

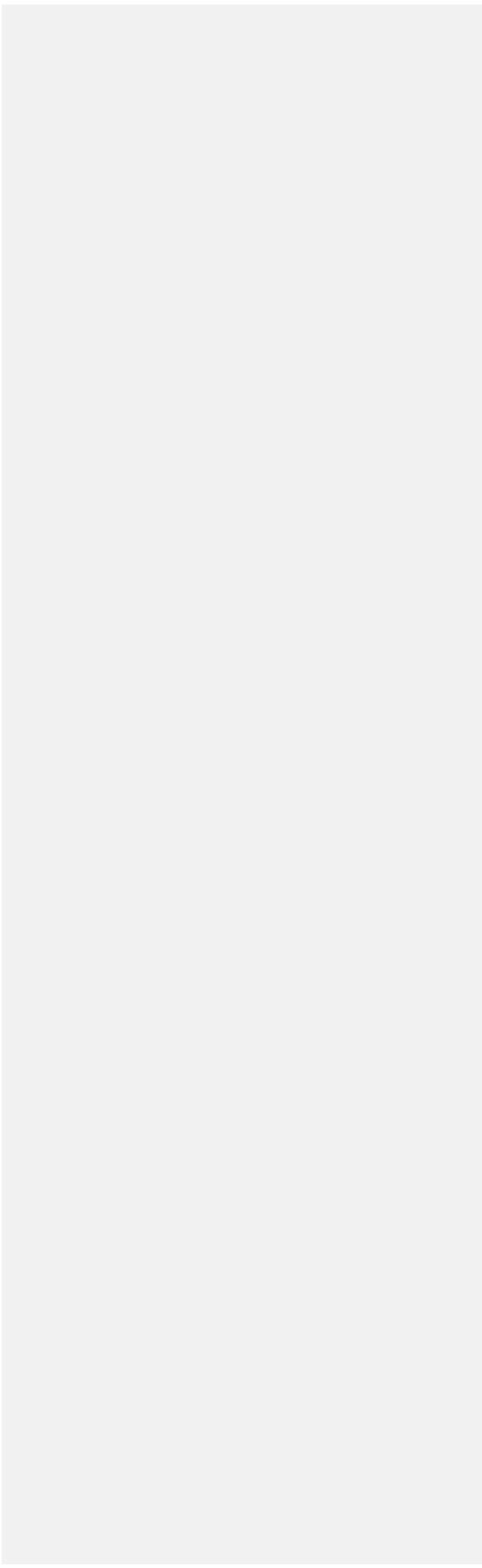
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Determination of a suitable low dose abdominopelvic CT protocol using model based iterative reconstruction through cadaveric study



25 Abstract

26 *Objective*

27 Cadaveric studies provide a means of safely assessing new technologies and optimising
28 scanning prior to clinical ~~validation~~ use. Reducing radiation exposure in a clinical setting
29 ~~usually requires can entail small~~ incremental dose reductions to avoid missing important
30 clinical findings. The use of cadavers allows assessment of the impact of more
31 substantial dose reductions on image quality. Our aim was to identify a suitable low
32 dose abdominopelvic CT protocol for ~~subsequent~~ clinical ~~use~~ validation.

33

34 *Methods*

35 Five human cadavers were scanned at one conventional dose and three low dose
36 settings. All scans were reconstructed using three different reconstruction algorithms:
37 filtered back projection (FBP), hybrid iterative reconstruction (60% FBP and 40%
38 adaptive statistical iterative reconstruction (ASIR40)), and model-based iterative
39 reconstruction (MBIR). Two readers rated the image quality both quantitatively and
40 qualitatively.

41

42 *Results*

43 MBIR reconstructions had significantly better objective image noise and higher
44 qualitative scores compared with both FBP and ASIR40 reconstructions at all dose
45 levels. The greatest absolute noise reduction, between MBIR and FBP, of 34.3 HU
46 (equating to a 68.1% reduction) was at the lowest dose level. MBIR reduced image
47 noise and improved image quality even in CT images acquired with a mean radiation
48 dose reduction of 62.2% compared with conventional dose studies reconstructed with

49 ASIR40, with lower levels of objective image noise, superior diagnostic acceptability
50 and contrast resolution, and comparable subjective image noise and streak artifact
51 scores.

