Chimera of digital radiography in spine surgery: False diagnosis of implant failure

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ABSTRACT

Background: Digital radiographs of the whole spine are made using marginally superimposed imaging plates exposed simultaneously to be combined by interpolation of the overlapping area. Post-processing artefacts in these radiographs leading to the misdiagnosis of implant breakage have not yet been described in the literature.

Methods: An erroneous fusion of a digital spine x-ray after scoliosis surgery created an image showing two broken rods, whereas both rods proved complete continuity intraoperatively. Following an interdisciplinary error analysis, the chain of errors was systematically reconstructed. Using the digital imaging material of patients operatively treated the same way; the reproducibility of the error was analyzed. Erroneous image fusions were produced by slight displacement of existing, not yet combined x-ray images of these patients.

Results: Under certain requirements, the false impression of implant breakage could be reproduced. Especially in the case of missing or malpositioned radiopaque markers, the hazard to overlook an erroneous image fusion is present. Within the post-processing step performed by qualified staff, control is indispensable and manual correction can be crucial.

Conclusions: This experimental study and causal analysis show the clinical relevance of post-processing artefacts in digital radiography. To prevent false diagnosis and maltreatment, the knowledge of possible sources of error is indispensable.

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1. Introduction

Digital radiography is being used in clinical practice since the mid-1980s.^{1,2} Computed radiography (CR) systems using photo-stimulable phosphor (PSP) image detector plates were first introduced commercially in 1983.³ In many hospitals, the classic x-ray film has been completely replaced by image-plate based CR cassettes. In addition to higher time and cost efficiency through rapid image availability, reduced storage space and lower film and development costs, digital radiography is associated with less

radiation exposure and has proven high reproducibility.^{4–7} Although the detailed information is reduced compared to conventional analog x-rays due to a lower spatial resolution,⁷ there is no relevance concerning this matter in clinical practice.^{4,8} For a better visualization of hidden details, the possibility of post-exposure image enhancement is available by subsequent adjustment of brightness, contrast and magnification or the application of digital filters.⁹

Digital measurement for scoliosis assessment has been proven to be superior to manual methods.¹⁰ The creation of digital x-ray images of the whole spine, like that of the whole leg, is difficult. Image acquisition is made using an imaging plate, which is a PSP-based plate made of barium fluorohalide.¹¹ The imaging plate is enclosed in a cassette, which is similar to a screen film cassette. Imaging plates of sufficient size to display the whole spine are not available.¹² In contrast to conventional x-rays, where films of any

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size can be used, current CR readers can only handle plates up to a maximum size of 43×43 cm. Thus, for computed radiographs of the whole spine, marginally superimposed imaging plates (Fig. 1) have to be used.¹³ These are exposed simultaneously, but digitized individually. This necessitates the supplemental post-processing step of digital image fusion.^{14,15} Artefacts caused by image composition during this process occur if the images are not precisely aligned.⁷ Initially, the process of image composition is fully automated. Structures in the overlapping area are smoothed by an interpolation software. A critical review by the technical staff is then essential, as manual corrections may be required.¹⁶ Even with technologic improvements, artefacts are still being encountered and may lead, in the worst case, to false diagnosis and mismanagement.¹¹ This report studies the clinical relevance of post-processing artefacts leading to the misdiagnosis of implant breakage that have not yet been described in published literature.

2. Materials and methods

This study is based on the critical causal analysis of the case of a 15-year-old adolescent female patient who presented with persistent pain after a mild contusion of the thoracic spine. Two and half years ago, she underwent a corrective surgery (according to Cotrel-Dubousset and Luque) because of a thoracolumbar scoliosis, Lenke type 6C with a thoracic Cobb angle of 47° and a lumbar Cobb angle of 76° , combined with coronal imbalance and distinct kyphosis. Despite having intensive conservative therapy with an individual corset treatment and physiotherapy, her scoliotic deformity was further progressive so that the surgical intervention was indicated. First a ventral release was carried out followed by dorsal instrumentation. The postoperative x-ray showed an incomplete correction of the deformity. Yet, the carrying axis of the spine was rectified in the frontal and the sagittal plane and the spinal balance was corrected; C7 being now located perpendicular to S1. The thoracic Cobb angle was corrected to 29° and the lumbar Cobb angle to 46° . In each follow-up examination afterwards, the

