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ORIGINAL ARTICLE

Metal Artefact Reduction by Dual-energy Computed Tomography Using Monoenergetic Extrapolation: In-vitro Determination of Optimal Monoenergetic Level with Different Metallic Implants Using a Phantom Body

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ABSTRACT

Objective: *To identify the optimal monoenergetic level, balancing metal artefacts, and the amount of noise present for imaging of metal implants using dual-energy computed tomography (CT) and focusing on the assessment of peri-prosthetic soft tissue.*

Methods: *Four metallic implants commonly used in the hips were placed in a phantom body: unipolar hemiprosthesis, dynamic hip screw (DHS), intra-medullary (IM) nail, and titanium insert. The unipolar hemiprosthesis was imaged at two points: the head and stem. The head of the hemiprosthesis and DHS were imaged in two axes: one axial to and one resembling the angle at its expected position in the hip with respect to the scanner. The IM nail was assessed both at the level with and without a screw inserted. A region of interest to measure the noise level of the images was first performed with different monoenergetic levels (70-170 kV with increments of 10 kV). Four monoenergetic levels were then chosen (80, 90, 105, 120 kV) for each implant and were assessed and scored (presence of least to most artefacts: score 1-4) by nine radiologists who were blinded to the monoenergetic level. A total of eight sets of images were assessed. The scores for different monoenergetic levels were compared using analysis of variance.*

Results: *In the first part of the experiment, the images with the least amount of noise were in the range of 85-95 kV, thus we included 90 kV among the images for subsequent scoring. The mean score for different monoenergetic levels for all implants was as follows: 3.94 for 80 kV, 2.68 for 90 kV, 1.50 for 105 kV, and 1.88 for 120 kV ($p < 0.001$), with 105 kV having the least metal artefacts. For subgroup analysis of individual implants, 105 kV was found to produce the best quality images with a statistically significant better score for hip stem, DHS, and IM nail. 120 kV trended towards being the best monoenergetic level when imaging the hip head and the IM nail with screw where relatively more artefacts were present. 90 kV trended towards being the best monoenergetic level when imaging the titanium insert where artefacts were nearly absent.*

Conclusion: *With regard to imaging the soft tissue around a metallic implant, the overall optimal monoenergetic level for reduction of metal artefacts using dual-energy CT is 105 kV. When more artefacts are inherently present, 120 kV trended towards being the best monoenergetic level. When artefacts are minimal, 90 kV trended towards being the optimal monoenergetic level with the least amount of noise present.*

Key Words: *Artifacts; Metals; Prostheses and implants; Tomography, X-ray computed*

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中文摘要

利用雙能量CT單能外推法減少金屬偽影：在假體內使用不同金屬植入物以確定最佳單能譜值

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目的：在利用雙能量CT為金屬植入物作成像並觀察周圍骨與軟組織病變的過程中，找出最佳單能水平、讓金屬偽影最低並平衡噪聲分佈。

方法：把單極半髖假肢、動力髖螺釘（DHS）、髓內釘和鈦插件四種常見用於臀部的金屬植入物置入假體內。在單極半髖假肢頭和桿部兩點進行成像。半髖假肢頭和DHS在兩個平面進行成像：即相對於掃描儀的中軸，以及在其臀部的預期位置。髓內釘則分別在插入螺絲和沒有插入螺絲時進行評估。用興趣區量出不同單能量（70至170 kV，每個升幅為10 kV）影像的噪聲水平。然後在每個植體上選擇四個單能量（80、90、105和120 kV），讓9名放射科醫生為每個單能量水平圖像評分（他們並不知道圖像的單能量水平）；1分為最少金屬偽影，4分最多。共評估了8套成像。利用方差分析比較不同單能量圖像的分數。

結果：實驗第一部分發現最少噪聲的成像均在85-95 kV的範圍內，因此我們把90 kV納入以下評分。所有金屬植入物的各單能水平平均分數為：80 kV 3.94分、90 kV 2.68分、105 kV 1.50分、120 kV 1.88分（p<0.001）；105 kV出現最少金屬偽影。對於個別的金屬植入物，半髖假肢的桿部、DHS和髓內釘在105 kV的情況下會得到最佳的去除金屬偽影效果，統計顯著。半髖假肢的頭部和有螺釘的髓內釘則在120 kV的情況下產生最佳單能水平，但相對金屬偽影較多。鈦插件在90 kV的情況下會產生最佳單能水平，而且幾乎沒有金屬偽影。

