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Patient deprivation and perceived scan burden negatively impact the quality of whole-body MRI

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AIM: To evaluate the association between the image quality of cancer staging whole-body magnetic resonance imaging (WB-MRI) and patient demographics, distress, and perceived scan burden.

MATERIALS AND METHODS: A sample of patients recruited prospectively to multicentre trials comparing WB-MRI with standard scans for staging lung and colorectal cancer were invited to complete two questionnaires. The baseline questionnaire, administered at recruitment, collated data on demographics, distress and co-morbidity. The follow-up questionnaire, completed after staging investigations, measured perceived WB-MRI scan burden (scored 1 low to 7 high). WB-MRI anatomical coverage, and technical quality was graded by a radiographic technician and grading combined to categorise the scan as "optimal", "sub-optimal" or "degraded". A radiologist categorised 30 scans to test interobserver agreement. Data were analysed using the chi-square, Fisher's exact, *t*-tests, and multinomial regression.

RESULTS: One hundred and fourteen patients were included in the study (53 lung, 61 colorectal; average age 65.3 years, SD=11.8; 66 men [57.9%]). Overall, 45.6% (n=52), scans were classified as "optimal" quality, 39.5% (n=45) "sub-optimal", and 14.9% (n=17) as "degraded". In adjusted analyses, greater deprivation level and higher patient-reported scan burden were both associated with a higher likelihood of having a sub-optimal versus an optimal scan (odds ratio [OR]: 4.465, 95% confidence interval [CI]: 1.454 to 13.709, p=0.009; OR: 1.987, CI: 1.153 to 3.425, p=0.013, respectively). None of the variables predicted the likelihood of having a degraded scan.

CONCLUSIONS: Deprivation and patients' perceived experience of the WB-MRI are related to image quality. Tailored protocols and individualised patient management before and during WB-MRI may improve image quality.

Introduction

Approximately 5–30% of patients report distress[1–5] whilst undergoing magnetic resonance imaging (MRI). Scan attributes, notably the relatively lengthy duration, narrow bore, requirement to remain still, and the repetitive loud noise together with the contextual threat of what the scan could

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reveal may all induce distress.[6] The diagnostic accuracy of MRI is related to image quality and patient-centric factors. Mobility motion artefacts created from processes under voluntary control, such as respiration, swallowing, and body movement, contribute to reductions in image quality.[7,8] Motion artefacts affect around 7% of outpatient imaging examinations[8,9] and often necessitate repeat imaging either during the initial scan thus increasing its duration, or at a later date, requiring patients to re-attend. Repeated imaging examinations have associated costs to patients and healthcare providers.[9]

A link between degradation of image quality by motion artefact and patient distress/anxiety has been described,[8] and interventions to improve image quality by reducing anxiety have been proposed;[10,11] however, the evidence base supporting a link between background anxiety and image quality is currently limited. Indeed, several studies have found little or no association.[8,12] There has been little investigation into whether other variables, such as the presence of comorbidities, patient perception of scan burden, and in the case of cancer staging, the site of the primary tumour impact on motion artefact and image quality.

Whole-body MRI (WB-MRI) is increasingly used for cancer staging[13–15] and the relatively long acquisition protocols increases the chance of patient motion-related artefacts. As WB-MRI disseminates in clinical practice the need to identify and ideally mitigate the predictors of poor scan quality is of increasing importance. The purpose of the present study was to evaluate the association between cancer staging WB-MRI image quality and patient demographics, distress, and perceived scan burden.

Materials and Methods

Participants and procedures

Patients recruited to two clinical trials comparing the diagnostic accuracy of WB-MRI with standard tests for staging colorectal and lung cancer, were invited to participate in the current study.[16] Patients were eligible for the main trials if they were referred for staging investigations following a confirmed or highly suspected diagnosis of colorectal (Streamline C trial) or non-small cell lung cancer (Streamline L trial). Patients recruited to the main trials underwent WB-MRI at their recruitment site, or nearby hospital in addition to all standard staging imaging such as computed tomography (CT) or integrated positron-emission tomography (PET-CT), performed as part of usual clinical care. Additional written consent was obtained for participation in the current study. Trial protocol details are published.[16] Full ethical permission was given by Camden and Islington National Research Ethics Service (NRES) on 03/10/2012, project numbers: 12/LO/1176 (Streamline C) and 12/LO/1177 (Streamline L). The WB-MRI protocol is shown in Electronic Supplementary Material Appendix B.