52

53 *Conclusion*

54 This cadaveric study demonstrates that MBIR reduces image noise and improves image
55 quality in abdominopelvic CT images acquired with dose reductions of up to 62%.

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57

58

59 *Keywords*

60 Abdominopelvic; Tomography, X-ray Computed; Cadaver; Iterative reconstruction;

61 Radiation exposure

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73 **Introduction**

74 There has been an exponential increase in the use of computed tomography (CT) in
75 recent years with CT currently imparting more than 50% of all radiation exposure from
76 diagnostic imaging¹. The relationship of radiation exposure from diagnostic imaging to
77 a quantifiable risk of cancer induction remains a controversial topic. However,
78 protracted exposure to low-level ionising radiation is widely believed to be associated
79 with an increased risk of malignancy²⁻⁴ and dose optimisation without loss of diagnostic
80 performance is essential to good practice when performing CT. Abdominopelvic CT
81 accounts for 50% of total CT collective dose⁵ in many patient cohorts, and dose
82 reduction strategies in this area will therefore have a significant impact on the overall
83 population dose from diagnostic imaging.

84 Potential dose reduction techniques that may be employed when performing
85 abdominopelvic CT include automatic exposure control⁶, low tube voltage techniques⁷,
86 scan range control⁸, and adaptive collimation⁹. ~~Some of these~~ strategies are limited by
87 a resultant increase in image noise and ~~resulting~~ reduced image quality especially with
88 traditional analytical reconstruction algorithms such as filtered back projection (FBP).
89 Advanced iterative reconstruction (IR) algorithms that reduce image noise facilitating
90 the generation of diagnostic quality images at reduced radiation doses have received
91 much attention in the literature recently¹⁰⁻¹². IR techniques create a set of synthesized
92 projections by accurately modelling the data collection process in CT. The model
93 incorporates statistical information of the CT system including photon statistics and
94 electronic acquisition noise to reduce image noise¹³.

95 Hybrid iterative reconstruction techniques such as adaptive statistical iterative
96 reconstruction (ASIR) (GE Healthcare, GE Medical Systems, Milwaukee, USA) is one

97 such method that may be blended with FBP to reduce noise while preserving image
98 quality and the familiar appearance of traditional FBP-reconstructed images. ASIR is
99 ~~the most a commonly~~ studied iterative algorithm in abdominopelvic CT ~~to date~~ with
100 studies reporting dose reductions ~~in the order of from~~ 25% to 74% with preserved
101 image quality and diagnostic value¹⁴⁻¹⁷.

102 ~~More r~~Recently, more computationally intense pure IR algorithms such as model-based
103 iterative reconstruction (MBIR) (Veo) (GE Healthcare, GE Medical Systems,
104 Milwaukee, USA) have become commercially available. In addition to incorporating
105 modelling of photon and noise statistics, pure IR algorithms such as MBIR use a more
106 complex system of prediction models including modelling of optic factors such as tube
107 and detector response, and the exact geometric features of the focal spot, CT cone beam
108 and absorbing voxels¹⁸. It is ~~necessary~~ preferable, however, to evaluate the diagnostic
109 quality of images reconstructed with MBIR before availing of the potential dose
110 reductions it is purported to provide. These data would also be informative for the
111 development of low dose scanning protocols in the clinical setting, which would likely
112 assist in the granting of ethical approval. ~~introduction of the technique into widespread~~
113 ~~clinical practice.~~

114 Several strategies may be used to compare the efficacy of reconstruction techniques in
115 noise reduction including technical and anthropomorphic phantoms^{19, 20} the split-dose
116 technique or the artificial addition of image noise to conventional dose images to
117 simulate low dose images²¹. Technical and anthropomorphic phantoms provide a safe,
118 objective and reproducible method of assessing the image quality of different
119 reconstruction algorithms over a range of radiation dose levels. Preliminary phantom

120 experiments with MBIR report a significant reduction in image noise and streak artifact,
121 with significant improvements in image quality compared to FBP and ASIR^{22, 23}.