結論：要為金屬植入物附近軟組織進行成像時，總體上使用雙能量CT 105 kV影像信號可達致最佳單能水平和最少金屬偽影。當金屬偽影無可避免時，使用120 kV影像信號可達致最佳單能水平。當偽影少時，使用90 kV影像信號可達致最佳單能水平並產生最少噪聲。

INTRODUCTION

Metal implants are known to cause artefacts when imaged by computed tomography (CT), thus degrading the image quality and obscuring details for accurate diagnosis. The use of dual-energy CT provides an attractive method for metal artefact reduction. It can reproduce different monoenergetic levels by means of data extrapolation. Different monoenergetic levels can reduce the artefacts by various degrees. The first reported optimal level was 105 kV.[1] We have occasionally found 120 kV to be a better monoenergetic level with regard to metal artefact reduction although this level also produced noisier images. Thus we formulated our study to identify the optimal monoenergetic level for imaging common hip implants such that metal artefacts would be minimised and the amount of noise would be balanced. We investigated this using a body phantom with common hip metallic implants.

This study aimed to identify the optimal monoenergetic level, balancing metal artefacts, and the amount of noise present, for imaging of metal implants using dual-energy CT focusing on the assessment of the periprosthetic soft tissue.

METHODS

Preparing the Phantoms

Four metallic implants commonly used in the hip were placed in a CT phantom body: unipolar hemiprosthesis, dynamic hip screw (DHS), intra-medullary (IM) nail, and titanium insert. They were placed in the central slot of the phantom with the interface between the implant and the phantom filled with KY jelly (Figure 1). Pre-inserted materials at the periphery of the phantom were left unremoved. A control phantom filled with jelly only was also prepared.

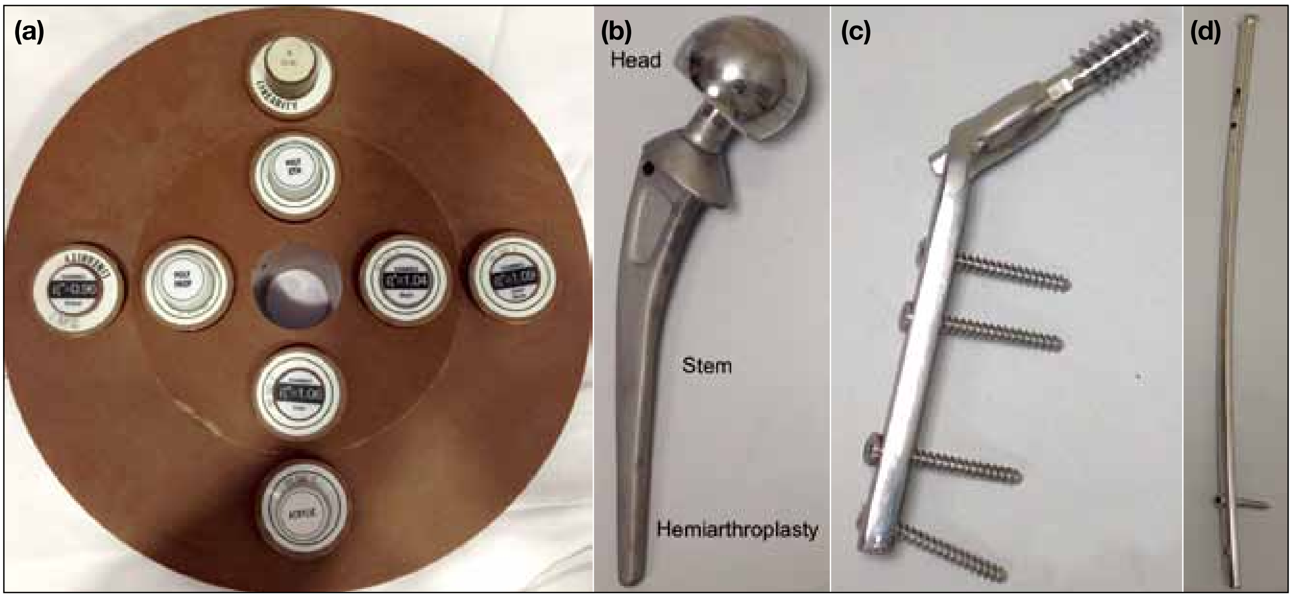

Figure 1. Photograph of the (a) phantom body and implants: (b) unipolar hemiprosthesis, (c) dynamic hip screw, and (d) intra-medullary nail.