Between March 2013 and July 2015, 392 consecutive patients recruited to the main trials were approached to participate in a series of patient experience studies (interview study, burden questionnaire, and discrete choice experiment), of whom 350 (89.3%) agreed. The results of these studies have been published elsewhere.[6,17,18] The present study uses some of the questionnaire data published previously[17] and reports a secondary analysis, the association with scan quality. The full recruitment pathway and reasons for exclusion are given in Fig 1.

In detail, consenting patients were mailed a baseline questionnaire within 1–2 days of trial registration, which they returned using a stamped addressed reply envelope. A second follow-up "post-staging" questionnaire was posted 1 month after baseline and was completed after all staging investigations were performed. Patients were paid £20 for participation in the study, which was continued until a minimum of 100 patients had returned both questionnaires (50 for lung and 50 for colorectal patients). The original questionnaire study was powered to assess whether WB-MRI posed a greater burden on patients than standard staging pathways.[17]

Baseline questionnaire content

Demographics

Age, gender, and ethnicity were captured in the questionnaire but missing data on age and gender was supplied via the central trial database (with patient consent). Postcode data, also supplied by the central trial database, was used to calculate an area based deprivation score for each individual using the 2010 English Indices of Deprivation scale,[19] categorised into quintiles from 1 (highest levels of deprivation) to 5 (lowest).

Co-morbidity

Patients were asked to report ("yes" or "no") whether they had any of the following diseases: heart or vascular disease, diabetes, epilepsy, stroke, arthritis, asthma, and mental or emotional disorders. There was also an option to provide details of any other illness. A response of "yes" to any illness was coded and summed to form a dichotomous "co-morbidity" variable ("present" or "absent"). Responses of "yes" to the presence of emotional disorder were excluded due to conceptual overlap with the measure of distress (12 item General Health Questionnaire [GHQ-12]).

Distress

GHQ-12[20] was used to assess psychological distress. An example item is *"In the last three months have you .... lost much sleep over worry"*. The GHQ-12 binary coding method (0,0,1,1) was used. A mean sum score (if at least 50% of items were answered) was created ranging from 0–12. A score of ≥4 is considered to be indicative of significant levels of distress.[21–23]

Post-staging questionnaire content

Scan experience

Patients described their WB-MRI experience by ticking agreement on a 1–7 Likert scaled 26 item measure where 1 and 7 were anchored to bi-polar statements related to scan discomfort (13 items), worry both about the test and the

