Dose Optimization and Reduction in CT of the Musculoskeletal System Including the Spine

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13.1 Introduction

Since its introduction in the 1970s, computerized tomography (CT) has played an important role in the diagnosis of musculoskeletal disorders. It rapidly became the examination of choice for the diagnosis of disc herniation, fractures, bone tumours and some developmental abnormalities. Although the image quality was altered by streak artefact associated with medical devices, CT was also indicated in postoperative imaging (Blum et al. 2000; Iochum et al. 2001; Cotten et al. 2002; Fayad et al. 2005a, 2005b).

However, the performance of CT was hampered by its relatively low contrast resolution, which led to poor soft tissue evaluation compared with magnetic resonance imaging (MRI). Intra-articular lesions are almost impossible to detect without the administration of intra-articular contrast medium, and soft tissue masses are frequently misdiagnosed. CT is also the largest single source of medical exposure to radioactivity. For all these reasons, MRI has superseded CT as the first-line investigation in many situations.

Nevertheless, tremendous interest is now being expressed in CT due to its increased availability, low cost compared with MRI, and improved performance thanks to the advent of multidetector row CT (MDCT). With MDCT, images can be produced with submillimetre acquisition, thus providing true isotropic high-resolution volume data sets. Multiplanar reconstructions and 3D imaging improve the evaluation of bone and soft tissue disorders. The short acquisition speed (a few seconds) eliminates the need for sedation, minimizes dependence on patient cooperation and fits the technique perfectly for use in the complete evaluation of polytraumatized patients. Finally, the possibility of retrospectively modifying reconstruction parameters improves the overall performance without increasing the dose exposure. For example, large and small field of view reconstructions can be obtained from a single acquisition, simultaneously providing an overview and a detailed analysis of different anatomical regions. The slice thickness can be retrospectively increased, enhancing the signal-to-noise ratio and improving the soft tissue analysis (Blum 2002; Walter et al. 2003; Fayad et al. 2005a, 2005b).

Assessing and reducing dose is an important issue because some patients are very young and may undergo repeated CT examinations; furthermore, radiosensitive organs may be exposed to high doses.

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In most situations, CT examinations are performed for the evaluation of high-contrast structures and low doses can be recommended.

13.2 Typical Dose in Musculoskeletal CT Examinations

The International Commission on Radiological Protection (1991) recommends the establishment of agreed levels for use in investigations; when greater exposure is proposed, the need for it, and the implications of its use, should be examined. The Council Directive of June 30, 1997 requires the member states of the European Community to promote the establishment and use of diagnostic reference levels that are expected not to be exceeded during standard procedures (European Community 1997). The European Commission suggests reference doses, defined by the weighted CT dose index (CTDIw) and dose–length product (DLP), to be used in various CT examinations (European Commission 1999).

For the lumbar spine, the proposed reference levels are a CTDIw of 35 mGy and a DLP of 800 mGy·cm. For the osseous pelvis, the proposed reference levels are a CTDIw of 25 mGy and a DLP of 520 mGy·cm (European Commission 1999). However, these doses are based on survey data from the late 1980s and early 1990s, prior to the widespread introduction of spiral CT and MDCT (Shrimpton and Edyvean 1998; Hidajat et al. 2001). Since that time, MDCT has changed practice dramatically, and guidelines should be reviewed accordingly (Hidajat et al. 2001; Bongartz et al. 2004).

Some surveys have been conducted recently, but most focus on the chest and abdomen, and very few data are available concerning musculoskeletal examinations (Tables 13.1–13.3) (Galanski et al. 2001; Hidajat et al. 2001; Brix et al. 2003; Hatzioannou et al. 2003). New guidelines (March 2004) resulting from the work of a European study group of radiologists and physicists involved in diagnostic CT recommend that the CTDIvol should remain below 40 mGy for exploration of the cervical spine, below 20 mGy for limb and peripheral joint examinations, and below 15 mGy for the lumbar spine, pelvic skeleton and the shoulder (Bongartz et al. 2004).