Imaging the Phantoms

The phantom with the inserted prostheses was imaged by dual-source CT scanner (SOMATOM Definition Flash; Siemens, Forchheim, Germany). The scanning protocol was as follows: 140 kV (with tin filter) + 100 kV (at ratio of 1:1); 200 mAs; 0.5 s rotation time; 0.7 pitch.

The unipolar hemiprosthesis was imaged at two areas: the head and stem. The head of the hemiprosthesis and DHS were imaged in two axes; one axial to the scanner and one resembling the angle of its expected position in the hip with respect to the scanner. The IM nail was assessed both at the level with and without a screw inserted. The jelly-only control was also imaged.

Image Reconstruction and Analysis

The CT images were reconstructed using the syngo.via software with monoenergetic function. This function decomposes the CT numbers of the images and can reproduce images at different monoenergetic levels via data extrapolation. For implants inserted at an angle, they were reconstructed such that a true axial image of the implant was obtained. The images were then exported and reviewed on the picture archiving and communication system. They were assessed with standardised soft tissue window (L:350;W:50) as our aim was to evaluate the effect of artefact on visualisation of the adjacent soft tissue and at the same time appreciate the change in noise level.

Monoenergetic Level with Least Amount of Noise

In the first part of the study, we aimed to identify the monoenergetic level with the least amount of noise, given the CT parameters. A 8 cm^2 region of interest (ROI) was positioned at a fixed position (Figure 2) to measure the standard deviation of Hounsfield unit to reflect the background noise at different monoenergetic levels (70-170 kV with increments of 10 kV). The monoenergetic level with the least amount of noise was selected as one of the references for the second part of the study.

Monoenergetic Level with Best Quality, Least Metal Artefacts, and Acceptable Noise Levels

In the second part of the study, we aimed to determine the monoenergetic level with the least amount of metal artefacts present such that the soft tissue background of the phantom was least obscured but balanced with the amount of noise present.

Four monoenergetic levels were then chosen (80, 90, 105, 120 kV) for each implant and were assessed and scored (presence of least to most artefacts: score of 1 to 4) by nine radiologists who were blinded to the monoenergetic level used. A total of eight sets of

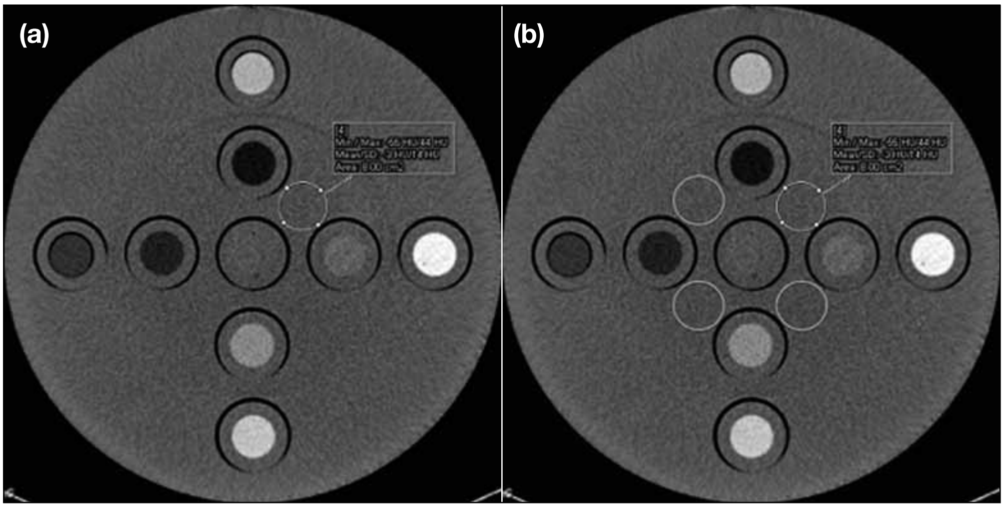

Figure 2. Images showing placement of an 8 cm² region of interest (ROI) at a fixed position to measure the background noise of jelly-only phantom, with (a) showing the ROI in the top right quadrant. (b) Measurement of ROI is also repeated in the other three quadrants shown in the second image.

images were assessed. The scores for the different monoenergetic levels were compared using analysis of variance. Statistical analysis was performed using the Statistical Package for the Social Sciences (version 20.0 for Mac.; SPSS Inc., Chicago [IL], USA).

