisted of one experienced doctor (>10 years of experience) and residents (one in radiology and two in

Abbreviations: LCD, liquid crystal display; PACS, Picture Archiving and Communication System orthopaedic surgery). Both groups were observed by a single investigator. The readers were blinded to the diagnoses and independently evaluated anonymised digital *x* rays of the cervical spine (ie, anterior–posterior, oblique, and trans-oral-dens). Readers made their diagnostic decisions in group consensus. We evaluated radiographs of 57 patients who arrived consecutively in 2004 to our emergency room after accidents. Radiographs were taken for all patients because of clinical suspicion of a spinal fracture. In 12 patients, a spinal fracture was confirmed and they underwent surgery or external stabilisation. Ten patients underwent a computed tomography or magnetic resonance imaging examination. Only radiographs of patients with acute fractures or no fractures were included in the study. Patients with fractures in which the acute trauma was questionable were excluded. Patients with no confirmed fractures were discharged from the hospital within 3 days of admission. Only one patient stayed >10 days in our hospital for other medical reasons.

We scored the images on a 3-point scale (1 = diagnosis not possible/bad image quality, 2 = diagnoses uncertain and further investigation recommended, 3 = clear diagnosis of fracture or no fracture) on a PACS workstation and two different personal computer monitors in the emergency room.We used this relatively small scoring system because in the emergency room it is important to decide quickly and certainly whether or not a fracture is present. This decision should be made with confidence by the doctor in charge. We used a PACS workstation located in the radiology department and two different personal computer monitors in the emergency room. For all monitors, comparable conditions for the evaluation of *x*-rays were established.

The observers started on either the PACS workstation monitors (radiologists) or the two personal computer monitors (orthopaedic surgeons). The reading was carried out in random order, which changed in between the different reading sessions. After 2–3 weeks interval (''washout'' period), the observers read the *x* rays on the other monitors. Ambient light was kept at the same level for all three monitors. We used dedicated software that provided similar processing features such as zoom, brightness changes, measurement tools and direct image comparison for all three monitors.

Table 3 summarises the monitor specifications and costs. The PACS workstation had two 1280×1024 colour thin film transistor active matrix monitors, 46 cm (18.1 inch) panel size with an active display size of 360×288 mm (H×V), 16.7 million colour display, ±80° viewing angles, 0.28×0.28 mm pixel pitch, 300:1 contrast ratio and 235 cd/m^2 brightness. The approximate cost of the PACS workstation was about £34 000 (€50 000), with display costs of about £17 000 (€25 000). As for the two personal computer monitors, personal computer monitor 1 (monitor 1) was a high-quality liquid crystal display (LCD) monitor made for observation of medical images: 1 megapixel, 1280×1024 TFT colour LCD monitor, 46-cm (18.1-inch) panel size with an active display size of 359×287 mm (H×V), 16.77 million colour display, 170° viewing angles, 0.2805×0.2805 mm pixel pitch, 27–64 kHz horizontal and 60 Hz vertical frequency, 400:1 contrast ratio, 250 cd/m^2 brightness, with an approximate cost of £1700 (€ 2500). Monitor 2 had a 1280×1024 colour LCD, 43 cm (17-inch) panel size with an active display size of 270.3×337.9 mm (H×V), 16.2 million display colours, 150° horizontal and 125° vertical viewing angles, 0.264×0.264 mm pixel pitch, 24–80 kHz horizontal frequency, 56–75 Hz vertical frequency, 500:1 contrast ratio and brightness 250 cd/m^2. The approximate cost was £250 (€360).

Table 1 Amount of each grade given by the two groups of readers for the different monitors

Reader	Grade	Amount of grade for CS *x* rays (%) (n = 57): PACS	Monitor 1	Monitor 2
Radiologists	1	1 (1.8%)	1 (1.8%)	2 (3.5%)
	2	11 (19.3%)	13 (22.8%)	13 (22.8%)
	3	45 (78.9%)	43 (75.4%)	42 (73.7%)
Orthopaedic surgeons	1	0 (0%)	0 (0%)	0 (0%)
	2	8 (14.0%)	7 (12.3%)	4 (7.0%)
	3	49 (86.0%)	50 (87.7%)	53 (93.0%)

CS, cervical spine; PACS, Picture Archiving and Communication System.
Grade 1 = diagnosis is not possible/bad image quality.
Grade 2 = diagnosis is uncertain and further investigation is recommended.
Grade 3 = clear diagnosis of fracture or no fracture.

For data analysis, confidence intervals at 95% were used to define statistical significance. We used mixed-effects logistic regression models to determine the possible effects of monitor type on the evaluation of *x* ray images. These were generalised linear mixed-effects models for dichotomous outcome variables. In contrast with ordinary linear regression, logistic regression fits a linear model structure to a non-linear transform of the outcome variable, the so-called logits.