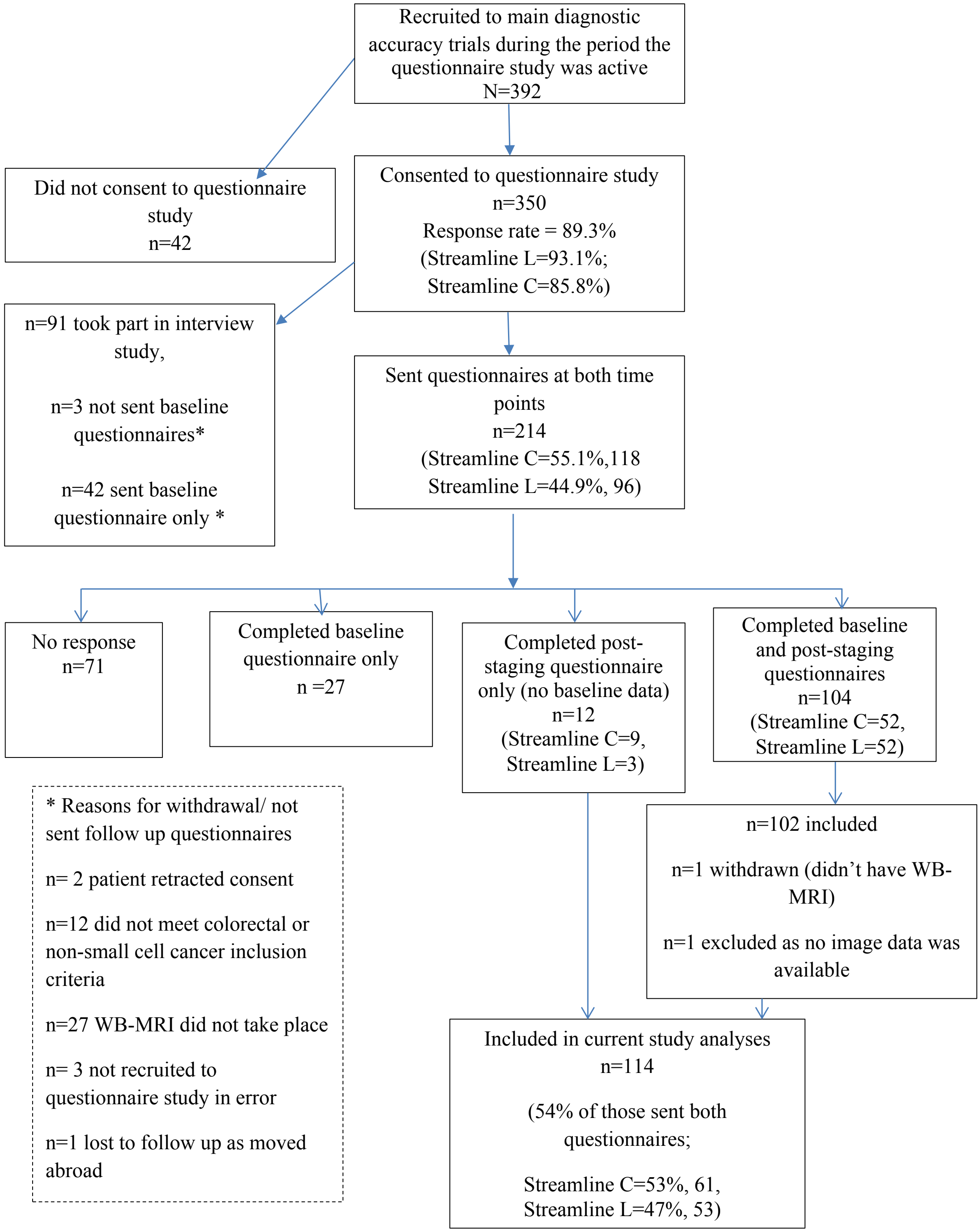

Figure 1 Flow diagram of participants through the study (March 2013 to July 2015).

scan findings (six items), and satisfaction (seven items). These questions were adapted from a survey previously used to assess the acceptability of colonoscopy.[24,25] An example worry item was 1="I was worried about what they would find" to 7= "I was not worried about what they would find". The sub-scores for the discomfort, worry, and satisfaction scales were computed from the mean of the completed items (if <50% of items were completed, the response was coded as missing). A total score "scan burden" was computed by taking the mean of reversed discomfort, worry, and satisfaction sub-scales with higher scores equating to greater scan burden (see Electronic Supplementary Material Appendix B).

Image quality

Images were assessed by a radiographic technician with 5 years of experience of WB-MRI and rated according to both anatomical coverage and technical quality. Ratings

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were performed blind to patient details in relation to responses to the patient experience questionnaire.

Anatomical coverage was rated as follows: A1, wrong examination performed; A2, more than one sequence/did not adequately cover the body (skull to mid-thigh), or designated organ(s); A3, one sequence did not optimally cover the body or designated organ(s) but the examination remained fully diagnostic; A4, all sequences optimally cover the body and designated organ(s).

Technical quality was scored as follows: T1, more than one sequence with substantial degradation of images severely limiting interpretation of those sequences, and not repeated; T2, one sequence with substantial degradation of images severely limiting interpretation of that sequence, and not repeated; T3, more than one sequence had a minor artefact, but all remained fully diagnostic and repeat although optimal, was not necessary OR all sequences initially technically inadequate (score 1 or 2) correctly repeated; T4, one sequence had a minor artefact, but remained fully diagnostic and repeat, although optimal, not necessary; T5, all sequences technically optimal with no artefact or degradation.

Image quality was coded according to a combination of both anatomical coverage and technical quality into three groups: degraded, sub-optimal, and optimal (see Table 1).