As this study did not involve patients. No approval was sought from the ethics committee.

RESULTS

Monoenergetic Level with Least Amount of Noise

In the first part of the study, images with the least amount of noise were in the range of 85 to 95 kV. This is shown in Figure 3 where the trough of the graph representing the least amount of noise lies in this range for both the jelly and the hemiprosthesis. We also repeated the measurement of noise in the other three quadrants in the jelly-only phantom. They also showed the trough to be in a similar range (Figure 4). We thus included 90 kV among one of the references in the second part of the experiment.

Monoenergetic Level with Best Quality, Least Metal Artefacts, and Acceptable Noise Levels

The mean score for the different monoenergetic levels for all implants is shown in Table 1. They were as follows: 3.94 for 80 kV, 2.68 for 90 kV, 1.50 for 105 kV, and 1.88 for 120 kV, with 105 kV having the least metal artefacts.

The sets of images with different monoenergetic levels are shown in Figures 5 and 6. An example of implants with a mild-to-moderate artefact (stem of hemiarthroplasty) and a severe artefact (IM nail with screw) are displayed.

For subgroup analysis of individual implants, a level of 105 kV produced the best quality images with statistically significant better scores when imaging the hip stem, DHS, and IM nail (Table 2). A level of 120

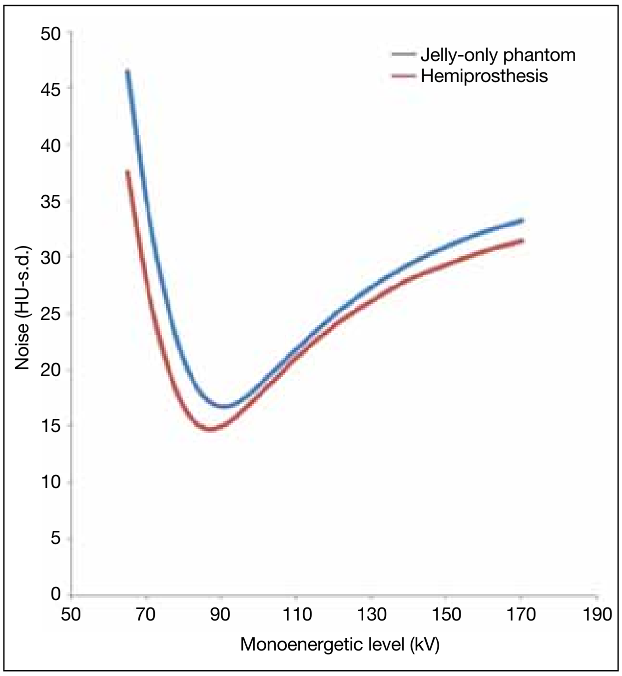

Figure 3. Noise level plotted against monoenergetic level for the jelly-only phantom and the hemiprosthesis.

kV trended towards being the best monoenergetic level when imaging the hip head and the IM nail with screw where more artefacts were inherently present. A level of 90 kV trended towards being the best monoenergetic level with titanium insert where artefact was nearly absent. When they were imaged at the anatomical position where artefacts were augmented by multiplanar reconstruction (MPR), 105 kV trended towards being the best monoenergetic level.

