Belgian multicentre study on lumbar spine imaging: Radiation dose and cost analysis; Evaluation of compliance with recommendations for efficient use of medical imaging

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ARTICLE INFO

Keywords:
Spine
Diagnostic imaging
Referral
Radiation dosimetry
Costs

ABSTRACT

Purpose: To assess compliance of lumbar spine imaging referrals with national imaging recommendations and to evaluate the impact of inappropriate imaging on the collective radiation dose and health insurance costs.

Method: In 2011 and 2015, 633 lumbar spine imaging referrals were evaluated across 9 Belgian hospitals. For each patient, a new clinical anamnesis and physical examination were performed. Together with the referral, this data were confronted with the national imaging recommendations. Collective radiation dose was estimated for the radiography and CT procedures. Cost analysis was based on national reimbursement fees. Statistical analysis was performed using multilevel linear and logistic regression models.

Results: The fraction of unjustified imaging referrals decreased from 50 % in 2011 to 41 % in 2015 (p=0.255). The odds of a justified examination are 3.1 times higher when the referral is done by a specialist instead of a general practitioner. The highest percentage of unjustified examinations was found for CT (85 % in 2011, 81 % in 2015; p=0.044). Seventy-five percent of the collective dose of both the 2011 and the 2015 study population was not justified. Adherence to the recommendations could result in an estimated 16 % and 5 % cost reduction for the 2011 and 2015 study samples, respectively.

Conclusions: Between 2011 and 2015, no significant improvement was found in requesting justified lumbar spine imaging procedures, although a positive trend was observed for CT. A shift from CT to MRI is necessary to improve the appropriateness of lumbar spine imaging referrals and to reduce the collective radiation dose.

1. Introduction

Inappropriate use of medical imaging has been reported in several studies [1–4]. Unjustified imaging adds avoidable costs to the healthcare budget and, in case of conventional radiography or CT procedures, patients are unnecessarily exposed to ionizing radiation. However, national recommendations are available to help the referring physician to optimally use medical imaging [5]. The reluctance of physicians to request a recommended imaging technique is mostly linked to a fear of missing a diagnosis, a fear of malpractice suits or an effort to be thorough [1,6].

The present study focuses on the appropriateness of lumbar spine imaging in Belgium. Imaging referrals of the lumbar spine were targeted because of the high incidence of low back pain (LBP) as a major health problem [7]. According to the Belgian 2013 health survey, 20.8 % of the population older than 15 suffered from LBP in the past 12 months [8]. Imaging of the lumbar spine is frequently requested to evaluate acute LBP. However, this indication does not routinely require imaging, since a spontaneous improvement is often seen within the first month after onset of the pain. Imaging is only justified when certain red flags or severe symptoms, like neurologic deficits, are present or when symptoms persist for longer than 6 weeks [9].

A prospective Belgian multicentre study was set up in 2011 to evaluate compliance with the national referral recommendations for medical imaging. Belgium has a relatively high radiation exposure for the population compared to its neighbouring countries, which
2. Materials and methods

2.1. Study design and patient recruitment

This multicentre study was set up across 9 Belgian hospitals. Characteristics of the participating hospitals are listed in Table 1. Hospitals were geographically spread across the country and a mixture of university and general hospitals was chosen to ensure a representative sample. The first part of the study was conducted in 2011, and a follow-up study was initiated in 2015, three years after a national awareness campaign to improve the imaging referral behaviour for medical imaging studies. All hospitals included in the study had conventional radiography, CT and MRI units, except for one general hospital, which had no MRI unit. This also reflects the current Belgian situation where not all hospitals have access to an MRI unit. Patient recruitment took 2 weeks per hospital in 2011 and, due to budgetary restrictions, only 1 week per hospital in 2015. Except for hospital 1 where a pilot study was performed with 184 patients in 2011, the number of patients included ranged from 30 to 66 in 2011 (median: 56) and 3 to 24 in 2015 (median: 19). Patients with a request for lumbar spine imaging were eligible for inclusion in the study if none of the following exclusion criteria were present: under 18 years of age, suffering from a pathology causing limited cooperation or already enrolled in another study. Every referred type of imaging study (radiography, CT, MRI or a combination of imaging studies) was included. Written informed consent was obtained from all patients, and the study was approved by the institutional ethics committee of the participating hospitals.