122 Many phantom models do not accurately reflect the complex relationship that exists

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123 between anatomical variability and image quality, and results of phantom studies may
124 not be entirely applicable to the clinical setting. However, patient studies to assess the
125 performance of reconstruction algorithms at different dose levels can often be

126 problematic to implement, as imaging large numbers of patients at different dose
127 settings introduces confounding factors in addition to ethical challenges. To date,

128 clinical studies assessing the use of MBIR in abdominopelvic CT are limited^{22, 24}.

129 The use of radiological images acquired from cadavers for research²³, teaching²⁵, and
130 training²⁶ purposes has been well described in the literature. Cadavers also provide an

131 excellent model with which to compare reconstruction algorithms by facilitating the

132 repeated scanning of one subject over a range of radiation dose settings without

133 movement artefact or dose concerns. This method has been used in thoracic CT imaging

134 to demonstrate maintenance of acceptable image quality despite 82% dose reduction

135 using MBIR²⁷. To the best of our knowledge, this is the first study to assess the image

136 quality of cadaveric abdominopelvic CT scans reconstructed with MBIR.

137 The aim of this study was to use cadaveric imaging to determine ~~the dose range at~~

138 ~~which MBIR~~ if MBIR improved image quality compared with ASIR and FBP, to ~~he~~

139 quantify the extent of this improvement and to assess if there was a benefit to MBIR

140 over conventional methods for low dose image reconstruction. ~~had the greatest efficacy~~

141 ~~for noise reduction while maintaining acceptable image quality. These data will provide~~

142 ~~essential information that will help guide the development of safe protocols which are~~

143 ~~more likely to be granted ethical approval for validation trials~~ performance of reduced
144 dose CT using MBIR.

145

146

147 **Methods**

148

149 *Subjects*

150 The study was conducted under the auspices of a 'License to Practice Anatomy' granted
151 to the Chair of the Department of Anatomy and Neuroscience of our institution under
152 the Anatomy Act 1832. Donors premorbidly signed written consent for the use of their
153 bodies for the purposes of education and research. Five human cadavers (4 male, 1
154 female) were included in the study. The median time from death to CT scanning was 38
155 days (range, 8 to 180). The cadavers were fresh frozen at -4°C and thawed for the
156 purpose of the study as per standard practice. Cadaver body-mass index (BMI) was not
157 measured directly but was estimated from effective diameter measurements taken from
158 the CT images and the regression equation in the Boos et al 2016 study²⁸; mean cadaver
159 BMI was estimated to be 30kg/m².

160

161 *CT technique*

162 All subjects were scanned with a 64-slice GE Discovery 750HD CT scanner (General
163 Electric Healthcare, Waukesha, WI, USA). Each cadaver was scanned without
164 intravenous or oral contrast in the supine position enclosed in a body bag without any
165 metallic fasteners. Scans were performed with the arms by the side ~~to minimise cadaver~~
166 ~~manipulation due to the affects of rigor mortis.~~

167 The protocol was employed with varying tube voltage (kV) and current (mA) settings of
168 80kV/225mA, 120kV/100mA, 100kV/225mA, and 120kV/200mA; the resultant
169 CTDI_{vol}, resulting in mean, mean dose length products (DLP) and mean size specific
170 dose estimates (SSDE) of 238.7±12.41mGy.cm/5.364±0.62mGy, 315.56±16.4mGy.cm
171 /7.091±0.82mGy, 447.2±23.35mGy.cm/10.04±1.162mGy and
172 630.91±332.7mGy.cm/14.172±1.64mGy respectively, can be seen in Table 1. The
173 radiation exposure resultant from the CT localizer radiographs was excluded from the
174 dose calculations.

175 The 120kV/200mA protocol was used as a reference conventional dose (CD) protocol
176 following a review of the radiation dose of 100 standard abdominopelvic CT studies
177 performed at our institution (mean DLP of 640.4±272.83mGy.cm). The 80kV/225mA,
178 120kV/100mA, and 100kV/225mA low dose protocols were given the names low dose
179 1 (LD1), low dose 2 (LD2), and low dose 3 (LD3), respectively. The gantry rotation
180 time (0.8 seconds), collimation (40 x 0.62mm), pitch factor (0.98), and slice thickness
181 (0.625 mm) were kept constant for all acquisitions.