In addition, a radiology research fellow with 2 years of experience of WB-MRI scored a sample of 30 datasets selected at random to test interobserver variation in quality ratings.

Statistical analysis

Analysis was performed using SPSS version 24. Parametric tests were used to analyse Likert data, as they have been shown to be robust for this purpose.[26] Deprivation levels were collapsed into three groups: highest deprivation (groups 1 and 2), group 3, and lowest deprivation (groups 4 and 5).

Proportional differences were assessed using the chi-square or Fisher's exact scores (if one or more of the cells in the contingency table had expected counts of <5), mean differences were assessed using *t*-tests. Multinominal logistic regression was used to assess predictors of a degraded or sub-optimal quality image relative to optimal quality image. Individual predictors were entered in unadjusted analyses and those items achieving or approaching statistical significance were then entered into adjusted analyses. Statistical significance was assigned at the 5% level, two-tailed unless specified otherwise.

Table 1
Image quality classification based on technical quality and anatomical coverage.

	Anatomical coverage			
Technical quality	A1	A2	A3	A4
T1	Degraded	Degraded	Degraded	Degraded
T2	Degraded	Degraded	Degraded	Degraded
T3	Degraded	Degraded	Suboptimal	Suboptimal
T4	Degraded	Degraded	Suboptimal	Suboptimal
T5	Degraded	Degraded	Suboptimal	Optimal

Agreement between two radiologists about image quality was assessed using percent agreement rather than the kappa coefficient. The latter is recommended when there is the possibility people will agree by chance rather than as a result of expertise. Where there is unlikely to be any guessing involved, percent agreement is recommended.[27]

Results

Full demographics of the 114 patients are shown in Table 3. Overall, 102 patients (mean age 66 years, SD 11 years; 60 male patients) completed both questionnaires and 12 (mean age 63 years, SD 9 years; nine male patients) completed the post-staging questionnaire only. Sixty-one patients were recruited to Streamline C and 53 to Streamline L. Female patients recruited to Streamline C (n=24) were significantly younger than those recruited to Streamline L ($n = 23$; 59 versus 70 years; F=10.119, df=1,45, p=0.003), with no significant age difference between males (67 years, n=30 versus 65 years, n=37 respectively, F=0.916, df=1,65, p=0.342). Patients recruited to Streamline L were significantly more likely to report additional comorbidity than those recruited to Streamline C (62.3% versus 34.4%, p=0.003) with no significant differences for the presence of baseline psychological distress between the two trial cohorts (see Table 2).

Image quality and interobserver agreement

Overall, 45.6% (52/114), scans were classified as "optimal" quality, 39.5% (45/114) "sub-optimal" and 14.9% (17/114) as "degraded". The radiographic technician and radiology fellow agreed on the classification of image quality in 23/30 datasets (77%) (see Table 3).

Patient demographic and psychological predictors of image quality

In the unadjusted multinomial regression analyses (see Table 4), the odds of a sub-optimal scan (relative to achieving an optimal scan) were increased if patients lived in an area of high deprivation (top 2 quintiles combined) (OR: 5.731, CI: 2.034 to 16.150; $p<0.001$), had suspected or confirmed lung cancer (OR: 2.400, CI: 1.060 to 5.434; p=0.036), or if they reported higher levels of WB-MRI related patient burden, (OR: 2.177, CI: 1.334 to 3.553; p=0.002). Entering sub-scale variables from the patient burden scale into the regression model revealed that all three subscales were predictive of increased odds of a sub-optimal scan compared to an optimal scan (discomfort: OR: 1.700, CI: 1.170 to 2.472, p=0.005; worry: OR: 1.914, CI: 1.281 to 2.858, p=0.002; satisfaction: OR: 0.436, CI: 0.242 to 0.787, p=0.006).

In adjusted analyses, high deprivation and scan burden remained significant predictors (OR: 4.465, CI: 1.454 to 13.709, p=0.009 and OR: 1.987, CI: 1.153 to 3.425; p=0.013 respectively).

Older age and presence of comorbidities both approached significance as predictors of likelihood of

Table 2
Patient characteristics.

