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Optimisation of imaging parameters during CT guided interventional procedures in patients with total hip arthroplasty

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ABSTRACT

Objective: To determine the optimal KV and mAs settings during CT guided injections in the presence of a total hip arthroplasty so that image quality is maintained whist keeping the dose as low as reasonably achievable.
Methods: A total hip arthroplasty phantom with needles with differing gauges was scanned using different CT parameters (from low dose to high dose) and evaluating if this had any effect on needle conspicuity. Conspicuity was graded from 1 to 3 by 2 independent blinded reviewers.
Results: Irrespective of the CT settings used (high dose or low dose parameters) needle conspicuity was not adversely affected by the THA for either scorer, therefore a kVp of 100 mA and a. In addition the needle gauge did not affect the conspicuity of the needle.
Conclusion: CT guided injections in this total hip arthroplasty phantom model can be performed without any adverse effect on the conspicuity of the needle tip on low dose CT settings.
Advancement in knowledge: This paper enables one to optimise the kV and mA while performing interventional procedures.

1. Introduction

Total hip arthroplasty (THA) is one of the most frequently performed operations in the UK. In 2018 the number of hip replacement procedures in England, Wales and Northern Ireland totalled 106,116 based on numbers submitted to the National Joint Registry.[1] The number of procedures performed is increasing year on year and it is predicted by 2035, the number of hip replacement procedures performed will increase to 439,097.[2] Whist the early results for THA were disappointing[3–10] advancements in component design, cementation techniques and improved surgical technique has led to significant improvement in clinical outcome and implant longevity over the last 30 years. Despite such developments, some patients continue to experience pain after surgery with up to 27% having mild discomfort and 6% having more severe pain11. Clinical assessment followed by the appropriate imaging is mandatory in the work-up of a painful THA. Radiographs are the first line of investigation followed by additional imaging techniques such as ultrasound, magnetic resonance imaging (MRI) and computed tomography (CT) when trying to identify an underlying osseous or soft tissue cause of pain. Image guided intervention such as peritendinous injection, soft tissue biopsy or bone biopsy around the THA can help identify pathological processes and potential pain generators around the hip. Interventions on such patients can be performed by ultrasound, fluoroscopy or under CT guidance. CT guided interventional procedures may be favoured as they allow pinpoint accuracy of needle placement and can visualise nearby important structures allowing them to be avoided.

Metal implants, however, pose certain challenges during CT guided interventional procedures, namely metal artefact which manifests itself as alternating bright and dark steaks across the image. This can potentially obscure the anatomical area of concern and/or the tip of the biopsy or injection needle, which could lead to misplacement of the needle. The 2 main causes for metal artefact are photon starvation and beam hardening although scatter, partial voluming effects, under sampling and motion are contributory.[12]

The objective of this study was to ascertain the optimum higher peak voltage (kVp) and the tube charge (tube current x time (mAs)

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levels when performing CT guided interventions in patients with THA so that image quality is maintained (reducing metal artefact) whist at the same time observing the ALARA principle of keeping the radiation dose as low as reasonably achievable to safely perform the procedure. Simulation of the "real life" situation was performed using multiple differing sized needles (from 22, 24, 25G) and a specially fabricated total hip arthroplasty phantom.

2. Materials and methods

The phantom was made by mixing 345g of generic agar powder in 3L of water. A cobalt chromium Striker total hip replacement model within a plasticized bony hemipelvis was suspended in the agar gel solution and was left overnight for the agar to harden.

Low dose CT protocol: Low dose CT was acquired using the Siemens Somatom Sensation AS (Siemens Medical Systems). 3 × 90 mm BD Univia™ Quinke spinal access needles of different sizes (25G, 24 G and 22G) (BD Medical, UK) were placed into the phantom at the site of the greatest cross sectional area of metal (and hence the greatest amount of metal artefact) and this was at the level of the femoral head/proximal neck) Fig. 1. After a planning scan the kVp was adjusted from 120 to 140 kVp, an auto mA setting was used which automatically adjusted the mA for a given kVp. Slice thickness was also varied from 0.6 to 1.5 mm. The dose was calculated as a product of the CTDIvol (mGy) and the craniocaudal length of the scan (z axis length) which gives the DLP(dose length product) per scan. For the biopsy software package settings (in which a much smaller area is scanned during one revolution of the scanner) the kVp was adjusted from 100 to 140 kVp slice thicknesses of 1.2 and 2.4 mm were performed and the total dose was calculated.