CT scanning plays an increasing role in the management of musculoskeletal disorders, particularly with the advent of 16-section multidetector CT, which has numerous advantages. First, most studies are completed in under 10 s, which helps minimize the need for patient cooperation. The speed of image acquisition with MDCT is particularly advantageous compared with MRI. Second, isotropic volume image data are acquired, allowing retrospective reconstruction of multiple high-resolution image sets from the original raw data – thereby enabling 3D CT images to be produced in numerous planes from only one acquisition. Third, the slice thickness and reconstruction algorithm can be retrospectively modified in order to improve the signal-to-noise ratio, and thereby the soft tissue analysis, without increasing the dose of radiation. Fourth, when used correctly, 3D CT volume imaging can help minimize the dose. Finally, although its high-contrast resolution means that MRI is undoubtedly superior to CT in detecting and defining soft tissue and bone marrow abnormalities, MDCT is essential in several settings, as follows. In postoperative cases, metal artefact typically prohibits MRI evaluation, but volume rendering of a MDCT axial database virtually eliminates streak artefact associated with hardware. In the evaluation of masses, CT, unlike MRI, allows for the detection and characterization of calcification, cortical disruption, and periosteal reaction. In the setting of trauma, fracture lines are exquisitely defined, as is the extent of fracture. Large anatomical areas (such as in patients with congenital thoracic deformities or skeletal dysplasias), and areas not easily evaluated by MRI (such as the ribs and skull), are clearly delineated using MDCT (Iochum et al. 2001; Walter et al. 2003; Fayad et al. 2005a, 2005b).

In our institution, CT is indicated in the following situations: complex fracture, fracture with vascular impairment, dislocation with fracture, occult fracture (other than hip and scaphoid), skeletal and soft tissue tumours, postoperative follow-up, bone dysplasia, disc herniation, and joint evaluation. CT arthrography of the shoulder, elbow, wrist, first metacarpophalangeal joint, hip, knee and ankle may be preferred to MRI or MR arthrography for preoperative evaluation.

We retrospectively evaluated the CTDIw and the DLP for the types of CT examination most commonly carried out for musculoskeletal disorders in our institution. CT was performed using 16-row MDCT (Sensation 16, Siemens, Erlangen).

All images, plus dose values (CTDIvol and PDL) as displayed on the scanner, were sent to the picture archiving and communications (PACS) system (Impax V5, Agfa, Belgium). Five anatomical regions were selected for the study: cervical spine, lumbar spine, pelvic skeleton, shoulder and knee. For the cervical spine and the pelvic skeleton, acquisitions were performed with a collimation of 16×0.75 mm. The tube voltage was generally equal to 120 kV and the mAs product was usually set to 250. For the lumbar spine, the acquisitions were performed with a 16×0.75 mm collimation, 120 kV and generally 350 or 400 mAs. For the shoulder, the acquisitions were performed with a 16×0.75 mm collimation, 120 kV and generally 300 mAs. For the knee, collimations of 12×0.75 mm or of 2×0.6 mm (for ultra-high resolution) were used. The tube voltage was 120 kV and mAs values ranged from 150 to 350. In all cases, the pitch factor was between 1 and 1.8. The automatic exposure control (AEC) was not used.

Significant variations in CTDIw and DLP were observed for each type of examination (Tables 13.4, 13.5). This can be explained by the adjustment of exposure parameters according to patient size. Exposure parameters were also lower when the examination was focused on bony structures, whereas the mAs product was higher when a precise soft tissue evaluation was necessary. The major influence on dose was probably the extent of the target volume, which was increased when multiple lesions were suspected.

Table 13.1. Weighted computed tomography dose index (*CTDIw*) in CT examinations in some recent surveys. Data in *parentheses* are the minimum and maximum. (*NA* Not available)

Author, year of publication	Type of CT scan	Cervical spine CTDIw (mGy)	Lumbar spine CTDIw (mGy)	Pelvis and pelvic skeleton CTDIw (mGy)[b]	Extremities CTDIw (mGy)
Galanski et al. (2001)	Single-slice CT	33.9	37.1	26	NA
Hidajat et al. (2001)	Conventional	NA	32.8 (12.7–62.7)[a]	32.7 (23.7–47.5)	NA
	Spiral CT	NA	24.8[a]	16.4 (12.6–25.3)	NA
Hatziioannou et al. (2003)	Conventional and spiral CT	49.2 (14.9–103.2)	29.6 (10.6–53.3)	22.4 (8.7, 43.7)	NA
Brix et al. (2003)	Dual-slice and quad-slice CT	26.0	30.3	21.8[b]	14.8

[a] CT scan performed for disk evaluation
[b] Only the survey reported by Galanski and Brix concerns CT scan performed specifically for the pelvic skeleton

Table 13.2. DLP in CT examinations in some recent surveys. Data in *parentheses* are the minimum and maximum. (*NA* Not available)