	Total N=114	Streamline L trial N=53	Streamline C Trial N=61	Group difference
Mean age[a]	65.27 (11.82)	68.52 (9.66)	62.45 (12.84)	t=2.816, df=112, p=0.006
Gender[a]				
Male	57.9 (66)	54.7 (29)	60.7 (37)	X^2=0.410, df=1, p=0.522
Ethnic group[c]				
White	91.8 (89)	93.6 (44)	90.0 (45)	p=0.716 Fisher's exact
Deprivation[a]				
1 and 2 (highest)	47.4 (54)	52.8 (28)	42.6 (26)	X^2= 3.025, df=2, p=0.220
3	21.9 (25)	24.5 (13)	19.7 (12)	
4 and 5 (lowest)	30.7 (35)	22.6 (12)	37.7 (23)	
Co-morbidity[a] (% yes)	47.4 (54)	62.3 (33)	34.4 (21)	X^2=8.815, df=1, p=0.003
Baseline GHQ12 Score[c], proportion with 4+ score, % (n)	42.0 (42)	48.0 (24)	36.0 (18)	X^2=1.478, df=1, p=0.224
WB-MRI Image quality (%(n))[a]				
'Optimal'	45.6 (52)	37.7 (20)	52.5 (32)	X^2=5.506 df=2 p=0.064
'Sub-optimal'	39.5 (45)	50.9 (27)	29.5 (18)	
'Degraded'	14.9 (17)	11.3 (6)	18.0 (11)	
Patient experience				
Total scan burden score[b]	2.21 (1.08)	2.34 (0.97)	2.09 (1.17)	t=1.241 (df=108), p=0.217
Discomfort sub-scale[b]	2.47 (1.22)	2.65 (1.18)	2.30 (1.24)	t=1.489, df=108, p=0.139
Worry sub-scale[b]	2.42 (1.25)	2.64 (1.19)	2.22 (1.29)	t=1.800, df=108, p=0.075
Satisfaction sub-scale[b]	1.74 (1.06)	1.74 (0.87)	1.74 (1.21)	t=−0.004, df=108, p=0.997

Numbers are percent (n) unless stated otherwise.
[a] No missing data.
[b] Missing data <5%.
[c] Missing data >5%.

having a degraded as compared with an optimal scan in unadjusted analyses, but no other predictors were significant at p<0.05 in either unadjusted or adjusted analyses. Notably there was no association between psychological distress and image quality.

Discussion

The present study examined demographic, clinical, and psychological predictors of WB-MRI examination quality. Patients with higher deprivation, suspected or proven lung cancer, and those reporting higher WB-MRI scan burden were more likely to have a sub-optimal scan in the unadjusted analysis. Furthermore, both the composite global measure of scan burden and the individual sub-scales of discomfort, worry, and low satisfaction were predictive in unadjusted analysis, showing that anxiety-related issues (worry) are not the only factor influencing image quality. Both deprivation and scan burden remained significant predictors in the adjusted analyses.

None of the variables included significantly predicted the likelihood of obtaining a degraded versus an optimal scan, although older age and presence of comorbidities both approached significance. This may in part reflect low study power as only 17 datasets were scored as degraded.

Table 3
Agreement between radiologists about image quality.

	Second radiologist		
First radiologist	Degraded	Suboptimal	Optimal
Degraded	3	1	0
Suboptimal	0	13	2
Optimal	0	4	7

General patient distress was not predictive of suboptimal scan quality. This is consistent with the existing literature, which has shown that general anxiety measures lack predictive ability for movement artefacts, and that concerns specific to the scan technology are more associated with reduced scan quality.[8] For example, Dantendorfer *et al.* examined predictors of movement artefacts (MA) that could not be attributed to "normal body pulsations," which impaired diagnosis such that the radiologist was unsure about the "presence, localisation, or size of a lesion". They found that the probability of having MAs was predicted by worries specific to the "big technical apparatus", but neither anxiety nor other views about the imminent examination, positive or negative, were significant predictors. Similarly, Klaming *et al.*, [12] graded motion in three ways (via software tracking, radiographer assessment, and radiologist assessment) and reported little evidence that anxiety (measured by the State Anxiety Inventory) increases motion artefacts. Furthermore, although Tornqvist *et al.* found that detailed written information prior to MRI reduced motion artefact, it had no actual effect on pre-scan patient anxiety levels.[10]

In the current study, discomfort, satisfaction, and worry during the WB-MRI, together with deprivation were significant predictors, underlining the benefit in looking beyond background emotional distress when understanding and addressing factors affecting image quality. The association between patient experience and scan quality of course may be bi-directional; while factors such as discomfort may impact on patients' ability to stay still and hence the clarity of images captured, patients' satisfaction with the scan may be influenced by cues picked up from their interaction with staff about the success or otherwise of the scan acquisition.