2 radiologists blinded to the individual scan data reviewed the image data to subjectively assess the visibility of the needles at the different scan settings. The visibility of the needle tip was scored based on a 3-point scale (1 - streak artefact present from THA which did impair needle tip visualisation, 2 – streak artefact from THA which did not impair needle tip visualisation, 3 – no streak from artefact THA). The individual needles were also assessed for the presence or absence of streak artefact associated with the needle itself and if this had a bearing on needle conspicuity. This was scored based on a scale from a study by McWillimas et al.[13] (1 – streak artefact from needle which impaired needle tip visualisation, 2 – Streak artefact from the needle tip but did not impair needle tip visualisation and 3- no needle tip streak artefact). The needles were placed parallel to the CT beam as would be expected during any CT guided interventional procedures. Hospital review board approval was obtained for this study.

Fig. 1. Total hip arthroplasty phantom. 25, 24 and 22 gauge needles positioned into the phantom at the maximal site of cross section of the metal to give the greatest degree of prosthesis related artefact.

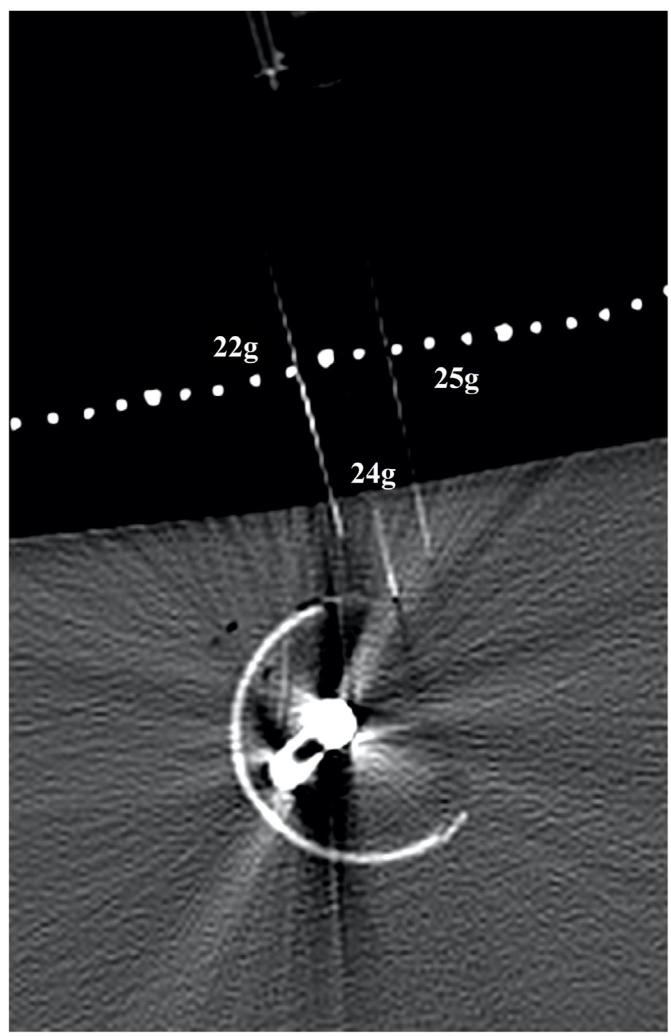

Fig. 2. CT appearances corresponding to series 11 in Table 1. Settings were KV 100, mAs 2.5, slice thickness 1.2 mm, DLP 8.3 mGycm (low dose). There are prosthesis related and needle related artefact but it does not obscure the tip of the needle.