182

183

184 *CT image reconstruction*

185 All images were reconstructed from the raw-data acquisitions. Each cadaver was
186 scanned at four different dose levels as detailed above and each of these data sets was
187 reconstructed using three different reconstruction techniques: filtered back projection;
188 our standard departmental reconstruction technique, hybrid iterative reconstruction
189 (60% FBP and 40% ASIR), labelled ASIR40; and pure iterative reconstruction (MBIR),

190 resulting in a total of 12 series per cadaver. Images were reconstructed from an
191 acquisition thickness of 0.625mm to a final slice thickness of 1.25mm for all series.

192

193

194 *Quantitative analysis of image noise*

195 Objective image quality analysis was performed independently on a dedicated
196 workstation (Advantage Workstation VolumeShare 2, Version 4.4, GE Medical
197 Systems, Milwaukee, WI) by two operators (FM, 5 years experience and DF, 1 year
198 experience). Attenuation values in Hounsfield units (HU) were measured at five levels
199 using circular ~~regions of interest (ROIs) histograms~~ of equal size (diameter 10mm). The
200 ~~regions of interest (ROIs)~~ were placed in the following anatomical structures: most
201 superior portion of liver parenchyma just inferior to liver parenchyma at the level of the
202 right hemi-diaphragm; liver parenchyma at the level of the porta hepatis; erector spinae
203 at the right renal hilum; psoas muscle at the iliac crest; and gluteus maximus muscle at
204 the roof of the acetabulum. The ROIs were placed in as homogenous an area as
205 possible, taking care to avoid fat planes and blood vessels. The standard deviation of the
206 mean attenuation in the ROI served as an objective measure of image noise²⁹. The
207 signal-to-noise ratio (SNR) of each ROI was calculated by dividing the mean HU by its
208 standard deviation³⁰. Each operator took measurements independently and the mean
209 measurement was used for analysis. The operators were blinded to the scanning
210 protocol and reconstruction technique used and the order of the series was randomized.

211

212

213 *Qualitative analysis*

214 Subjective image quality assessment was performed independently on the Advantage
215 Workstation by two readers (FM, 5 years experience and MT, 6 years experience).
216 Subjective image noise, diagnostic acceptability, and contrast resolution were graded on
217 a 10-point scale at 5 anatomical levels: right hemi-diaphragm, porta hepatis, right renal
218 hilum, iliac crest, and roof of the acetabulum. Image noise was graded as acceptable
219 (score of 5) if average graininess was seen with satisfactory depiction of small
220 anatomical structures such as blood vessels and tissue interfaces, unacceptable (score of
221 1) if graininess interfered with structure depiction, and excellent (score of 10) if there
222 was no appreciable mottle. Diagnostic acceptability was graded as acceptable (score of
223 5), unacceptable (score of 1), or excellent (score of 10) if depiction of solid organs,
224 large bowel, small bowel, peri-colonic fat, and peri-enteric fat for diagnostic
225 interpretation and degree of image degradation by beam hardening artifacts was
226 satisfactory, unsatisfactory or considerably superior, respectively. Contrast resolution
227 was also graded at the liver, spleen and buttock musculature using a 10-point scale in
228 which a score of 10 represented superior contrast between different abdominal soft
229 tissues, a score of 1 indicated the poorest contrast, and a score of 5 indicated acceptable
230 contrast. Streak artifact was also graded at each level using a 3-point scale: 0, no streak
231 artifact present; 1, streak artifact present but not interfering with image interpretation;
232 and 2, streak artifact present and interfering with image interpretation.

233 The parameters of image quality were selected on the basis of previous studies and the
234 *European Guidelines on Quality criteria for Computed Tomography*^{31,32}. The authors
235 had used these methods previously and trained the other readers before analysis with a
236 set of 5 practice scans³³. The order of the data sets was randomized and the readers were
237 blinded to the scanning protocol and reconstruction technique. The readers used a

238 combination of axial and coronal reformats for interpretation and altered the CT level
239 and window width at their discretion.

240

241

242 *Statistical analysis*

243 Data was exported from Microsoft Office Excel 2010 (Microsoft Corporation, CA,
244 USA) into GraphPad Prism version 6.0 (GraphPad Software Incorporated, San Diego,
245 USA) and Statistical Package for the Social Sciences (SPSS) version 22 (IBM, Chicago,
246 Illinois, USA) for further analysis. Distribution of variables was assessed using
247 D'Agostino-Pearson omnibus normality test. Inter-observer concordance was assessed
248 with Cohen's κ test.