In this study, the outcome variables were defined as ''1'' for an image evaluation yielding grade 3 (ie, clear diagnosis of fracture or no fracture) and ''0'' for grade 1 or 2. The model used monitor display type and reader group as explanatory variables. The PACS workstation was used as the reference display and the orthopaedic surgeons group as the reference reader group. Owing to the grouped design with repeated readings of each image, the image number provided a random effect on image evaluation. The PACS workstation was used as the reference display. Owing to the grouped design with repeated readings of each image and by each reader group, the particular variance–covariance structure of the data was modelled using reader group and image number as random effects on display quality. Display type and reader group were both used as explanatory variables to determine group-specific differences, whereas only the image identifier was used as random effect in the model. The PACS workstation and the orthopaedic surgeons group provided the reference data.

Logistic regression models may be interpreted in terms of odds ratios.[3] We refer the reader to the introduction of Hosmer and Lemeshow[3] for technical details. For this study, the odds were the ratio of the probability of an image being grade 3 to the probability of its receiving a lower grade on a given monitor display and by a given reader group. For example, the ratio of the odds of a display of interest to the odds of a reference display (ie, PACS) indicated how many times higher or lower was the chance to obtain good image quality with the display of interest compared with the reference display. An odds ratio >1 reflected an average increase in the grades obtained with the display of interest, and an odds ratio <1 a lower grade than the one achieved with the reference display.

RESULTS

The most common score for the displayed radiographs was grade 3, meaning a clear diagnosis of fracture or no fracture. When using the PACS monitor, radiologists assigned 45 of 57 (78.9%) patients as grade 3, versus 75.4% with monitor 1 and 73.7% with monitor 2, whereas the group of orthopaedic surgeons assigned 86.0% of the radiographs with this same grade when using PACS, versus 87.7% with monitor 1 and 93.0% with monitor 2. The group of radiologists scored significantly more displayed studies as grade 2 (uncertain diagnosis) for all monitors than did the orthopaedic surgeons (table 1).

Table 2 Coefficients defining the logistic mixed-effects model relating image quality to display type (Picture Archiving and Communication Systemas reference) and evaluator group (orthopaedic surgeons as reference), and the odds ratios for the comparison with the reference group

Variable	Coefficient (95% CI)	Standard error	p Value	Odds ratio (95% CI)
Intercept	2.90 (2.14 to 3.66)	0.39	0.001*	–
Monitor 1	−0.09 (−0.70 to +0.52)	0.31	0.78	0.92 (0.50 to 1.69)
Monitor 2	0.09 (−0.54 to +0.72)	0.32	0.78	0.91 (0.49 to 1.70)
Radiologist	−1.29 (−1.82 to −0.76)	0.27	0.001 *	0.28 (0.16 to 0.47)

95% confidence intervals were used to define statistical significance (*). Grades did not differ significantly between display types, but the radiologist group assigned significantly lower grades to the images than the reference group. Coefficients are given on the logit scale.

Results of the logistic regression showed that overall the grades did not differ considerably between standard personal computer monitors and the PACS workstation (table 2). The radiologists were almost four times as likely to consider an *x* ray-based diagnosis as uncertain (ie, grade 2) as the reference group of orthopaedic surgeons, with an odds ratio of 0.28. This effect is highly significant ($p<0.001$).

When comparing observer consistency in display type, both groups of readers consistently graded seven cervical spine fracture cases with the same grade across all three monitors. In two cases, the group of radiologists gave a lower grade for monitor 2, whereas the reference group graded consistently. In two cases, both groups gave better ratings for both personal computer monitors than for the PACS workstation. In one case, the orthopaedic readers gave a lower grade on both personal computer monitors, whereas the radiologists were consistent in grading on PACS versus monitor 2.

All cases with fractures confirmed on the PACS monitor were also confirmed on the personal computer monitors. In only one case were both reader groups unsure about the diagnosis on all three monitors.

DISCUSSION

We investigated the difference in observer confidence for cervical spine fractures between expensive workstations and low-cost computer monitors. We found no significant difference in the diagnostic value between two LCD personal computer monitors and the PACS workstation. The observers performed equally well on all three different monitors.

We found a slight difference between the groups of orthopaedic surgeons and radiologists for monitor 2, the smallest and least expensive monitor with the highest contrast ratio among the three in this study. The radiologists tended to score grade 2 more often and preferred performing further diagnostic examinations such as magnetic resonance imaging or computed tomography (table 2). This may be related to the familiarity of orthopaedic surgeons with personal computer monitors because they did not have PACS workstations available either in the emergency room or on their services. In both groups the grades were higher when the more familiar monitors were used. This might be a result of biased judgement.