correct placement of an intact spinal fixation system was attested. Six months after the primary surgery, a complete bony fusion of the upper thoracic spine was found in a revision surgery for removal of a dislocated, non-load-bearing hook at the cranial end of the left rod. After that, the symptom-free patient was seen several times for clinical and radiological follow-up examinations. Each time, a good bony fusion and a well seated instrumentation was confirmed. At her last presentation after the above mentioned trunk contusion, the computed radiograph of the spine showed a mismatch of both Harrington-rods in their middle part, suggesting a fracture of both rods at the level of the 11th thoracic vertebra (Fig. 2). In contrary to previous diagnostic findings, this fracture inevitably suggested at least a partial segmental instability and an insufficient bony fusion of the lumbar spine. An adequate traumatic or otherwise causal event could not be found in her history. During the surgery performed consequently for implant removal and revision, however, a solid bony fusion and completely intact fixation implants were found. Accordingly, the removal of the spinal fixation system was possible without any problems. The case was discussed in a medical event quality assurance meeting which included an interdisciplinary expert team composed of radiologists, orthopaedic surgeons and radiology technicians. The retrospective causal analysis led to the only conclusion that due to a faulty process in the creation of the digital x-ray image, an illusion was created that was judged as a rod breakage by radiologists and spine surgeons as well. Following an exact error analysis, an experimental study was designed based on the comprehensive knowledge of the chain of possible errors leading to the misdiagnosis of rod breakage. Based on the radiological image material of another five patients with comparable spinal fixation, the incident described above was

Fig. 1. Arrangement of the PSP plates inside an X-ray cassette for generating large-sized computed radiographs (CRs). To create CRs, both white PSP plates are arranged in the X-ray cassette lying below. In the development process, they are automatically removed and reintroduced slightly displaced afterwards.

Fig. 2. Chimera of rod breakage (black arrow) due to an erroneous fusion in the composed CR.

simulated, the chain of errors was reconstructed and the resulting error was reproduced.

3. Results

The retrospective causal analysis of the case presented above suggested that the chimera of failure of the internal fixation device could be created through an erroneous fusion caused by the software used for post-processing. To support this hypothesis, a study was carried out using the postoperative radiographs of further patients who underwent multisegmental dorsal spinal instrumentation. Fig. 3A shows separately the thoracic and lumbar digital images of the spine of a patient prior to image fusion and prior to cutting the image to the area of the central beam. The overlapping zone needed for each image fusion is visible. In this case, the caudal portion of the thoracic imaging plate was positioned further from the focus than the cranial portion of the lumbar imaging plate during the exposure, identifiable by the lower exposure in the overlapping region. The passage through the plate, which was situated nearer to the focus, deliberately attenuated the x-rays. The radiopaque cross marker, which is easily identifiable, is placed on each separate image in the area of the central beam. The correctly merged x-ray image (Fig. 3B) was created through the automated software-based fusion. As in most cases, no further modification was necessary. To simulate the error, the two separate images were dislocated minimally relative to each other and re-fused (Fig. 3C). Now, the impression of an implant failure with a diffuse fracture line (black arrow), which can be interpreted as a fracture parallel to the imaging plate, arose in this case, too. But if the examiner is appropriately sensitized, he immediately recognizes the incongruent radiopaque cross marker (white arrow). In the clinical case described above, the marker was not positioned in the area of the central beam and therefore was exposed inadequately. Accordingly, it was hidden in the final step of post-processing and could not be used for image fusion or for identification of the erroneous fusion. Furthermore, in this simulation as in the clinical case described, a diffuse interruption of the 10th and 11th rib and an artefact of the

12th thoracic vertebra can be seen. The examiner is, however, firstly distracted by the software-related interpolation and soft-focus effect of the structures in the overlapping area. In our simulation, as in the described clinical case, the hard to notice but unexplainable discontinuity of single ribs went unnoticed. Instead, the attention is drawn to the pretended failure of the implant due to its high radiopacity and the resulting high contrast that clearly distinguishes it from the surrounding structures.

The chimera of rod breakage could be reproduced similarly in other cases, dependent on the course of the overlapping zone. When the overlapping zone was positioned differently, however, the erroneous fusion could be recognized at first glance. Fig. 4A shows another CR of the whole spine after multisegmental thoracolumbar instrumentation. The overlapping zone crosses two pedicle screws. After intentional erroneous fusion by slight displacement of the individual images (Fig. 4B), the image is immediately

Fig. 4. (A) Correctly composed CR after multisegmental instrumentation. The overlapping zone crosses two pedicle screws. (B) Erroneous fusion, created by displacement of the individual images so that the two pedicle screws appear conspicuously blurred.