249 Two-way analysis of variance was used to compare three or more groups of parametric
250 indices. Tukey's multiple comparisons test was used to assess differences between
251 reconstruction techniques at each dose level for quantitative and qualitative parameters.
252 Mean differences between reconstruction algorithms and their 95% confidence intervals
253 were calculated at each dose level. Percentage noise and dose reduction compared with
254 FBP and ASIR40 was determined for the MBIR data sets. Dunnett's test was used to
255 compare the quantitative and qualitative parameters of the low dose MBIR series with
256 CD ASIR40 series. P values less than 0.05 were considered to be statistically
257 significant.

258

259

260 **Results**

261

262 *Quantitative analysis of image noise*

263 Objective image noise was significantly different at each dose level ($p < 0.0001$) and
264 between each reconstruction algorithm at every dose level ($p < 0.0001$ for all
265 comparisons) with the greatest levels of image noise at LD1 (Figure 1a). MBIR
266 reconstructions had significantly lower measures of objective image noise compared
267 with both FBP and ASIR40 reconstructions at all dose levels ($p < 0.0001$ for all
268 comparisons) with the greatest mean difference observed for both at the LD1 level;
269 mean differences of 34.263HU (CI, 30.492 to 38.354) and 20.56HU (CI, 16.475 to
270 24.64) compared with FBP and ASIR40, respectively.

271 MBIR facilitated percentage noise reductions of 68.1%, 69.2%, 61.02%, and 65%
272 compared with FBP and 56.2%, 57.9%, 52.6%, and 56.6% compared with ASIR40 at
273 the LD1, LD2, LD3, and CD levels, respectively.

274 SNR for MBIR data sets was significantly higher than both FBP and ASIR40 data sets
275 at each dose level ($p < 0.0001$) with the greatest mean difference compared with FBP at
276 LD2 (2.62 (CI, 1.67 to 3.56)) and compared with ASIR40 at CD (2.263 (CI, 1.3 to 3.2))
277 (Figure 1b). No significant difference was observed in SNR between FBP and ASIR40
278 data sets at all dose levels.

279

280

281 *Qualitative analysis*

282 There was excellent agreement between the two raters for the assessment of diagnostic
283 acceptability and presence of streak artifact (k , 0.824 and 0.868, $p < 0.001$) with
284 moderate agreement for the assessment of subjective image noise and contrast
285 resolution (k , 0.795 and 0.623, $p < 0.001$). Using mean scores for further analysis it was

286 shown that subjective image noise, diagnostic acceptability, and contrast resolution
287 scores were significantly different between each reconstruction algorithm at each dose
288 level ($p < 0.0001$ for all comparisons).

289 MBIR reconstructions had significantly higher qualitative scores compared with both
290 FBP and ASIR40 reconstructions at all dose levels ($p < 0.0001$ for all comparisons) with
291 the greatest mean differences observed for all qualitative measures at the LD1 level
292 (Figures 2, 3 and 4) . Figure 5 is an example of the images obtained following
293 reconstruction with FBP, ASIR and MBIR at the LD1 dose level (80kV, 225mA).

294 MBIR reconstructions had significantly lower levels of streak artifact compared with
295 FBP ($p < 0.001$) and ASIR40 ($p < 0.01$) at the lowest dose level only (LD1). All other
296 comparisons were non-significant (Figure 6).

297 No statistically significant difference in image noise or SNR was seen between the
298 MBIR reconstructed images at the various dose levels (Figures 1 and 2). An example of
299 the MBIR reconstructed images at the four dose levels can be seen in Figure 7.

300

301 *Comparison of low dose MBIR with conventional dose ASIR40*

302 Our standard practice currently is to use conventional dose ASIR40 in the clinical
303 setting. LD MBIR series were acquired with a mean dose reduction compared with CD
304 ASIR40 of 62.47%, 50%, and 29.12% for LD1 MBIR, LD2 MBIR, and LD3 MBIR
305 series, respectively. All LD MBIR reconstructions had significantly lower levels of
306 objective image noise compared with the CD ASIR40 protocol ($p < 0.0001$ for all
307 comparisons).