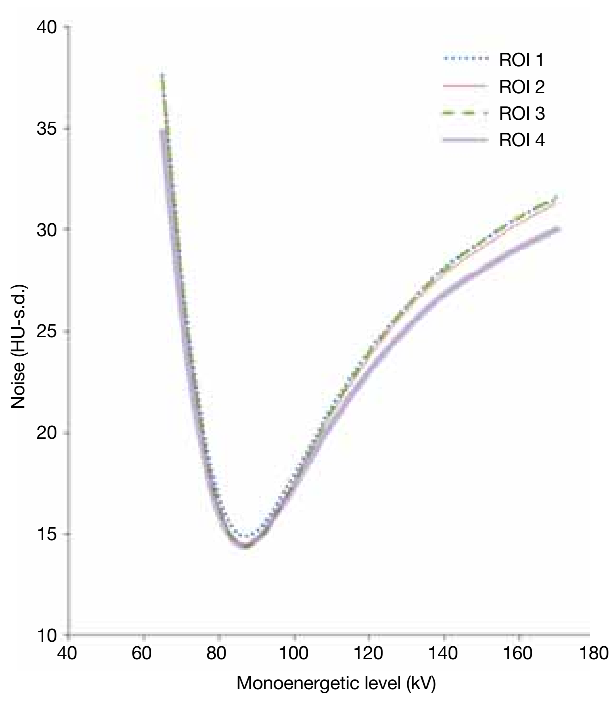

Figure 4. Noise level against monoenergetic level for four regions of interest in the jelly phantom.

Table 1. Mean scores of different monoenergetic levels for all implants. The best score is shaded in grey.

Monoenergetic level (kV)	Mean score (the lower the less artefact)	p Value (using the best monoenergetic level as reference)
80	3.94	<0.001
90	2.68	<0.001
105	1.50	-
120	1.88	0.01

DISCUSSION

The increasing use of dual-source or dual-energy CT scanners has brought about many new clinical applications of CT. In musculoskeletal imaging, these include diagnosis of gout, assessment of bone marrow oedema, and metal artefact reduction.

Metal implants are known to cause artefacts when imaged at CT due to the effects of photon starvation and beam hardening.[2] These artefacts impair assessment of the internal structure of the implant as well as obscure the detail of the soft tissue in its vicinity and their interface. With single-source CT scanners, methods to reduce the degree of artefacts include using higher kV and mA and narrowing the collimation.[3] With dual-source / dual-energy CT scanners, metal artefacts due to beam hardening have been found to be, though not entirely, significantly reduced.[1,4,5] The source images acquired with the two energies can be decomposed, reproducing images at different monoenergetic levels via data extrapolation. This only requires one scan to be obtained and the patient dose is kept the same. Bamberg et al[1] were the first to report a range of 95 kV to 150 kV as suitable levels for reconstruction and specified 105 kV as the optimal monoenergetic level. Subsequent studies reported optimal monoenergetic levels ranging from 105 kV to 148 kV.[5-8] These studies varied in terms of the region imaged, material, and the geometry of the implants that may affect the optimal monoenergetic level.

The conclusion of these studies resulted in a wide range of monoenergetic levels. In daily practice, it

Table 2. Mean scores of different monoenergetic levels for individual implants. The best score is shaded in grey.

Mono-energetic level (kV)	Mean score (p value)							
	Hemiprosthesis – head	Hemiprosthesis – stem	Dynamic hip screw	Intra-medullary nail	Intra-medullary nail with screw	Titanium insert	Hemipros-thesis – head anatomical position	Dynamic hip screw-anatomical position
80	4 (<0.001)	4 (<0.001)	4 (<0.001)	4 (<0.001)	3.89 (<0.001)	4 (<0.001)	3.67 (<0.001)	4 (<0.001)
90	3 (<0.001)	2.78 (<0.001)	2.67 (<0.001)	2.89 (<0.001)	2.89 (0.01)	1.67	2.89 (<0.001)	2.67 (0.005)
105	1.56 (0.67)	1.11	1.33	1	1.78 (0.26)	2.11 (0.27)	1.56	1.56
120	1.44	2.11 (<0.001)	2 (0.04)	2.11 (<0.001)	1.44	2.22 (0.19)	1.89 (0.40)	1.78 (0.50)