If further diagnostic tests such as computed tomography or magnetic resonance imaging were considered necessary, it was mostly owing to poor image acquisition through radiographs. This finding agreed with previously published studies showing that 10–20% of cervical spine injuries were not detected with radiographs.[4–6]

Recently published studies have shown that high-resolution LCD monitors might be equivalent to high-resolution greyscale display cathode-ray tube monitors in chest radiographs and the detection of pulmonary nodules.[7 8] Doyle *et al*[9] could not find any difference between personal computer colour monitors and PACS monochrome workstation monitors on wrist fractures. They used a more defined grading system with five steps starting from ''definitely normal'', ''probably normal'', ''unsure'' to ''probable fracture'' and ''definite fracture''. We did not include the steps in between the definite statements because, unlike wrist fractures, a definite statement in cervical spine fractures is more important because of the clinically devastating consequences of an unsure statement. Results of another small study compared the reliability of personal computer monitor displays with PACS workstation displays on hand radiographs of patients with rheumatoid arthritis. Doyle *et al*[10] found similar results for hand radiographs on both displays. Those studies either included fewer patients or were dealing with less devastating injuries that, unlike those in this study, did not require immediate clinical decisions and actions. We confirmed similar observer satisfaction-related findings on expensive, high-resolution LCD monitors in comparison with a low-cost personal computer monitor, which did not considerably alter observer confidence on the detection of cervical spine fractures.

Results of a different study by Yamamoto *et al*[11] showed that scanned radiographs transmitted by modems left some difficulties in securing confident interpretation and reading of cervical spine injuries. We did not use *x* ray images that were scanned and transmitted to computers. Our radiographs were digitally acquired, processed and digitally transmitted to the personal computer monitors for diagnosis.

Table 3 Technical data of all three displays provided by the 2manufacturers

	Panel size	Display size (horizontal×vertical) (mm)	Resolution	Viewing angles (deg)	Pixel pitch	Contrast ratio	Brightness (cd/m^2)	Costs
PACS workstation	18.1″	360×288	1280×1024	±80	0.28×0.28	300:1	235	£17 000 (€25 000)
PC monitor 1	18.1″	359×287	1280×1024	170	0.2805×02 805	400:1	250	£1700 (€2500)
PC monitor 2	17″	270.3×337.9	1280×1024	150	0.269×0.269	500:1	250	£250 (€360)

PACS, Picture Archiving and Communication System; PC, personal computer.

One limitation of our study was the inability to blind the observers about the type of monitor they were using. We were unable to do this because the monitors came in different sizes and shapes. Secondly, we did not place the three monitors next to each other to compare image contrast and sharpness because we wanted the observers to have no direct comparison between the monitors to ensure that they graded the images independently. Another limitation was that not all three monitors used the same software. However, we expected this to play a negligible part as all different software programs used provided the same features, such as adjustment for brightness and zoom.

Beyond the scope of this retrospective study, however, future research warrants an investigation into whether cheaper monitors would lead to an increase of C spine computed tomography requests in the emergency room, and also an evaluation of personal computer monitors versus the PACS workstation on the diagnostic value of computed tomography, MRI and radiographs of different organ systems. For this study, the amount of time spent on scoring monitors was consistent with common diagnostic practice in the emergency room. Only intermittent work at the monitors was necessary in the emergency room, unlike continuous reading in radiology departments. Therefore, we did not evaluate whether one type of display monitor prompted the observers to become tired sooner than another.

One important aspect of our findings is that the operating costs of the emergency room can be reduced by using monitors of relatively lower cost, yet affording a similar confidence to doctors when interpreting radiographs. Recently established fast internet and intranet connections, as well as reliable diagnosis made on lower cost monitor may pave the way for initial diagnosis of cervical spine fractures using LCD personal computer monitors. In addition, these monitors are more readily available than PACS workstations in the healthcare settings of both developed and developing countries; therefore, they can be used by doctors to make similarly confident diagnoses remotely.[12] Considering resource accessibility and financial constraints in hospitals, it may be practical that imaging data is evaluated on considerably cheaper LCD personal computer monitors.[13] The two LCD personal computer monitors (18.1-inch and 17-inch screens) are not much smaller than the PACS workstation (18.1-inch screen), but are more affordable and available while providing comparable confidence in diagnosis to doctors. The PACS workstation in this study costs 10 times as much as monitor 1 and nearly 70 times as much as monitor 2.

This study does not show that PACS workstations are no longer necessary and can be replaced by LCD personal computer monitors for routine clinical readings in all images. However, we find that LCD personal computer monitors are useful for offering a quick, accurate diagnosis comparable to PACS workstation for reading digitally transmitted cervical spine *x* rays in the emergency room. By lowering purchasing and maintenance costs in this aspect, the emergency room can invest money in other essential areas.

In addition, it is not necessary to confirm the findings of cervical spine fractures made on the personal computer monitors on PACS workstations. Therefore, without the need to confirm the diagnosis by another reader, patient turnover in the emergency room may also be increased. This implies a shorter waiting time to diagnosis for patients and may result in higher patient satisfaction. Lastly, the ability to make a quick and accurate diagnosis on LCD monitors may also reduce work-related stress for healthcare professionals in the emergency room.

CONCLUSION

LCD personal computer monitors and PACS workstation with similar viewing panels did not differ significantly in the diagnostic quality of cervical spine fracture *x* rays. LCD personal computer monitors are sufficient for fast, accurate diagnosis in the emergency room for the evaluation of cervical spine injuries at considerably reduced costs.

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