Author, year of publication	Type of CT scan	Cervical spine DLP (mGy·cm)	Lumbar spine DLP (mGy·cm)	Pelvis and pelvic skeleton DLP (mGy·cm)[b]	Extremities DLP (mGy·cm)
Galanski et al. (2001)	Single-slice CT	129	216	487	NA
Hidajat et al. (2001)	Conventional	NA	391 (130–980)[a]	845 (504–2018)	NA
	Spiral CT	NA	270[a]	306 (168–488)	NA
Hatziioannou et al. (2003)	Conventional and spiral CT	295 (56–760)	203 (63–508)	336 (131–676)	NA
Brix et al. (2003)	Dual-slice and quad-slice	277	445	440	171

[a] CT scan performed for disc evaluation
[b] Only the survey reported by Galanski and Brix concerns CT scan performed specifically for the pelvic skeleton

Table 13.3. Effective dose in CT examinations in some recent surveys. Data in *parentheses* are the minimum and maximum. (*NA* Not available)

Author, year of publication	Type of CT scan	Cervical spine E*exam* (mSv)	Lumbar spine E*exam* (mSv)	Pelvis and pelvic skeleton E*exam* (mSv)[b]	Extremities E*exam* (mSv)
Galanski et al. (2001)	Singleslice CT	2.1	2.7	8.8	NA
Hidajat et al. (2001)	Conventional spiral CT	NA	NA	NA	NA
Hatziioannou et al. (2003)	Conventional and spiral CT	1.59 (0.30–4.10)	NA	6.38 (2.49–12.85)	NA
Brix et al. (2003)	Dual-slice and quad-slice	2.9	8.1	8.2	NA

[a] CT scan performed for disk evaluation
[b] Only the survey reported by Galanski and Brix concerns CT scan performed specifically for the pelvic skeleton

Table 13.4. CTDIvol in musculoskeletal examinations in the present authors' institution

	CTDIvol (mGy)					
	Cervical spine	Lumbar spine	Pelvis, skeleton	Shoulder	Knee	Knee (ultra-high resolution)[a]
Mean	21	32	21	25	18	17
Range	18.5–45.2	23.4–56.4	15.6–33.4	23.4–35.0	10.9–31.2	14.6–32.2
3rd quartile	21.4	35.0	23.4	27.3	21.8	17.3

[a] Acquisition with a collimation of 2×0.6 mm

Table 13.5. Dose–length product (*DLP*) in musculoskeletal examinations in the present authors' institution

	DLP (mGy·cm)					
	Cervical spine	Lumbar spine	Pelvis, skeleton	Shoulder	Knee	Knee (ultra-high resolution)[a]
Mean	411	782	602	332	425	263
Range	321–766	399–1527	366–1359	253–688	195–757	174–539
3rd quartile	455.2	825.5	680.2	349.2	555	287.5

[a] Acquisition with a collimation of 2×0.6 mm

With the advent of MDCT, and more specifically 16-section MDCT, the possible applications of CT scanning in musculoskeletal disorders have dramatically increased, and major changes have been made to scanning protocols. The entire spine can be explored for fractures (Fig. 13.1). Whole-body CT has been recommended for the diagnosis of multiple myeloma (Horger et al. 2005). Musculoskeletal explorations can be combined with CT angiography for the diagnosis of post-trauma vascular lesions, evaluation of musculoskeletal tumours, and diagnosis of artery entrapment syndromes (Fig. 13.2) (Karcaaltincaba et al. 2004; Fayad et al. 2005b). CT of the lumbar spine may be combined with sacroiliac joint evaluation when a spondyloarthropathy is suspected. All these new applications lead to an extended target volume or to multiphasic explorations.