2.2. Assessing compliance with national referral recommendations

A new clinical anamnesis and physical examination were performed for every patient by a radiology resident in 2011 and a medical graduate in 2015, both trained by the principal investigator, an attending radiologist with 25 years of experience in musculoskeletal imaging. Based on this information and the Belgian referral recommendations for medical imaging (See Supplementary Material), referrals were then classified as justified or unjustified. The Belgian recommendations are based on those developed by the French Society of Radiology (2005), which are an update of the recommendations of the European Association of Radiology (2002) [5]. If a referral was classified as inappropriate, the preferred imaging modality was noted. Appropriateness of the referrals was also evaluated by the principal investigator. In case of a difference in opinion, a decision was made based on consensus.

2.3. Collective radiation dose estimation

For collective radiation dose estimation, CT and radiography images were collected retrospectively. CT images were available for 230 out of 259 procedures. CT exposure parameters, together with volume computed tomography dose index (CTDIvol) and dose-length product (DLP), served as input for the software package CT-EXPO (version 2.4; Medizinische Hochschule) to calculate the effective dose (E). Images were available for 184 out of 201 radiotherapy procedures. However, calculation of E based on actual radiographic exposure parameters was not possible as this information was not always available. Therefore, the collective dose of the radiography procedures was calculated with the mean E of a lumbar spine radiography in Belgium, as estimated in the DDM2 study (3.2 mSv) [10].

The collective radiation dose (expressed in man Sv) from the radiography and CT procedures was calculated by multiplying the mean E from the particular procedure type with the number of corresponding procedures in the sample.

2.4. Cost estimations

An exact estimation of the cost of an imaging procedure is difficult as it covers imaging devices, supplies, equipment and personnel. As an alternative, reimbursement fees (based on procedure-specific reimbursement rates from the Belgian National Institute for Health and Disability Insurance) were used to estimate the financial implications of inappropriate imaging [11].

2.5. Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics software (version 25, IBM Corporation). To evaluate the appropriateness of imaging referrals, a logistic regression model with a generalized estimating equations (GEE) approach was developed to account for hospital clustering and the unbalanced design of the study (unequal sample size in 2011 and 2015). For the model, an exchangeable correlation matrix was assumed. Appropriateness of the referral was included as a dependent variable, whereas year, study type (radiography, CT, MRI or combined) and the interaction term of both were included as independent factors. The effect of different parameters (gender, age, type and region of hospital, type of referring physician) on the appropriateness of referrals was also investigated, for which each parameter was separately introduced in the model as a fixed factor. Furthermore, multilevel linear regression analysis was conducted to estimate the average E. To account for clustering, hospital and CT device were entered as a random factor. Year and age were entered as fixed factors.

3. Results

3.1. Sample characteristics

A total of 490 lumbar spine imaging referrals were included in 2011 and 143 in 2015. A breakdown per imaging modality is presented in Table 2. Mean age of the referred patients was 51 (range 18–89 years) in 2011 and 56 (range 21–90 years) in 2015. Fifty-nine percent of the patient population was female in 2011, whereas in 2015, this fraction

### Table 1: Overview of the type and region of the participating hospitals in 2011 and 2015

<table>
<thead>
<tr>
<th>Hospital</th>
<th>Type of hospital</th>
<th>Size of hospital</th>
<th>Region</th>
<th>Included in study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>University hospital</td>
<td>large</td>
<td>Flanders</td>
<td>yes yes</td>
</tr>
<tr>
<td>2</td>
<td>University hospital</td>
<td>large</td>
<td>Flanders</td>
<td>yes yes</td>
</tr>
<tr>
<td>3</td>
<td>University hospital</td>
<td>large</td>
<td>Brussels</td>
<td>no yes</td>
</tr>
<tr>
<td>4</td>
<td>University hospital</td>
<td>large</td>
<td>Brussels</td>
<td>yes no</td>
</tr>
<tr>
<td>5</td>
<td>General hospital</td>
<td>large</td>
<td>Flanders</td>
<td>yes yes</td>
</tr>
<tr>
<td>6</td>
<td>General hospital</td>
<td>large</td>
<td>Flanders</td>
<td>yes yes</td>
</tr>
<tr>
<td>7</td>
<td>General hospital</td>
<td>large</td>
<td>Flanders</td>
<td>no yes</td>
</tr>
<tr>
<td>8</td>
<td>General hospital</td>
<td>large</td>
<td>Wallonia</td>
<td>yes yes</td>
</tr>
<tr>
<td>9</td>
<td>General hospital</td>
<td>medium</td>
<td>Wallonia</td>
<td>yes yes</td>
</tr>
</tbody>
</table>

* Size of hospital: small: fewer than 100 beds; medium: 100–499 beds, large: 500 or more beds.

b This hospital has no MRI unit.
was 49%. Twenty-five percent (123/490) of the requested imaging procedures in 2011 were at general practitioners’ request compared to 41 % (59/143) in 2015.