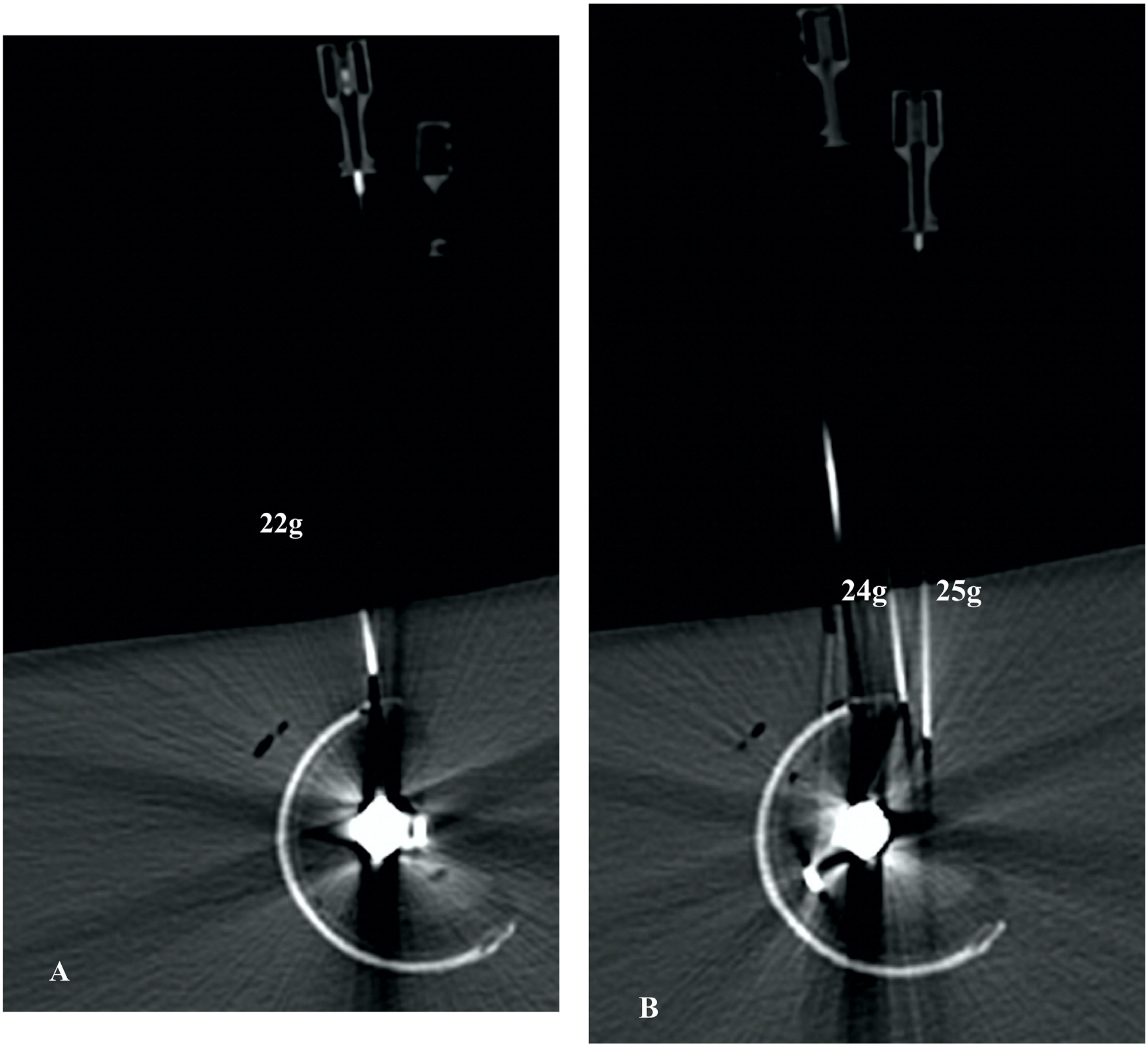

Fig. 3. CT appearances in series 15 in Table 1. Settings were KV 140, mAs 6.5. Slice thickness 2.4 mm, DLP 12.4 mGycm (high dose). 3a shows the 22 gauge needle. 3b shows the 24 and 25 gauge needle (for the same CT settings). There are prosthesis related and needle related artefact but it does not obscure the tip of the needle.

3. Results

At all settings of KV and mAs there was streak artefact form the THA (prosthesis related) but this did not have any effect on the needle conspicuity (prosthesis related score of 2 for all settings) (Figs. 2 and 3). There was a 100% interobserver correlation. In addition at all settings of KV and mAs there was some streak artefact generated from the tip of the needle itself but again it did not impact on the conspicuity of the needle tip (Needle related score of 2 for all settings). Again there was 100% interobserver correlation. The cross sectional size of the needle also made no difference to the degree of conspicuity either from the streak artefact form the prosthesis or the needle itself for either scorer. Slice thickness did not make a difference to the degree of conspicuity either from the prosthesis or the needle itself for either scorer. A summary of the results is presented in Table 1. There was perfect agreement between the readers and kappa correlation was 1.