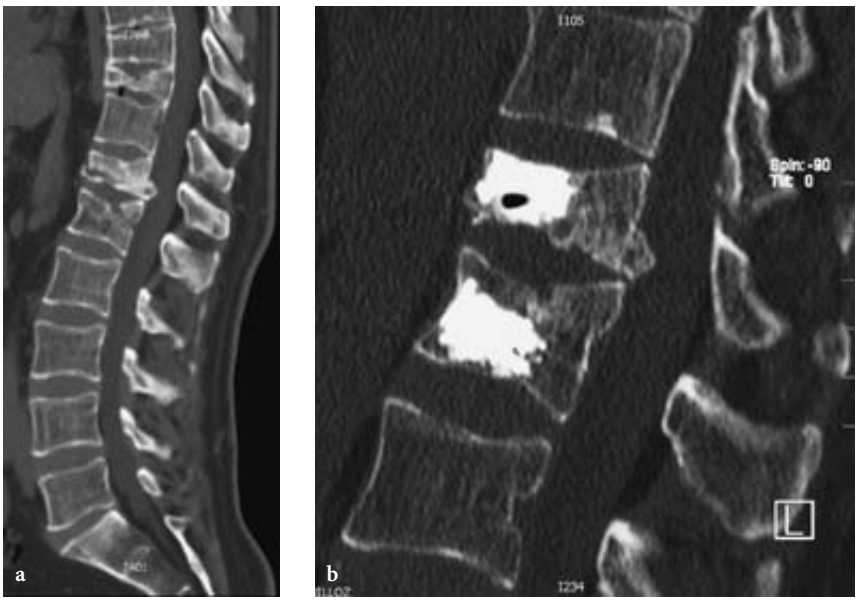

Fig. 13.1a, b. Vertebral fractures in a 38-year-old man. **a** Sagittal multiplanar reformation (*MPR*) with low-dose MDCT of the thoraco-lumbar spine. **b** Follow-up after kyphoplasty

13.3 Motion Studies

With improved temporal resolution, MDCT permits cinematic evaluation of the joints. Due to the limited width of the detectors (no more than 4 cm), only rotational motion can be explored at present. However, this technique could help in kinesiology studies and in the diagnosis of occult instabilities. Batch et al. (2004a) conducted a study involving a rotational phantom and patients undergoing shoulder arthrography with 16-section MDCT. Using a 12×1.5 mm collimation (18 mm), a partial scanning technique and a rotation time of 0.5 s, a structure located 3 cm away from the centre of rotation could rotate at the speed of one revolution in 15.8 s without significant artefact. With two motion acquisitions, one each in the upper and lower portions of the gleno-humeral joint, it is possible to evaluate the most important parts of the joint. With low-dose acquisitions (120 kV and 50 mAs) lasting 10 s, the total CTDIvol and DLP are respectively 144.4 mGy and 260 mGy·cm. Therefore, this technique could replace acquisitions obtained in different positions. The image quality obtained with such acquisitions also suggests that low-dose protocols could be applied to shoulder CT arthrography (Batch et al. 2004b). Finally, it is probable that with the advent of large detectors, CT motion studies will gain importance.

13.4 Modalities for Dose Reduction in Musculoskeletal CT

CT scanner manufacturers have made significant efforts to reduce radiation doses while maintaining good image quality. All the technical approaches to dose reduction are described in detail in the literature (Linton and Mettler 2003; Kalra et al. 2004; Althen 2005). Radiologists and radiographers are now aware of the need for ALARA (as low as reasonably achievable) protocols, but they sometimes appear reluctant to reduce the dose. Another issue is that new CT applications lead to an extended volume of exploration and multiphasic acquisitions, again resulting in increased doses of radiation.

Various investigators have focused on the possibility of lowering the dose used for CT without altering its diagnostic capabilities. Their work concerns pulmonary nodule detection, CT colonography, renal colic, acute appendicitis, chronic sinusitis and screening (Rusinek et al. 1998; van Gelder et al. 2002; Tack et al. 2003a, 2003b; Keyzer et al. 2004). A recent study by Horger et al. (2005) showed that whole-body low-dose MDCT is appropriate for the diagnosis of lytic bone changes and for the assessment of fracture risk in multiple myeloma patients – among whom it represents a serious alternative to current standards. A 16×1.5 mm collimation was