308 All low dose MBIR series and conventional dose ASIR40 series had above average to
309 excellent subjective image noise, diagnostic acceptability, and contrast resolution
310 scores.

311

312 Diagnostic acceptability and contrast resolution scores were superior for all LD MBIR
313 series compared with CD ASIR40 ($p < 0.0001$ for all comparisons). LD2 MBIR and LD3
314 MBIR had superior subjective image noise scores compared with CD ASIR40
315 ($p < 0.0001$ for both comparisons) with no significant difference in subjective image
316 noise between LD1 MBIR and CD ASIR40 reconstructions (Figure 2). Streak artifact
317 was similar between all of the LD MBIR and the CD ASIR40 reconstructions (Figure 6)
318 with no statistically significant difference observed.

319

320

321 **Discussion**

322 Iterative reconstruction algorithms serve to improve image quality by noise reduction
323 and improved spatial resolution over filtered back projection. Blending ASIR with FBP
324 is less computationally intense than MBIR, modelling only photon and electronic noise
325 statistics in order to reduce computational time. MBIR incorporates modelling of certain
326 parameters previously omitted from blended or hybrid iterative reconstruction
327 algorithms. These include a system model that addresses the nonlinear, polychromatic
328 nature of x-ray tubes by modelling the photons in the data set, a statistical noise model
329 that considers the focal spot and detector size, and a prior model that corrects unrealistic
330 situations in the reconstruction process to decrease the computational time³⁴. The
331 incorporation of system optic information enables reductions in image noise and

332 artifacts with improvements in spatial resolution. The major limitation of these
333 additional data processing steps is the prolonged reconstruction time required (45
334 minutes in one series³⁵), compared with FBP and ASIR, and although this may preclude
335 its use in the emergency setting, it is unlikely to be a significant issue for most routine
336 abdominopelvic CT examinations. Reconstruction times were many hours for such
337 examinations only a few years ago. With improved computational efficiency
338 reconstruction times will likely continue to improve and allow MBIR to be used in all
339 clinical settings. Anecdotally it was been noted that greater dose reductions required
340 longer reconstruction times, although this may preclude its use in the emergency setting,
341 it is unlikely to be a significant issue for most routine abdominopelvic CT examinations.
342 With improved computational efficiency, this time will likely reduce significantly and
343 allow MBIR to be used in all clinical settings.

344 MBIR has been shown to reduce image noise and improve image quality at
345 conventional dose levels compared ~~with~~ both FBP and ASIR^{13, 18}. The utility of MBIR
346 at preserving image quality at lower radiation dose levels has also been investigated.

347 ~~Many studies have demonstrated~~ Successful use of MBIR in chest CT has been
348 demonstrated with reported ~~ing~~ dose reductions of up to 79% ~~with~~ and preserved image
349 quality³⁶. However, few studies have investigated the utility of MBIR in
350 abdominopelvic CT^{22, 24} or the dose range at which MBIR has the greatest efficacy for
351 noise reduction.

352 In ~~the present paper~~ our study, MBIR datasets had significantly lower levels of objective
353 image noise compared with both FBP and ASIR⁴⁰ at both conventional and low dose
354 levels with the greatest absolute noise reduction observed at the lowest radiation dose
355 level. A similar finding was observed for the qualitative indices with the greatest

356 improvement in image quality also observed at the lowest dose level. In addition, MBIR
357 significantly reduced streak artifact at the lowest dose level only.

358 Compared with ~~our current~~the standard-conventional dose CT protocol reconstructed
359 with ASIR40, MBIR facilitated the acquisition of images with lower levels of image
360 noise, higher diagnostic quality and contrast resolution scores, and comparable
361 subjective image noise and streak artifact scores, while enabling a 62% dose reduction.
362 Findings suggest that the greatest utility of MBIR in abdominopelvic CT is reduced
363 image noise which helps maintain image quality in spite of low radiation dose
364 acquisition, thus enabling the creation of diagnostic quality studies at substantially
365 reduced radiation doses.