3.2. Justification of imaging referrals

If all imaging referrals had been in compliance with the recommendations, there would have been 14 % fewer referrals in the study sample of 2011 (423 instead of 490) and 6 % fewer in 2015 (134 instead of 143). Specifically for CT, there would have been a decrease of 85 % (23 instead of 155) and 81 % (13 procedures instead of 69) in referrals in 2011 and 2015, respectively. Table 2 displays the imaging procedures that should have been requested instead of the unjustified referrals. Analysis of these procedures showed that MRI should have been the preferred imaging modality in 73 % (97/132) and 86 % (48/56) of the unjustified CT procedures in 2011 and 2015, respectively. If the recommendations had been adhered to, the number of MRI procedures would have increased by 63 % (259 instead of 159) in 2011 and by 110 % (101 instead of 49) in 2015.

To estimate the fractions of unjustified procedures in 2011 and 2015, logistic regression with a GEE model was used to adjust for clustering and account for the unbalanced design of the study. The model estimated that 50 % of the lumbar spine procedures in 2011 were inappropriate (95 %CI: 41 %– 59 %). In 2015, the fraction of unjustified requests decreased to 41 % (95 %CI: 36 %– 47 %). No significant improvement in the requesting behaviour was observed between 2011 and 2015 for imaging of the lumbar spine (p=0.255).

However, a review of the results per imaging modality revealed that the odds ratio (OR) of a justified CT referral in 2015 was estimated at 1.4 times higher in 2015 than in 2011 (p=0.044) (Table 3). The same trend was observed for MRI (OR:1.9) and combined referrals (OR:3.1), although not statistically significant (p=0.500 and p=0.314, respectively). The opposite was found for radiography referrals, with the odds of a justified referral 50 % lower in 2015 than in 2011 (p=0.001). The highest percentage of inappropriate examinations was found for CT procedures (85 % in 2011; 81 % in 2015). Inappropriate radiography and CT procedures were primarily done if there was an indication of LBP with the presence of neurological deficits, for which an MRI should have been performed. Many unjustified MRI procedures were requested in cases for which an imaging study was not indicated, such as an acute LBP without red flags, having lasted for less than 7 weeks or cases for which previous imaging of the patient was available from a few weeks or months before the current request.

The effect of patient-specific features, such as age and gender, on the appropriateness of the referral was investigated, but no significant association could be demonstrated (p = 0.675 and p = 0.582, respectively). Type and region of the hospital also had no significant impact (p = 0.455 and p = 0.097, respectively). However, the type of prescribing physician was significantly associated with the justification of the procedures (p = 0.002). The odds of a justified imaging procedure were 3.1 times higher when the referral came from a medical specialist instead of a general practitioner.

3.3. Collective radiation dose

The average E of the CT procedures was estimated with a multilevel linear regression model, and decreased from 13.9 mSv (95 %CI:10.4–18.4) in 2011 to 8.9 mSv (95 %CI: 6.7–11.8) in 2015 (p < 0.001). The DDM2 study estimated E for lumbar spine CT at 10.1 mSv in 2014. For radiography, a value of 3.2 mSv was used [10]. The collective radiation dose for the 2011 study population was 3122 man mSv for 358 radiography and CT procedures, 83 % of which originated from unjustified referrals. As shown in Table 4, 2329 man mSv (75 %) resulted from unjustified procedures. For the study population of 2015, the collective dose was 721 man mSv for 98 radiography and CT procedures. Eighty-nine percent of this dose was the result of CT procedures, and 75 % (541 man mSv) originated from unjustified imaging procedures.