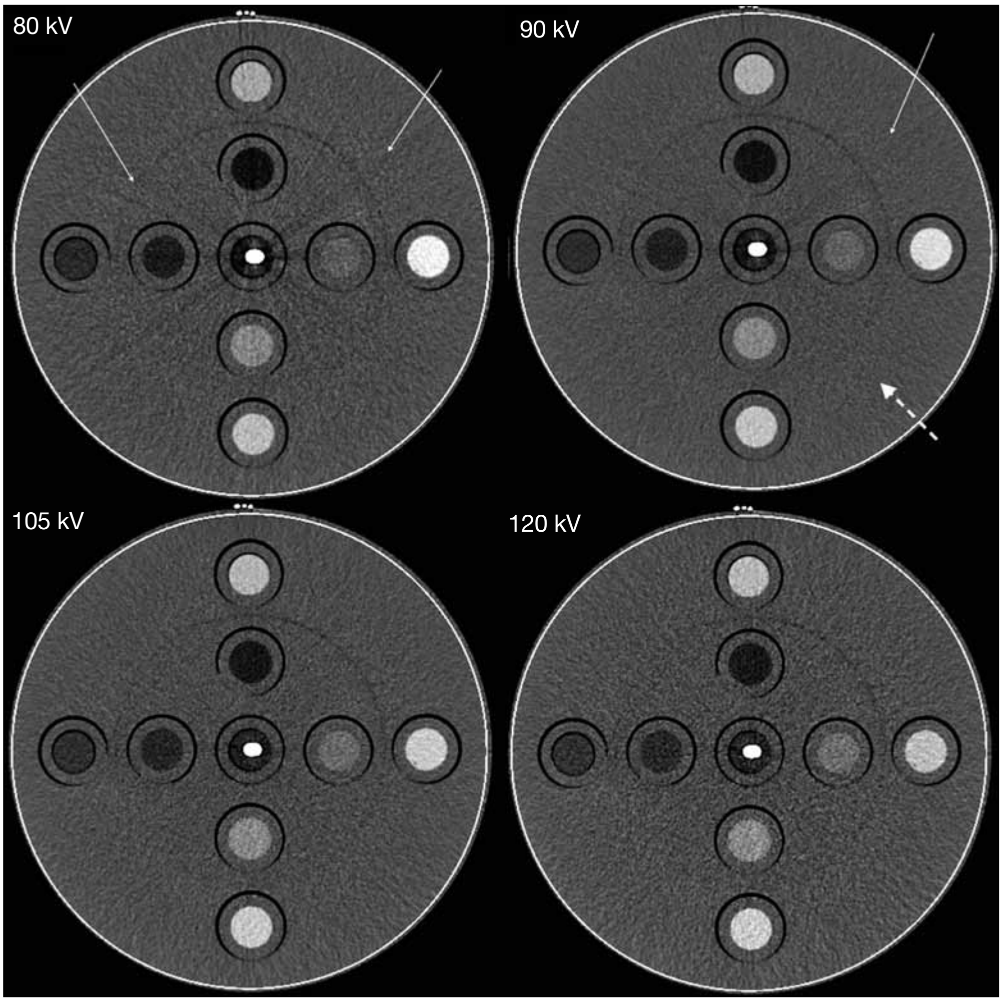

Figure 5. Images of stem of hemiarthroplasty. 105 kV has the best quality and 80 kV the worst quality. Beam hardening artefacts are shown as dark bands (solid arrows), and the 90 kV image has the least amount of background noise (dotted arrow).

is impossible to archive image reconstruction at all of these monoenergetic levels and clinicians who do not have access to the radiological database require a single set of images to review. Thus obtaining a single set of images with the best image quality is necessary. Artefacts should be minimised and at the same time the images should be of an acceptable noise level. In addition, imaging is often driven by protocol and a radiologist may not be available at the time of imaging to choose the optimal monoenergetic level. Therefore it is more practical if the optimal monoenergetic level can be confined to a few useful ones that can be generalised to all patients. We focused our analysis on the visualisation of soft tissue in the vicinity of the implant in contrast to previous studies that looked at the visibility of the implant itself. We used soft tissue window in our analysis such that we could simultaneously appreciate the change in the background noise and degree of obscuration by the streak artefacts.

In the first part of our study the monoenergetic level with the least amount of noise was in the range of 85 kV to 95 kV and the noise increased with increasing kV after 95 kV: 120 kV images were noisier than 105 kV images. This level, however, is dependant on the amount of noise in the source images and the dose distribution and is thus specific for the CT parameters used.[9]

In the second part of our study, 105 kV was the overall best monoenergetic level for all implants combined. This agrees with Bamberg et al[1] who reported 105 kV as a quite robust level that could be considered the best level for implants in general. Nonetheless, in our subgroup analysis of individual implants, 120 kV