366
367 Cadaveric study has been used in the past to assess CT dose optimization in chest^{27, 37, 38}
368 and orthopaedic CT^{39, 40}, however this is the first multi-specimen cadaveric study in the
369 literature to assess radiation dose optimization in abdominal CT. A cadaver more
370 closely simulates actual body composition than a phantom and ethical concerns over
371 live human radiation dose experiments are not present with cadaveric study. A further
372 advantage of cadaveric study is the ability to utilize cadavers of different body habitus;
373 with a phantom study this would involve acquiring multiple (often very expensive) CT
374 phantoms. Cadaveric study allows experimentation with a near perfect simulation for
375 live human tissue and allows the use of multiple different radiation exposures to assess
376 for differences in radiation dose and image quality. Decreasing radiation dose in clinical
377 studies ~~in live humans~~ introduces a risk to patients regarding suboptimal images leading
378 to impaired diagnostic confidence of the radiologist and therefore these studies often
379 use small increments of radiation reduction to minimize this. With cadaveric study,

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380 large reductions in radiation dose can be instituted and the images assessed for quality
381 without the same concerns over missed diagnosis. This type of study also obviates
382 additional radiation exposure to a patient, which may occur due to additional research
383 scanning or from the requirement for repeat scanning due to *insufficient diagnostic*
384 *confidence in the original images. Having confirmed the ability of MBIR to maintain*
385 *image quality in a low-dose setting, the present results help support ethical applications*
386 *to allow validation of these methods of radiation dose reduction in clinical*
387 *practice. decreased diagnostic confidence from the original images. Having confirmed*
388 *the ability of MBIR to maintain image quality in the low dose setting, we can now*
389 *confidently set up CT protocols with markedly reduced radiation dose to confirm the*
390 *applicability of these findings to clinical practice.*

391

392 MBIR-reconstructed images have an impasto appearance different to FBP- and lower
393 percentages of blended ASIR/FPB-reconstructed images¹⁴. Initial studies of ASIR also
394 reported a similar phenomenon⁴¹, but partial blending with FBP and further
395 technological advancements in the algorithm have minimized this effect. Other studies
396 have reported new artifacts in MBIR-reconstructed images such as a 'staircase effect' at
397 bone interfaces and a 'bordering blacked-out artifact' on skin surfaces¹⁸. Although these
398 artifacts were visible in all planes, predominantly on axial reformations, the overall
399 effect on image quality was deemed to be minor. In the present paper, the readers were
400 familiar with the altered appearance of MBIR-reconstructed images and believed this
401 phenomenon did not interfere with diagnostic acceptability and was minimized in the
402 coronal plane.

403 ~~We recognize the~~The limitations of ~~this study are recognised~~our study. We studied the
 404 ~~image~~ image quality characteristics of abdominopelvic CT scans reconstructed with three
 405 different reconstruction algorithms ~~were studied~~. An assessment of the ~~utility~~ability of
 406 MBIR ~~reconstructed~~ images ~~to detect~~for the detection -and characterization of
 407 pathological findings was not made and further clinical studies are required to validate
 408 its diagnostic ability. ~~Cadavers were scanned with the arms by their sides and this may~~
 409 ~~have resulted in~~in which had potential to ~~decrease~~overall image quality compared
 410 with clinical image datasets; ~~nonetheless, we feel that~~comparison between ~~the different~~
 411 ~~reconstruction~~reconstruction algorithms on the same cadavers should remainremains
 412 valid. €
 413 Evaluation of the impact of MBIR on contrast resolution of liver and other solid organs
 414 following intravenous contrast administration was not possible. Furthermore, cadaveric
 415 imaging precludes the administration of intravenous and oral contrast media. Low dose
 416 clinical images reconstructed with MBIR have not been deemed adequate for the
 417 assessment of solid organ **lesions** but adequate for assessment of retroperitoneal
 418 adenopathy or acute complications of Crohn's disease. It is important therefore to
 419 emphasise that the use of cadaveric imaging should only be undertaken if it provides an
 420 appropriate substitute for clinical imaging. Quantitative analysis needs to be
 421 supplemented with a qualitative assessment of image acceptability in the anticipated
 422 application. Although cadaveric imaging may show promise, validation through careful
 423 conducted clinical studies remains essential.
 424 Previous clinical studies using intravenous and oral contrast have reported a reduction
 425 in streak artifact with the use of MBIR^{13, 18}. In the present paper reduced streak artifact
 426 was only observed on MBIR images compared with alternative reconstruction