3.4. Cost

The total cost of the 490 lumbar spine imaging examinations in 2011 for the national health insurance was €62,955, with unjustified referrals accounting for €31,098 (49 %). If the recommendations had

<table>
<thead>
<tr>
<th>Imaging referrals</th>
<th>Number of procedures (percentages) that should have been requested instead of the unjustified referrals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modality</td>
<td>Total</td>
</tr>
<tr>
<td>2011</td>
<td></td>
</tr>
<tr>
<td>Radiography</td>
<td>137</td>
</tr>
<tr>
<td>CT</td>
<td>155</td>
</tr>
<tr>
<td>MRI</td>
<td>159</td>
</tr>
<tr>
<td>Combined</td>
<td>39</td>
</tr>
<tr>
<td>2015</td>
<td></td>
</tr>
<tr>
<td>Radiography</td>
<td>21</td>
</tr>
<tr>
<td>CT</td>
<td>69</td>
</tr>
<tr>
<td>MRI</td>
<td>48</td>
</tr>
<tr>
<td>Combined</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3

Estimated odds ratio (OR) and 95 % confidence interval (CI) with logistic regression analysis for justification of the lumbar spine imaging referrals in 2015 versus 2011 per imaging modality. Fractions of unjustified referrals were also estimated by means of the logistic regression model.

<table>
<thead>
<tr>
<th>Modality</th>
<th>OR</th>
<th>p value</th>
<th>Estimated fraction of unjustified referrals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2011</td>
</tr>
<tr>
<td>Radiography</td>
<td>0.5 (95 % CI: 0.4-0.8)</td>
<td>0.001</td>
<td>27 % (95 % CI: 22-34)</td>
</tr>
<tr>
<td>CT</td>
<td>1.4 (95 % CI: 1.0-1.9)</td>
<td>0.044</td>
<td>85 % (95 % CI: 75-92)</td>
</tr>
<tr>
<td>MRI</td>
<td>1.9 (95 % CI: 0.6-6.3)</td>
<td>0.300</td>
<td>17 % (95 % CI: 9-32)</td>
</tr>
<tr>
<td>Combined</td>
<td>3.1 (95 % CI: 0.3-29.1)</td>
<td>0.314</td>
<td>68% (95 % CI: 47-83)</td>
</tr>
</tbody>
</table>

OR odds ratio, CI confidence interval.
were still not in compliance with the recommendations (85% in 2011 and 81% in 2015). The persistent inadequate use of CT procedures may be attributed to the insufficient number of MRI units in Belgium. In 2015, only 12 MRI units were available for 1 million inhabitants compared to 23 CT units [12,13].

A research group from Oulu University Hospital (Finland) observed that 77% of the lumbar spine CT procedures were not in compliance with the referral criteria. Most of these unjustified procedures could have been replaced by MRI procedures [14]. Another study by the same research group analysed 150 common MRI procedures, 7% of which were not justified. Specific for lumbar spine, 2 out of 30 procedures were not appropriate [2]. These results are in line with those of the present study, in which more than 80% of the CT referrals were found to be inappropriate and could have been replaced by an MRI, a radiography or no imaging at all (see Table 2). Most of the unjustified CT procedures had been done for LBP with the presence of neurological complications. For this indication, MRI is the preferred imaging modality because it allows for superior soft tissue visualisation [15]. In addition, MRI avoids exposure to ionizing radiation and the associated health risk [16]. A shift from CT to MRI was needed in 73% of the unjustified referrals in 2011 and in 86% of such referrals in 2015. However, an MRI is an expensive diagnostic test for the Belgian federal government, and the long examination time in comparison with a CT scan results in long waiting lists for MRI examinations [15]. Median waiting time for a CT study was 8 days in both 2011 and 2015. For MRI, median waiting time was 20 days in 2011 and had even increased to 24 days in 2015 [17]. Increasing the number of MRI devices will reduce the waiting lists and will further encourage the substitution of CT for MRI.

The high number of inappropriate imaging procedures contributed to unnecessary patient radiation exposure. Seventy-five percent of the collective radiation dose for both the 2011 and 2015 study population was not justified. Limiting inappropriate imaging is essential to reduce patient exposure to ionizing radiation. In addition, unjustified use of imaging is responsible for unnecessary costs for the national health insurance. About 50% of the estimated expenses in the 2011 and 2015 samples came from unjustified imaging procedures. If the recommendations had been correctly applied, the total cost could have been reduced by 16% in the 2011 study sample and by 5% in the 2015 study sample. Despite a considerable decrease of collective radiation dose, health insurance costs would not be reduced as dramatically when the recommendations would have been correctly applied. A shift from CT to MRI would avoid the radiation exposure but the costs from the unjustified CT referrals would partially make a shift to MRI. If the recommendations would have been correctly applied, the expected reduction in costs would mainly be the result of the prevention of imaging procedures that should not have been requested at all. Although MRI is expensive, this factor will not influence the referring physician as the patient’s contribution on medical imaging cost is limited in Belgium. The decision-making process of physicians is country-dependent based on individual healthcare systems in each country.