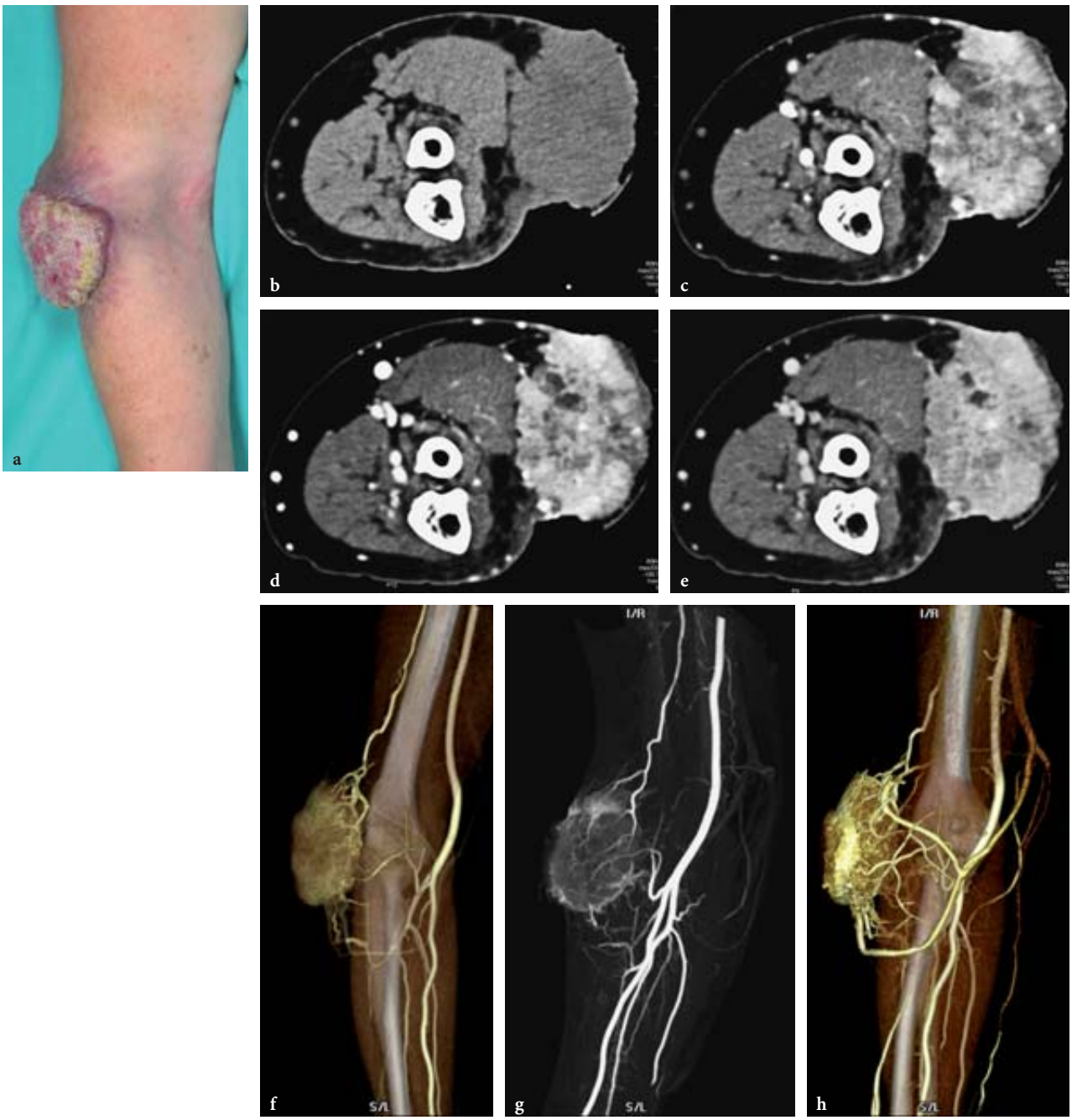

Fig. 13.2a–h. Multiphasic exploration with CT in a case of Merkel cell tumour of the elbow. Four acquisitions were performed with 80 kV and 230 mAs: before IV injection of contrast media and at the arterial, venous and equilibrium phases. **a** Photography of the elbow showing a large hypervascularized tumour. **b–e** Axial slices obtained at the different phases showing a large mass with a rapid initial enhancement followed by sustained late enhancement and some areas of necrosis highly suggestive of a malignant tumour. **f, g** Volume rendering technique (*VRT*) and maximum intensity projection (*MIP*) obtained from the arterial acquisition highlighting the three arteries feeding the tumour. **h** VRT obtained from the venous phase demonstrating the vascular relationship of the tumour as well as rapid venous opacification. In such cases, multiphasic MDCT provides a precise topographic and compartmental analysis of the tumour, a vascular map of the anatomical region and a dynamic evaluation of the lesion

used with a tube voltage of 120 kV and a tube current time product ranging from 40 to 70 mAs. The effective radiation dose of MDCT calculated at a tube current time product of 40 mAs was 1.7-fold higher than the mean radiation dose associated with conventional X-ray (4.1 mSv versus 2.4 mSv) (Horger et al. 2005).