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Table 4
Predictors of image quality.

Predictor	Odds ratios/Exp_B (CI)			
	Degraded		Sub-optimal	
	Unadjusted	Adjusted	Unadjusted	Adjusted
Demographic and clinical variables				
Age[a]	1.051 (0.998–1.107) p=0.061	1.051 (0.995–1.110) p=0.077	1.027 (0.991–1.063)	1.019 (0.977–1.063)
Gender[a]				
Male	1.00	–	1.00	–
Female	0.450 (0.139–1.459)	–	0.656 (0.291–1.477)	–
Ethnicity[c]				
White	1.00	–	1.00	–
Not white	0.487 (0.073–3.245)	–	0.900 (0.171–4.745)	–
Quintile deprived[a]				
Lowest (4&5)	1.00	1.00	1.00	1.00
3	1.410 (0.358–5.553)	1.088 (0.242–4.884)	1.692 (0.484–5.919)	0.873 (0.218–3.495)
Highest (1&2)	1.294 (0.354–4.732)	1.418 (0.346–5.809)	5.731 (2.034–16.150); p<0.001	4.465 (1.454–13.709) P=0.009
Co-morbidity (omitting distress)[a]				
Yes	1.00	1.00	1.00	1.00
No	0.341 (0.109–1.067) P=0.064	0.391 (0.111–1.384)	0.598 (0.266–1.342)	0.714 (0.259–1.970)
Cancer site[a]				
Colorectal	1.00	1.00	1.00	1.00
Lung	0.873 (0.279–2.731)	0.418 (0.117–1.492)	2.400 (1.060–5.434); p=0.036	1.710 (0.624–4.683)
Baseline GHQ-12[c]				
Yes	1.00	–	1.00	–
No	1.467 (0.436–4.937)	–	0.702 (0.295–1.668)	–
Scan experience				
Total WB-MRI patient burden score[b]	1.563 (0.845–2.892)	1.610 (0.832–3.113)	2.177 (1.334–3.553); p=0.002	1.987 (1.153–3.425); p=0.013

[a] No missing data.
[b] Missing data less than 5%.
[c] Missing data greater than 5%.

Patient deprivation was the biggest predictor of having a sub-optimal scan. Both higher deprivation and presence of comorbidities are associated with lower self-efficacy (belief in one's ability to do something such as a task).[28] Powell *et al.* have reported that self-efficacy is a better predictor of scan quality than anxiety, claustrophobia, or distress, and in a randomised study, they found that a DVD targeting improved self-efficacy significantly improved MRI scan quality.[29] Self-efficacy was not measured in the present study, so the potential mediators of the link between deprivation and presence of comorbidities on image quality could not be directly tested; however, based on the known association between deprivation and self-efficacy, the present results support, albeit indirectly, the concept that self-efficacy, belief in one's ability to stay still in the scan, can influence the incidence of motion artefacts.

Deprivation is also associated with poorer health outcomes among cancer patients, with higher deprivation associated with both higher cancer incidence and mortality, particularly for lung cancer.[30] It is unclear as to the clinical implications of a suboptimal scan in terms of diagnostic accuracy and hence how the association found in the current study potentially contributes to poorer treatment outcomes remains speculative.

In the unadjusted analysis, patients with known or suspected lung cancer were more likely to have suboptimal scans than those with colorectal cancer, and that patients with additional comorbidity were more likely to have degraded scans. Lung cancer patients had significantly greater co-morbidity and it is possible that respiratory symptoms conflicted with the demands of the scan, i.e., breath-holding and lying still; however, neither cancer type nor comorbidity were significant predictors in the adjusted analysis.