Several studies have demonstrated the positive effect of initiatives reinforcing the use of referral recommendations, although these results could not be confirmed in the present study. Between 2006 and 2009, several interventions were introduced at Oulu University Hospital to improve the justification of CT procedures. Through education, guideline implementation and an increased MRI capacity, the proportion of indicated lumbar spine CT procedures increased from 23% in 2005 to 81% in 2009 [4]. For lumbar spine radiography as well, a significant increase in justified procedures was seen after active implementation of the referral guidelines [18,19]. In addition to the shortage of MRI capacity, the lack of an overall significant improvement in requesting behaviour found in the present study may be due to the time between the awareness campaign in 2012 and the follow-up study in 2015. It is possible that a significant reduction in unjustified referrals was achieved in the first year after initiating the campaign, but that this effect could not be sustained until 2015. A study of Matowe et al. showed no significant effect of disseminating the recommendations

### Table 4
Collective radiation dose, expressed in man mSv, of the justified and unjustified referrals in 2011 and 2015.

<table>
<thead>
<tr>
<th></th>
<th>2011 Justified (n = 143)</th>
<th>2011 Unjustified (n = 215)</th>
<th>2015 Justified (n = 30)</th>
<th>2015 Unjustified (n = 68)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiography</td>
<td>350</td>
<td>192</td>
<td>47</td>
<td>35</td>
</tr>
<tr>
<td>CT</td>
<td>444</td>
<td>2137</td>
<td>133</td>
<td>506</td>
</tr>
<tr>
<td>Total</td>
<td>794 (25 %)</td>
<td>2329 (75 %)</td>
<td>180 (25 %)</td>
<td>541 (75 %)</td>
</tr>
</tbody>
</table>

**Fig. 1.** Costs for the national health insurance per imaging modality in 2011 (A) and 2015 (B). The estimated costs in the sample are compared to the calculated theoretical costs if the recommendations had been followed.

been followed, there would have been a theoretical cost of €52,674; which implies a cost reduction of €10,282 (16%) in this sample. In 2015, the total cost was estimated at €20,823 for the 143 lumbar spine imaging examinations, with €10,468 (50%) covering inappropriate referrals. If the recommendations had been correctly applied, this cost would have been estimated at €19,776; thus being reduced by €1047 (5%). The possible cost reduction is the highest for CT procedures with a potential reduction of 85% in 2011 and 81% in 2015 (Fig. 1). In contrast, the cost for MRI procedures would have increased by 60% in 2011 and 108% in 2015 if the referrals had been in compliance with the recommendations.

### 4. Discussion

The present study shows that despite the awareness initiatives of 2012, there was no significant improvement in the prescription of justified lumbar spine imaging between 2011 and 2015. However, a review of the appropriateness of the imaging referrals per imaging modality revealed a statistically significant decrease in unjustified CT procedures between 2011 and 2015. Nevertheless, many CT referrals were still not in compliance with the recommendations (85% in 2011 and 81% in 2015). The persistent inadequate use of CT procedures may be attributed to the insufficient number of MRI units in Belgium. In 2015, only 12 MRI units were available for 1 million inhabitants compared to 23 CT units [12,13].

A research group from Oulu University Hospital (Finland) observed that 77% of the lumbar spine CT procedures were not in compliance with the referral criteria. Most of these unjustified procedures could have been replaced by MRI procedures [14]. Another study by the same research group analysed 150 common MRI procedures, 7% of which were not justified. Specific for lumbar spine, 2 out of 30 procedures were not appropriate [2]. These results are in line with those of the present study, in which more than 80% of the CT referrals were found to be inappropriate and could have been replaced by an MRI, a radiography or no imaging at all (see Table 2). Most of the unjustified CT procedures had been done for LBP with the presence of neurological complications. For this indication, MRI is the preferred imaging modality because it allows for superior soft tissue visualisation [15]. In addition, MRI avoids exposure to ionizing radiation and the associated health risk [16]. A shift from CT to MRI was needed in 73% of the unjustified referrals in 2011 and in 86% of such referrals in 2015. However, an MRI is an expensive diagnostic test for the Belgian federal government, and the long examination time in comparison with a CT scan results in long waiting lists for MRI examinations [15]. Median waiting time for a CT study was 8 days in both 2011 and 2015. For MRI, median waiting time was 20 days in 2011 and had even increased to 24 days in 2015 [17]. Increasing the number of MRI devices will reduce the waiting lists and will further encourage the substitution of CT for MRI.