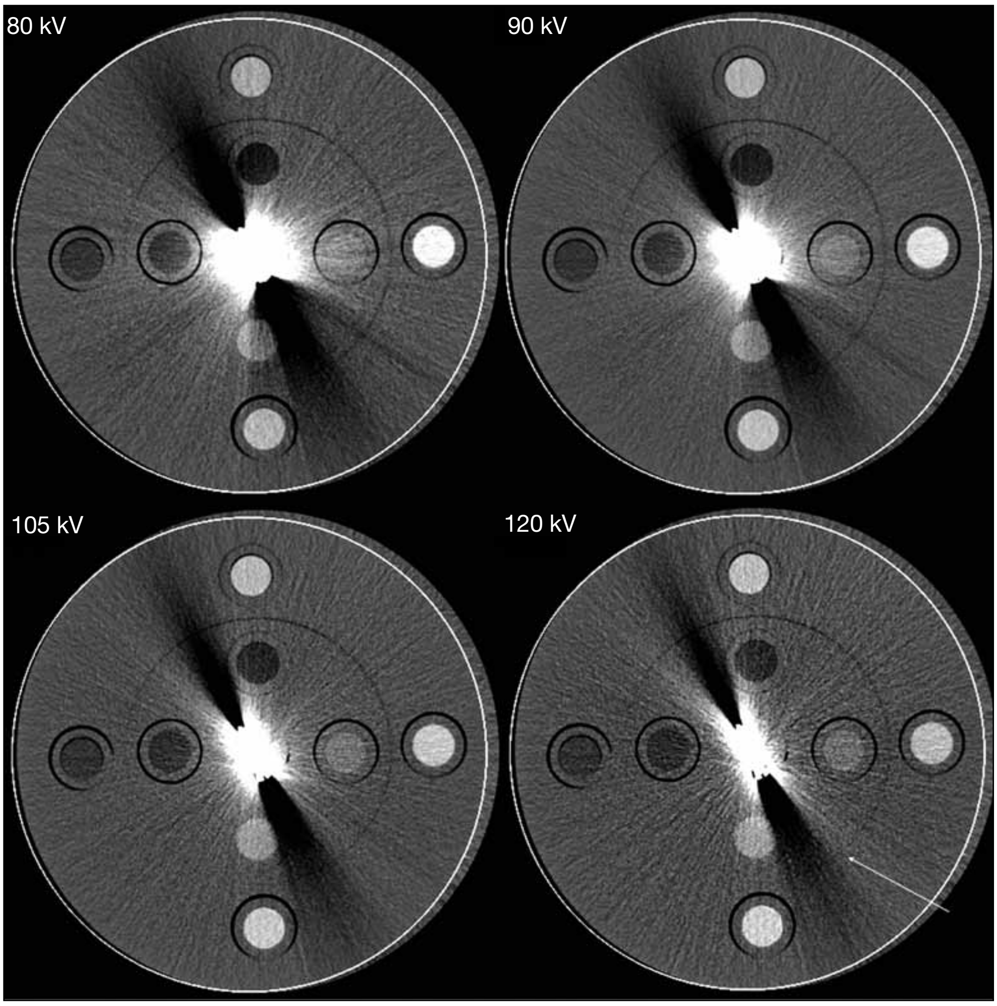

Figure 6. Images of intramedullary nail with screw. 120 kV has the best quality and 80 kV the worst quality. The narrowest band of artefacts is shown with 120 kV (arrow).

trended towards being the best monoenergetic level when implants produced more inherent artefacts such as with images of the head of the hemiprosthesis and the IM nail with screw inserted. The more significant artefacts with these image sets may be related to the thickness and non-circular configuration of the implant rather than the material itself. This is because the stem compared with the head of the same hemiprosthesis and the IM nail without the screw compared with the same IM nail with the screw present produced much fewer artefacts. 90 kV trended towards being the best monoenergetic level with titanium insert where artefact was almost absent. This may be because when there are no artefacts, background noise became the discriminating factor rather than the streak artefacts. When they were imaged at the anatomical position where artefacts were augmented by MPR, 105 kV only trended to being the best monoenergetic level with no statistical difference in score compared with 120 kV.

A limitation of our study is that we only compared four monoenergetic levels in the second part of our study based on previous literature and our routine practice. The implants that we included in our study were also only those that are commonly used in the hip region while those used elsewhere in the body were not investigated.

CONCLUSION

With regard to imaging the soft tissue around a metallic implant, the overall optimal monoenergetic level for reduction of metal artefacts using dual-energy CT is 105 kV. When more artefacts are inherently present, 120 kV trended towards being the best monoenergetic level. When artefacts are minimal, 90 kV trended towards being the best monoenergetic level with the least amount of noise present.

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