Fig. 3. (A) Thoracic and lumbar individual images. Good to see are the lesser exposition of the lower thoracic PSP plate in the overlapping area and the radiopaque marker crosses. (B) Correct fusion to a CR of the whole spine. (C) Simulated erroneous fusion, creating the impression of a discontinuity of the left rod (black arrow). Note the incongruent radiopaque marker cross (white arrow).

Fig. 5. (A) CR after dorsal instrumentation and implantation of intervertebral cages. The overlapping zone crosses two pedicle screws and the cranial cage. (B) Simulated erroneous fusion. A shadow around the cage occurs. The incongruent point-shaped markers are noticeable.

recognizable as an artefact because of the diffuse display of the pedicle screws. Fig. 5A shows the correctly composed image of a patient's spine after implantation of intervertebral cages. The overlapping zone crosses the cranial cage and two pedicle screws. After displacement of the individual images (Fig. 5B), the image can also be identified as unrealistic by the double contour of the cage and the pedicle screws. Accordingly, when the overlapping zone intersects a cross connector, the radiograph could be identified as an erroneously fused digital image without radiopaque markers at first glance, too.

4. Discussion

The presented clinical case and the study based on it show the artefact susceptibility of digital x-ray imaging. It can generate unrealistic images that are not seen in conventional radiography that uses multiple x-ray films to show the whole spine or the whole leg. These films are fixed together and are immovable against each other during film development. The false presentation of a displacement of properly implanted materials and the resulting misdiagnosis of rod breakage are therefore unthinkable.

Adequate knowledge of the described technical aspects of digital radiography, the possible control mechanisms and the necessary prerequisites of image fusion are of great clinical significance, not only for radiologists, but also for the treating physician or surgeon. Misdiagnosis due to faulty digital processing, as shown above, can easily lead to incorrect treatment. Digital radiography appears to have a final error rate and therefore its results show some degree of uncertainty. Using current CR systems, software- and hardware-related artefacts have decreased, making operator errors more evident.¹¹ Computed radiography artefacts are broadly classified into image-acquisition and image-processing artefacts.¹⁵ The artefact encountered in this clinical case and which was simulated afterwards can be classified as a third type that we call post-processing artefacts. The performed experimental simulation of the faulty image fusion shows that a series of erroneous processes is necessary to generate the described composition artefact. Nevertheless, similar misrepresentations may result in everyday clinical practice and can go easily unnoticed.

The results of this study strongly indicate the utmost importance of the radiopaque markers and their correct positioning (Fig. 5). When properly located in the central beam and the overlapping zone of the imaging plates, these markers represent

effective means of error prevention. This confirms the hypothesis, that carefulness and correct use of already existing utilities during digital radiography play an important role in preventing misdiagnosis. Most artefacts in computed radiography are due to operator errors.¹⁵ A continuous training of radiographers in this technique and a thorough x-ray evaluation seem therefore inevitable.

The misdiagnosis of bilateral Harrington-rod breakage in this case rose suspicion of segmental instability. Implant removal without replacement was possible due to the intraoperative finding of a stable spondylodesis with full bony fusion. The indication for surgical revision due to material failure with no or inadequate trauma, particularly when diagnosed through a merged digital x-ray image, should, therefore, be carefully questioned and accurately analyzed by the treating surgeon. Similarly, Supakul et al. found that 16% of digital scoliosis studies had stitching errors that could result in a false diagnosis.¹⁷ Repeat radiographs and/or computer tomography may sometimes be necessary in doubtful cases to avoid medico-legal problems. New innovative technologies like EOS-Imaging are now available to provide a low-dose, high-resolution 3-D imaging of the whole spine and make such errors practically impossible.¹⁸

In summary, we conclude that when a plausibility conflict between clinical and radiological findings exists, the findings of fused digital images must be questioned. False images in CR are rare but can lead to serious consequences and medico-legal implications with malpractice claims. The awareness of this problem and the knowledge of possible sources of error can help to avoid such problems. In addition to a thorough post-processing work by qualified staff, expert control is indispensable and manual correction can be crucial.

Conflicts of interest

None.

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