The high number of inappropriate imaging procedures contributed to unnecessary patient radiation exposure. Seventy-five percent of the collective radiation dose for both the 2011 and 2015 study population was not justified. Limiting inappropriate imaging is essential to reduce patient exposure to ionizing radiation. In addition, unjustified use of imaging is responsible for unnecessary costs for the national health insurance. About 50% of the estimated expenses in the 2011 and 2015 samples came from unjustified imaging procedures. If the recommendations had been correctly applied, the total cost could have been reduced by 16% in the 2011 study sample and by 5% in the 2015 study sample. Despite a considerable decrease of collective radiation dose, health insurance costs would not be reduced as dramatically when the recommendations would have been correctly applied. A shift from CT to MRI would avoid the radiation exposure but the costs from the unjustified CT referrals would partially make a shift to MRI. If the recommendations would have been correctly applied, the expected reduction in costs would mainly be the result of the prevention of imaging procedures that should not have been requested at all. Although MRI is expensive, this factor will not influence the referring physician as the patient’s contribution on medical imaging cost is limited in Belgium. The decision-making process of physicians is country-dependent based on individual healthcare systems in each country.

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without further support through other initiatives on the total number of referrals [20]. Active implementation of the recommendations is essential to reduce the incidence of inappropriate imaging [4,18].

Education and training of physicians on the appropriate use of medical imaging play a crucial role in further improving appropriateness [4,18]. In contrast to Cristofaro et al., who showed no significant difference between general practitioners and medical specialists [3], our study found that general practitioners request more inappropriate imaging procedures than medical specialists. This discrepancy may be linked to medical specialists having had a better clinical experience with LBP and a more thorough education on the indications of medical imaging. In addition, general practitioners have to deal with a variety of medical disciplines, which makes it almost impossible to keep abreast of all imaging recommendations for the different types of pathologies.

Clinical decision support (CDS) systems could assist the general practitioner in choosing the appropriate imaging procedure. The integration of a CDS system in the clinical workflow has already been shown to have a positive effect on the appropriateness of imaging referral [21–23]. Application and improvement of these systems should be further stimulated in the future [24]. Moreover, as of April 1, 2014, the Belgian radiologists are legally allowed to autonomously substitute the requested imaging procedure with a procedure that is more appropriate according to the recommendations, which should further enhance the appropriateness of the imaging referrals. Future research could focus on the impact of radiologists becoming active contributors in the selection of imaging modalities.

One of the strengths of the present study lies in the new physical examination and anamnesis that was performed on every patient. This methodology had not been previously applied in studies that address the justification of imaging procedures [4,14,25]. In combination with the information in the referral and the patient files, this examination presumably provided us the same information as the referring physician.

However, this study also has some limitations. Although this study represents a small proportion of the population and a single country’s experience, it can probably be extrapolated to other parts of the world too; similar results were found in other countries like Finland and the UK [14,20]. Imaging choices for clinicians are largely based upon the imaging techniques they have at their reach. The evaluation of the appropriateness of imaging referrals is not always straightforward. The recommendations do not cover all potential diseases or situations, which means that physicians can make different decisions in such cases. An additional limitation is the small sample size for 2015 due to a difference in patient inclusion time. This caused an unbalanced study design, which was accounted for in the applied logistic regression model.

In conclusion, the present study shows that there was no significant improvement in requesting justified lumbar spine imaging procedures between 2011 and 2015, although a positive trend was observed for CT. A shift from CT to MRI is necessary to improve the appropriateness of lumbar spine imaging referrals. The discrepancy between the recommendations and clinical practice is currently causing unnecessary radiation exposure and increased costs for the national health insurance budget.

Declaration of Competing Interest

We wish to draw the attention of the Editor to the following facts which may be considered as potential conflicts of interest and to significant financial contributions to this work.

This study has received funding by the Belgian College of Radiology. The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Acknowledgements

This study received funding from the Belgian College of Radiology.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j. ejrad.2020.108864.

References