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427 techniques at the lowest dose level only. This suggests that the improved performance
428 of MBIR for streak artefact removal occurs mainly in the low dose setting. This will
429 require further assessment. This is particularly relevant to the assessment of streak
430 artifact. Also, evaluation of the impact of pure IR on contrast resolution of liver and
431 other solid organs post contrast was not possible; it is important to acknowledge this as
432 this is a vital factor in abdominal imaging. Previous clinical studies using intravenous
433 and oral contrast have reported a reduction in streak artifact with the use of MBIR^{13,18}.
434 However, in the present paper reduced streak artifact was only observed in MBIR-
435 reconstructed images at the lowest dose level only, indicating a possible under
436 evaluation of the ability of MBIR to reduce streak artifact in our study.
437 Furthermore, due to the inherent difference in the appearance of MBIR-reconstructed
438 images described above, readers may have not been completely blinded to the
439 reconstruction algorithm during subjective analysis. ~~However, blinding to the imaging~~
440 ~~protocol was satisfactory.~~ Finally, the results of our study may not be completely
441 applicable to pure iterative reconstruction algorithms available from other vendors and
442 independent validation of these techniques ~~would~~ may also be required.

443

444 **Conclusion**

445 In conclusion, this cadaveric study demonstrates that MBIR can facilitate the
446 acquisition of abdominopelvic CT scans with lower levels of image noise and greater
447 image quality compared with conventional dose images reconstructed with FBP or
448 ASIR40, while enabling ~~up to 62%~~ significant radiation dose reduction. These data will
449 provide essential information that will help guide the development of safe protocols
450 which are more likely to be granted ethical approval for the purposes of clinical

451 ~~validation. Further analysis of low dose imaging reconstructed with MBIR will focus on~~
452 ~~the clinical utility of MBIR at this dose range.~~

453

454

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605

606 **Table & Figure Legend**

607

608 **Table 1.**

609 CTDI_{vol}, DLP and SSDE for each of the different CT protocols

610

611 **Figure 1.**

612 a) Variation in objective image noise and b) SNR with choice of reconstruction
613 algorithm at each low dose (LD) and conventional dose (CD) protocol. Data are plotted
614 as mean and standard deviation. FBP (filtered back projection); ASIR40 (40% adaptive
615 statistical iterative reconstruction); MBIR (model based iterative reconstruction).

616

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618

619

620 **Figure 2.**

621 Variation in subjective noise scores with choice of reconstruction algorithm at each low
622 dose (LD) and conventional dose (CD) protocol. Data are plotted as mean and standard
623 deviation. FBP (filtered back projection); ASIR40 (40% adaptive statistical iterative
624 reconstruction); MBIR (model based iterative reconstruction).

625

626 **Figure 3.**

627 Variation in diagnostic acceptability scores with choice of reconstruction algorithm at
628 each low dose (LD) and conventional dose (CD) protocol. Data are plotted as mean and
629 standard deviation. FBP (filtered back projection); ASIR40 (40% adaptive statistical
630 iterative reconstruction); MBIR (model based iterative reconstruction).

631

632 **Figure 4.**

633 Variation in contrast resolution scores with choice of reconstruction algorithm at each
634 low dose (LD) and conventional dose (CD) protocol. Data are plotted as mean and
635 standard deviation. FBP (filtered back projection); ASIR40 (40% adaptive statistical
636 iterative reconstruction); MBIR (model based iterative reconstruction).

637

638 **Figure 5.**

639 An example of the images obtained through FBP, ASIR and MBIR reconstructions at
640 the LD1 dose level (80kV, 225mA).

641

642 **Figure 6.**

643 Variation in streak with choice of reconstruction algorithm at each low dose (LD) and
644 conventional dose (CD) protocol. Data are plotted as mean and standard deviation. FBP
645 (filtered back projection); ASIR40 (40% adaptive statistical iterative reconstruction);
646 MBIR (model based iterative reconstruction).

647

648 **Figure 7.**

649 An example of the MBIR reconstructed images at the four dose levels CD, LD1, LD2
650 and LD3.

651