Due to the high contrast of bony structures, low-dose protocols should be enthusiastically recommended for their evaluation. Such protocols are particularly suited for the diagnosis and evaluation of fractures or of bone tumours and lytic processes. However, doses should not be reduced when exploring the cervicothoracic junction as the noise from the shoulder degrades the image quality. Low-dose protocols are also well adapted to CT arthrography (with the exception of the shoulders of large patients), as the intra-articular contrast medium produces a high contrast interface between intra-articular structures. No study has yet determined whether low-dose protocols would be of value when soft tissue evaluation is also necessary. With regard to disc evaluation, a good signal-to-noise ratio is necessary in order to detect subtle changes, for example in cases of disc sequestration or facet joint synovial cyst.

One of the main advantages of MDCT in evaluating musculoskeletal disorders is the possibility of retrospectively modifying the slice thickness. The acquisition can be performed with the thin slices best suited for bony structure evaluation. Reconstructing thicker slices with a standard convolution filter produces images with a better signal-to-noise ratio, thus improving soft tissue evaluation (Fig. 13.3). Thicker slices can also be obtained using multiplanar reconstruction software.

Some authors recommend modulating tube current in order to decrease the dose. When evaluating the cervicothoracic junction, Schaefer-Prokop et al. (2003) favours automatic current modulation, and increasing the maximum mAs setting by a factor of 1.5–2 to ensure sufficient exposure during the lateral projection while significantly reducing the dose on the AP projections. Automatic current modulation can also be used for pelvic examinations. A dose reduction of 23%–45% is possible with no significant difference in subjective assessments of image quality (Iball et al. 2006). Mastora et al. (2001) found that online tube current modulation resulted in a 35% reduction in the product of mean tube current and time with no loss in image quality when exploring the thoracic outlet for suspected thoracic outlet syndrome.

Finally, the classic recommendations concerning patient positioning remain crucial in order to reduce the noise and streak artefacts and to minimize exposure. The region of interest has to be placed as close as possible to the centre of the gantry in order to improve the spatial resolution and the signal-to-noise ratio. The explored volume has to be as thin as possible to limit scattered radiation and beam hardening artefacts. That is why shoulder girdles are placed on different levels when exploring the shoulder.

With MDCT, the isotropic volume allows multiplanar reformation (MPR) to be performed in any plane of interest, including traditional axial, coronal, sagittal and oblique planes. The plane of choice for the acquisition is the one which offers a minimal width of the explored region, in order to improve the signal-to-noise ratio and to limit beam hardening artefacts. Therefore, the spine is explored without tilting the gantry. Using a four-row MDCT, Ludig et al. (2000) compared the radiation dose between two protocols on the same patients, using the same collimation (4×1 mm), slice thickness (1.25 mm), MPR thickness, pitch factor, tube voltage, tube current time product and convolution filter. With the first protocol, three helical acquisitions were obtained. They were localized on L3–L4, L4–L5 and L5–S1 discs from the level of the pedicle of the upper vertebra to the level of the pedicle of the lower vertebra, with gantry tilting in order to obtain slices parallel to the disc planes. In the second protocol, one single acquisition was performed in the axial plane from the level of L3 pedicles to S1 and secondary MPR were obtained in the disc planes. Skin dose was compared for 12 patients. Thermoluminescent dosimeters were placed on the right antero-superior iliac process, the omphalus, the sternum and L4 spinous process. The average skin dose with the first protocol was 101 mGy on the right antero-superior iliac process, 82 mGy on the omphalus, 129 mGy on the L4 spinous process and less than 1 mGy on the sternum. The average skin dose with the second protocol was 74 mGy on the right antero-superior iliac process, 88 mGy on the omphalus, 83 mGy on the L4 spinous process and less than 1 mGy on the sternum. Although the target volume was about 40% greater with the second protocol, the effective dose was slightly reduced and the signal-to-