4. Discussion

Photon starvation occurs due to the high atomic numbers of the materials used in a hip prosthesis. When photons pass through any material they interact with the material by the photoelectric effect and Compton scatter. At the energies used in diagnostic imaging, the likely hood that the photoelectric effect occurs is proportional to Z/E^3 (Z is the atomic number and E is the energy of the photon). As hip replacements are made up of materials with high atomic numbers, the amount of photoelectric interactions increases whereas Compton scatter is fairly constant which results in an increased proportion of the photons to be absorbed by the hip replacement relative to the surrounding soft tissues. This results in the X-ray beam becoming markedly attenuated after passing through the hip prosthesis with much fewer photons reaching the detectors. This results in large statistical errors in the projection data with the formation of bright and dark streaks along the direction of greatest attenuation.

Table 1
Summary of the results. Conspicuity of the needle tip was scored on a 1–3 scale based on artefact from the prosthesis (P) and the needle tip (N).

Scan	Slice thickness mm	kV	mAs	Craniocaudal Length of images obtained (cm)	DLP (mGy cm)	CTDIvol (mGy)	Lateral needle conspicuity (25G) Rad1 Black Rad 2 Red		Middle needle Conspicuity (24G) Rad1 Black Rad 2 Red		Medial needle conspicuity (22G) Rad1 Black Rad 2 Red	
							P	N	P	N	P	N
1	0.6	100	4.9	13.4	71.2	4.9	2 2	2 2	2 2	2 2	2 2	2 2
2	0.6	120	8.3	13.4	120.5	8.3	2 2	2 2	2 2	2 2	2 2	2 2
3	0.6	140	12.6	13.4	182.8	12.6	2 2	2 2	2 2	2 2	2 2	2 2
4	1.0	100	4.9	13.4	70.8	4.9	2 2	2 2	2 2	2 2	2 2	2 2
5	1.0	120	8.3	13.4	120.5	8.3	2 2	2 2	2 2	2 2	2 2	2 2
6	1.0	140	12.5	13.4	181.7	12.5	2 2	2 2	2 2	2 2	2 2	2 2
7	1.5	100	4.9	13.4	70.8	4.9	2 2	2 2	2 2	2 2	2 2	2 2
8	1.5	120	8.3	13.4	120.4	8.3	2 2	2 2	2 2	2 2	2 2	2 2
9	1.5	140	12.8	13.4	186.0	12.8	2 2	2 2	2 2	2 2	2 2	2 2
10	(isequence) 1.2	120	4.3	2.2	8.3	4.3	2 2	2 2	2 2	2 2	2 2	2 2
11	(isequence) 1.2	100	2.5	2.2	4.9	2.5	2 2	2 2	2 2	2 2	2 2	2 2
12	(isequence) 1.2	140	6.5	2.2	12.4	6.5	2 2	2 2	2 2	2 2	2 2	2 2
13	(isequence) 2.4	120	4.3	2.2	8.3	4.3	2 2	2 2	2 2	2 2	2 2	2 2
14	(iseqeunce) 2.4	100	2.5	2.2	4.9	2.5	2 2	2 2	2 2	2 2	2 2	2 2
15	(iseqeunce) 2.4	140	6.5	2.2	12.4	6.5	2 2	2 2	2 2	2 2	2 2	2 2

Prosthesis related: 1 - streak artefact present which did impair needle tip visualisation, 2 – streak artefact which did not impair needle tip visualisation, 3 – no streak artefact.
Needle related: 1 – streak artefact from needle which did impair needle tip visualisation, 2 – Streak artefact from the needle tip which did not impair needle tip visualisation, 3 - no needle tip streak artefact.
Individual radiologist scores for each CT setting are documented in black for scorer 1 and red for scorer 2. The CTDIvol (mGy) and the DLP (mGy cm) was calculated per scan run.