As noted above, although the sample size was reasonable, it is possible that the study was underpowered to detect predictors of degraded scans. The average age of the sample was slightly lower than that of cancer patients in the general population, which may have affected the ability of the study to detect associations between image quality and age. The grading of image quality encompassed factors that may not have been in the direct control of patients; however, all scans were performed at sites trained in WB-MRI techniques as part of the main trials, and there was an ongoing quality-assurance programme during the trials. Thus, it is likely that poor scan quality was in the main due to patient-related factors impeding the ability to acquire good-quality images (either first time or after repeat acquisitions); however, it is acknowledged that some aspects of impaired scan quality may have been due purely to technical or radiographer error. The grading system potentially underestimated the severity of image quality impairment as successful repeat of poor-quality images allowed a higher score; however, such a grading system is pragmatic and consistent with the ultimate goal of achieving a high diagnostic scan before the patients leave the MRI suite. Finally, the definition of suboptimal and degraded scan quality was based on expert radiographer and radiologist opinion and not on any direct assessment of impaired diagnostic accuracy, which was inferred.

In conclusion, there is an association between impaired WB-MRI image quality and both social deprivation and patient-perceived burden of WB-MRI. The findings further strengthen the need for in-depth understanding of patient motivation and experiences in order to better refine patient preparation and scan protocols. In particular, future research should explore the mediators between social deprivation and impaired scan quality.

Conflict of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Professor Taylor reports personal fees from Robarts, outside the submitted work.

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Appendix A

The authors of this paper are part of a wider group that form the Streamline trials investigators and include the following collaborators: A Aboagye, L Agoramoorthy, S Ahmed, A Amadi, G Anand, G Atkin, A Austria, S Ball, F Bazari, R Beable, S Beare, H Beedham, T Beeston, N Bharwani, G Bhatnagar, A Bhowmik, L Blakeway, D Blunt, P Boavida, D Boisfer, D Breen, J Bridgewater, S Burke, R Butawan, Y Campbell, E Chang, D Chao, S Chukundah, C S Clarke, B Collins, C Collins, V Conteh, J Couture, J Crosbie, H Curtis, A Daniel, L Davis, K Desai, M Duggan, S Ellis, C Elton, A Engledow, C Everitt, S Ferdous, A Frow, M Furneaux, N Gibbons, R Glynne-Jones, A Gogbashian, V Goh, S Gourtsoyianni, A Green, Laura Green, Liz Green, A Groves, A Guthrie, E Hadley, S Halligan, A Hameeduddin, G Hanid, S Hans, B Hans, A Higginson, L Honeyfield, H Hughes, J Hughes, L Hurl, E Isaac, M Jackson, A Jalloh, S Janes, R Jannapureddy, A Jayme, A Johnson, E Johnson, P Julka, J Kalasthry, E Karapanagiotou, S Karp, C Kay, J Kellaway, S Khan, D Koh, T Light, P Limbu, S Lock, I Locke, T Loke, A Lowe, N Lucas, S Maheswaran, S Mallett, E Marwood, J McGowan, F Mckirdy, T Mills-Baldock, T Moon, V Morgan, S Morris, A Morton, S Nasseri, N Navani, P Nichols, C Norman, E Ntala, A Nunes, A Obichere, J O'Donohue, I Olaleye, A Oliver, A Onajobi, T O'Shaughnessy, A Padhani, H Pardoe, W Partridge, U Patel, K Perry, W Piga, D Prezzi, K Prior, S Punwani, J Pyers, H Rafiee, F Rahman, I Rajanpandian, S Ramesh, S Raouf, K Reczko, A Reinhardt, D Robinson, A Rockall, P Russell, K Sargus, E Scurr, K Shahabuddin, A Sharp, B Shepherd, K Shiu, H Sidhu, I Simcock, C Simeon, A Smith, D Smith, D Snell, J Spence, R Srirajaskanthan, V Stachini, S Stegner, J Stirling, N Strickland, K Tarver, J Teague, M Thaha, M Train, S Tulmuntaha, N Tunariu, K van Ree, A Verjee, C Wanstall, S Weir, S Wijeyekoon, J Wilson, S Wilson, T Win, L Woodrow, D Yu

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crad.2019.10.019.

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