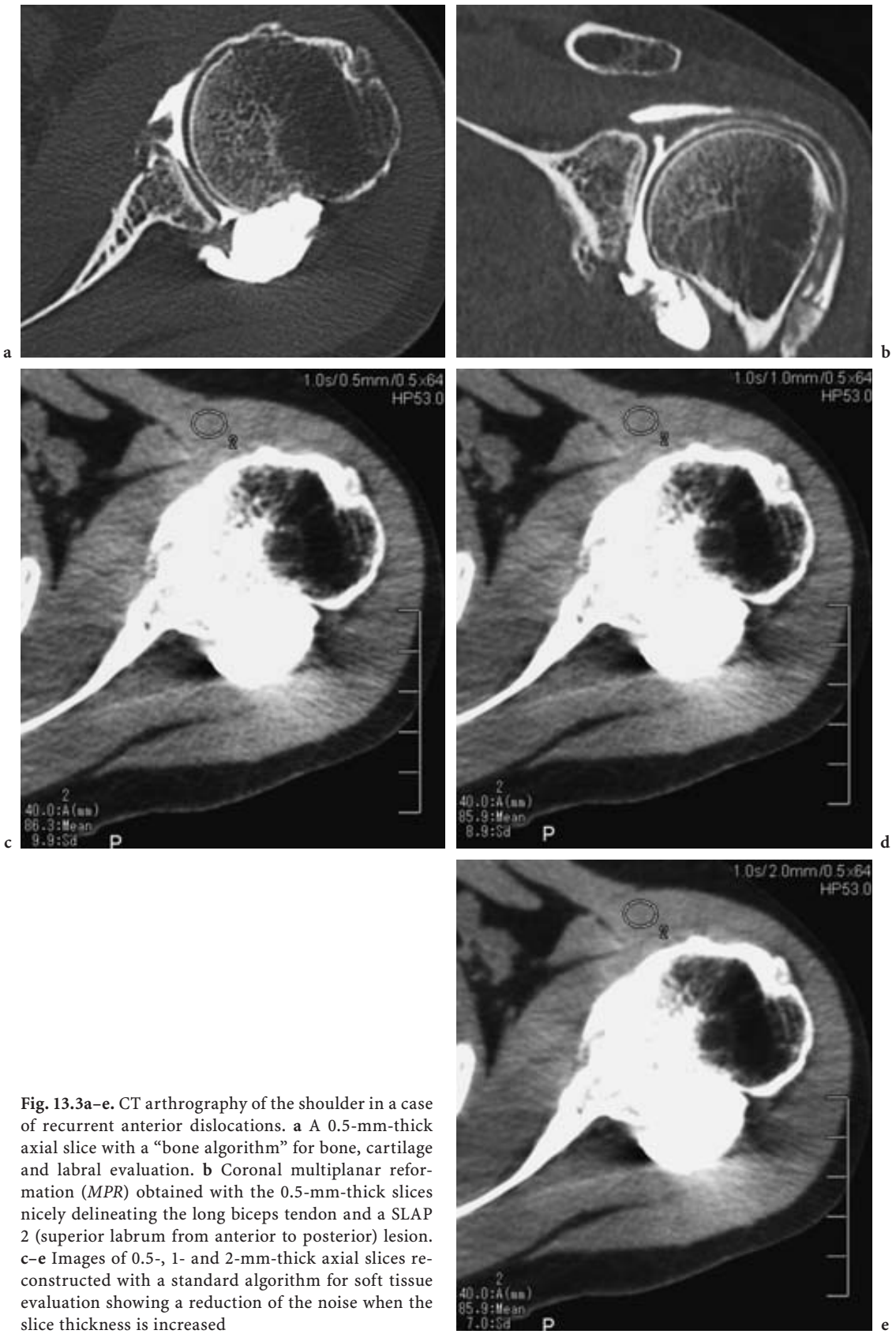

Fig. 13.3a–e. CT arthrography of the shoulder in a case of recurrent anterior dislocations. **a** A 0.5-mm-thick axial slice with a "bone algorithm" for bone, cartilage and labral evaluation. **b** Coronal multiplanar reformation (*MPR*) obtained with the 0.5-mm-thick slices nicely delineating the long biceps tendon and a SLAP 2 (superior labrum from anterior to posterior) lesion. **c–e** Images of 0.5-, 1- and 2-mm-thick axial slices reconstructed with a standard algorithm for soft tissue evaluation showing a reduction of the noise when the slice thickness is increased