Beam hardening occurs when the polychromatic X-ray beam, which is made up of photons with a range of energies pass through a material. The lower energy photons of the beam are preferentially absorbed resulting in the mean energy of the photons within the beam to increase. This is amplified in situations when the beam passes through material with high atomic number such as a hip prosthesis. The projection data is interpreted as passing through a lower attenuation material and therefore appears darker than it should.

Simple approaches to correct the effects of photon starvation and beam hardening include increasing the higher peak voltage (kVp) and increasing the tube charge (tube current x time (mAs). Whist this can reduce the metal artefact there will be a concomitant increase in the radiation dose to the patient. Most modern CT scanners have biopsy packages, which allow control of the scanner using a foot switch allowing immediate acquisition of a number of contiguous slices on a single rotation of the scanner to confirm needle position. Because of this, the total dose during such procedures is fairly low despite the requirement to increase the kVp and mAs to reduce the effects of photon starvation and beam hardening.

No specific studies have been performed looking at the visibility of the needle tip during interventional procedures in patients with a total hip arthroplasty and the strategies to improve visualisation. There have been previous studies looking at the presence of streak artefact specifically around the biopsy needle during CT guided procedures. Stattaus et al.[14] evaluated the occurrence of streak artefact from the biopsy needle during the CT guided biopsy of small hepatic lesions. They showed that lesions which were poorly visualised due to streak artefact from the biopsy needle were associated with an increase in the false negative biopsy rate by 12.8%. McWilliams et al.[13] evaluated the factors that influenced the visualisation of the needle tip during CT guided needle biopsy. They demonstrated that both streak artefact and needle tip visualisation was improved in cases where the central stylet was removed. The presence of streak artefact tends to occur when 2 adjacent structures have markedly differing attenuation values. The main contributing factors for the streak artefact around total hip arthroplasty are due to beam hardening and photon starvation as explained before. The use of a bow tie filter (to absorb lower energy photons creates a more homogenous beam) can help reduce metal artefact but there is a decrease in signal to noise ratio unless the radiation exposure is increased, in addition extension of the window width to 40,000HU can reduce streak artefact.[15] British health and safety legislation state the radiation administered to an individual as part of a radiological investigation should be as low as reasonably practicable (ALARP) and therefore this study concentrated on simple manoeuvres to reduce the degree of metal artefact including increasing the higher peak voltage and increasing the tube charge which are which can easily be undertaken by the operator during CT biopsy to help optimise the image. Patient factors which can have an implication on image quality include body habitus, ability to breath hold and movement in the scanner, the use of a phantom standardised such variables.

The study clearly demonstrates that needle tip visualisation (at the site of maximal metal artefact-which is where the cross sectional area of the THA is greatest) is still well preserved despite decreasing the kVp to the lowest value of 100 kVp (keeping a constant mA of 60 mAs which is the minimum value on the scanner) (Figs. 2 and 3). The effect of varying mA on needle visualisation was evaluated using a mini-helical acquisition with using the auto mA setting which adjusts the mA depending on the kVp. The scan was performed over a fixed distance and varying slice thickness. Again, needle tip visualisation was not affected with the use of dose reducing parameters. The use of different needles with differing cross sectional diameters did result in focal streak artefact at the tip of the needle but did not affect the conspicuity of the needle tip at any of the various CT settings (see Table 1 and Figs. 2 and 3).

The limitations of this study include the fact that this is a phantom based study. In the real life situation there would be additional factors which may affect needle conspicuity such as body habitus, the ability to breath hold and the presence of air at the needle tip (especially if instilling local anaesthetic along the tract with the stylet removed) which can adversely affect needle conspicuity. Additionally the fact that the needle sizes are all fairly similar is also a limitation, further work could look at the effect of a wider range of needle sizes and also using a soft tissue surrogate in the phantom to be able to assess visibility of the tip in an adjacent soft tissue structure as how the needle appears in a target structure or how far away the tip is from a critical structure is important clinically but this has not been specifically addressed in this study.

In conclusion, this phantom based study shows that injections around the hip can be performed in patients with total hip arthroplasty without any adverse effect on the conspicuity of the needle tip on low dose (biopsy package) CT settings. In addition the gauge of the needle does not have a significant bearing on the conspicuity of the needle tip, which gives the user a choice of needle options depending on the clinical scenario without fear of obscuration of the needle tip.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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