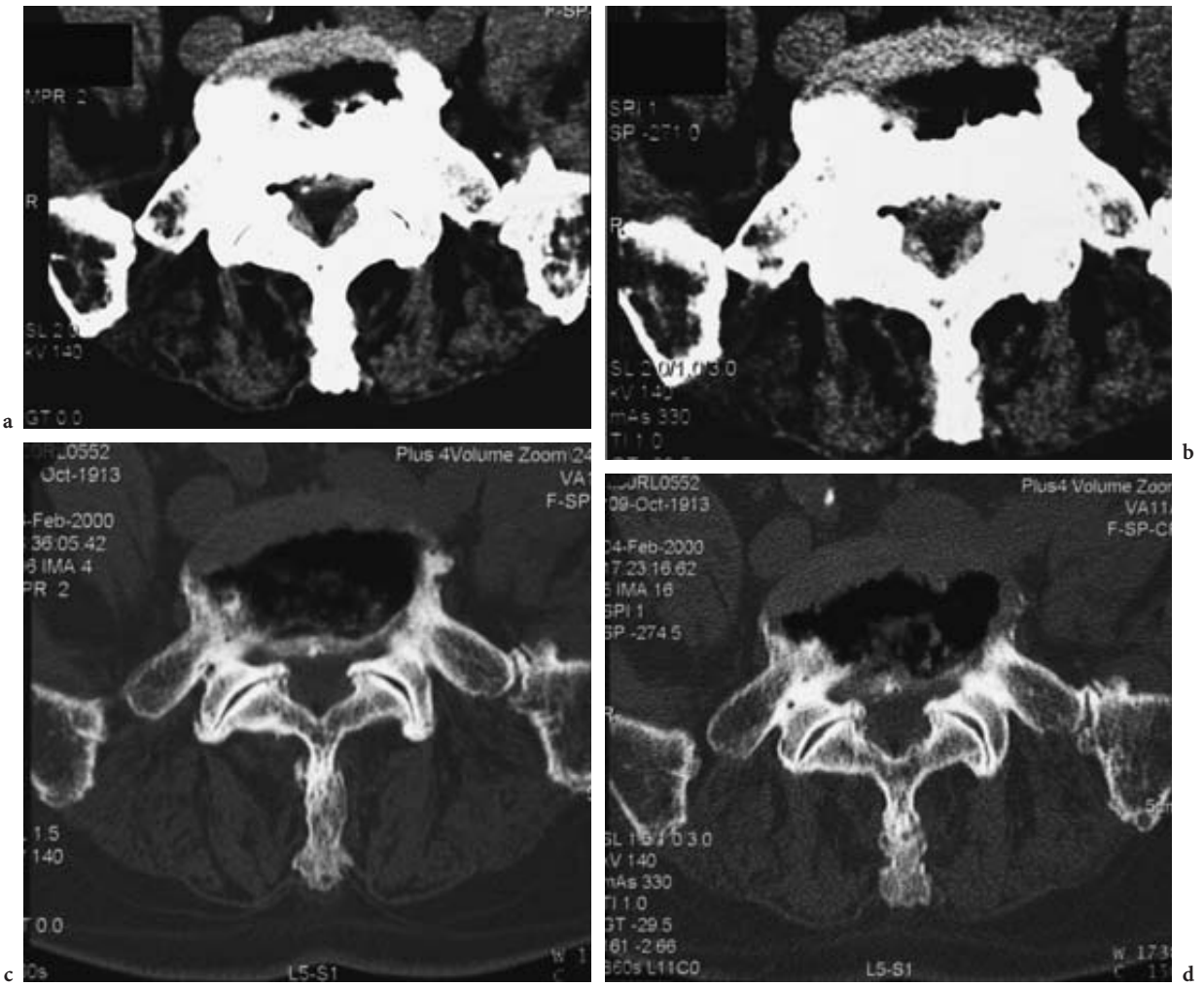

Fig. 13.4a–d. Comparison of oblique MPR obtained with an axial MDCT acquisition and oblique native slices from a tilted MDCT acquisition for the evaluation of L5–S1 vertebrae. The collimation is 4×1 mm. The inclination of the gantry is 29.5° for the tilted acquisition. MPR and native slices acquisition and reconstruction parameters are identical for soft tissue evaluation and bony analysis. **a**, **b** A 2-mm-thick MPR and native slice with a soft tissue algorithm showing a significant reduction of the noise of the MPR image with a better delineation of the disc compared to the native oblique slice. **c**, **d** A 1.5-mm-thick MPR and native slice with a bone algorithm showing equivalent in-plane spatial resolution

noise ratio was improved (up to 25%, depending on the gantry tilting) (Fig. 13.4).

13.5 Conclusion

MDCT is widely used in the diagnosis of musculoskeletal disorders. Few data are available on radiation dose for musculoskeletal CT examinations. New CT applications lead to extended volume exploration and multiphasic acquisitions, resulting in increased dose of radiation. However, most examinations should be performed with low-dose protocols.

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