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HEAD, NECK AND DENTAL RADIOLOGY

Value of structured reporting in neuromuscular disorders

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Abstract

Objective To assess whether structured reports (SRs) of MRI in patients with inherited neuromuscular disorders (IND) provide more clinically relevant information than non-structured reports (NSRs) and whether neuroradiologists' expertise affects completeness of reports.

Material and methods Lower limbs' MRI reports of patients with IND produced by neuroradiologists with different level of expertise (> 15 years vs. < 15 years of experience in reading IND-MRI) before and after implementation of a SR template were included. Reports were assessed for the presence of 9 key features relevant for IND management. Reports and images were evaluated by neurologists who assessed: disease-specific muscular involvement pattern; presence of sufficient information to order the appropriate genetic/diagnostic tests; presence of sufficient information to make therapeutic decision/perform biopsy and necessity to review MRI images. Mann–Whitney and Fisher's exact tests were used to compare the number of key features for NSR and SR and neurologists' answers for reports produced by neuroradiologists with different experience.

Results Thirty-one SRs and 101 NSRs were reviewed. A median of 8 and 6 key features was present in SR and NSR, respectively (p value < 0.0001). When reports were produced by less expert neuroradiologists, neurologists recognized muscular involvement pattern, had sufficient information for clinical decision-making/perform biopsy more often with SR than NSR (p values: < 0.0001), and needed to evaluate images less often with SR (p value: 0.0001). When reports produced by expert neuroradiologists were evaluated, no significant difference in neurologists' answers was observed.

Conclusion SR of IND-MRI contained more often clinically relevant information considered important for disease management than NSR. Radiologist's expertise affects completeness of NSR reports.

Keywords Magnetic resonance imaging · Neuromuscular diseases · Limb-girdle muscular dystrophies · Sarcoglycanopathies · Structured reporting

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Introduction

Over the last few years, substantial progress has been made in the genetic diagnosis of inherited neuromuscular disorders (IND) with the identification of over 400 genetically distinct forms. This complex genetic heterogeneity makes the diagnosis extremely challenging since the most commonly used diagnostic tests, including muscle enzymes, electrophysiological studies, and muscle biopsy, are not always specific [1]. Furthermore, the clinical picture does not necessarily help in individuating the different disorders. It is well known that mutations in the same gene can originate different phenotypes and that the same phenotype and even the same muscle alteration detected by electron microscope can be the consequence of different genetic defects [2, 3].

There has been increasing evidence that muscle MRI can be an important additional tool in diagnosis and follow-up of patients with IND, providing valuable information on muscle bulk, shape, volume, dystrophic, and inflammatory changes [4–8]. MRI often allows recognition of specific patterns of muscle involvement and has proved to be helpful in narrowing the differential diagnosis, aiding in the selection of the appropriate genetic and biochemical diagnostic investigations, as well as identifying which muscle to target for pathological studies [4–8].

The advent of new next-generation sequencing and other molecular tools has significantly facilitated the diagnostic pathway in IND; nonetheless, muscle MRI still plays a relevant role in solving diagnostic dilemmas and in the interpretation of the results obtained from molecular panels. Despite the bulk of evidence published in the last two decades, the use of muscle MRI is still relatively limited to research settings or to a limited number of tertiary care centers. Many clinicians and radiologists report difficulties in interpreting and reporting the MRI findings. In the past decades, to overcome variability and increase completeness, consistency and readability of radiologic reports, structured report (SR) templates have been adopted in many fields of radiology, from oncologic imaging to neuroradiology [9–12].

Various studies analyzed the impact of clinician experience in evaluating SR in different fields of radiology, showing that SR more often contains adequate information for patient care with decreased variability compared to non-structured report (NSR), in most cases [9–16]. For these reasons, SR is often preferred by clinicians and radiologists [17]. Thus far, since muscle MRI of IND has been mainly limited to tertiary care centers in which clinicians are often involved in the interpretation of the MRI, and consequently, little has been reported about the possible use of SR in neuromuscular disorders and how SRs are perceived by the referring clinician. The difficulties in this field are related to the accuracy of the reports but also to the fact that their interpretation should be based on the knowledge of the patterns of muscle involvement reported in the literature.

The aim of this study was to establish whether SR of MRI in patients with IND provides more clinically relevant information for disease management compared with NSR and whether the completeness of MRI reports is affected by neuroradiologists level of expertise.

Materials and methods

Study population

Institutional review board approval at all the institutions was obtained for this HIPAA compliant study. Informed patient consent was waived by the institutional review boards. From each institution, the radiology information system (RIS) at the radiology departments of the various institution was queried for reports of MRI of the lower limbs with indication of "suspected/known IND" generated 3 years before (from November 1, 2013, to October 31, 2016) and 1 year after implementation of a SR template (from November 1, 2016, to October 1, 2017). Only reports produced by a randomly selected neuroradiologist for each institution were included.

In order to establish whether the level of expertise might have affected the accuracy of the SR and NSR, it was noted whether the MRI reports were produced by neuroradiologists with more than 15 years of expertise (experienced neuroradiologists in reading MRI for suspected/known IND) or by less experienced neuroradiologists (less than 15 years of expertise) in the corresponding referral clinical Center for IND. All neuroradiologists reported a minimum of 50 MRI reports for suspected/known IND per year.

MRI protocol

Given the retrospective nature and multi-institutional nature of the study, technical MRI parameters varied among the different institutions. In all cases, 1.5T or 3T MRI scanners were used. At a minimum, sequential, non-contrast-enhanced, axial turbo spin echo (TSE) T1-weighted (T1W) and short-time inversion recovery (STIR) sequences were used to study the lower limb muscles including the pelvic girdle, the thighs, and lower legs bilaterally.

Subjects lay in the scanner in the feet-first supine position, with the lower limbs lying in a comfortable position on the scanner bed. A flexible body coil was placed over the lower limbs. A fabricated thermoplastic splint and sandbags were used to stabilize the limbs and to minimize motion,

when necessary. The patients did not receive any sedation and the total examination time was approximately 30 min.

Turbo spin echo, T1W, and STIR sequences were acquired on axial plane selected with respect to the long axis of the femoral shaft for the thighs and with respect to the long axis of the tibia and fibula for the lower legs. The slices were set up to cover the entire extension of the lower limbs. Each muscle was evaluated throughout its length.

Scan parameters were as follows: TSE T1 > TR 600 ms, TE 20 ms, FOV 16–38 cm (selected according to patient's size), pixel 1 × 1, slice thickness 5 mm, flip angle 90°, interslice gap 0.5 mm. STIR > TR 4500 ms, TE 100 ms, TI 150 ms, FOV 16–38 cm (selected according to patient size), pixel 1 × 1, slice thickness 5 mm, interslice gap 0.5 mm.

Descriptive analysis was used to identify the muscles that were more frequently affected in the different segments. All experienced neuroradiologists assessed MRI scans for normal or abnormal signal intensity within the different muscles groups scoring them using Mercuri classification, as follows: Stage 0: normal appearance; Stage 1: scattered small areas of increased intensity on T1W images; Stage 2a: numerous discrete areas of increased intensity on T1W images involving less than 30% of the volume of the muscle; Stage 2b: numerous discrete areas of increased intensity on T1W images with early confluence of, 30–60% of the volume of the muscle; Stage 3: washed-out appearance due to confluent areas of increased intensity on T1W images with muscle still present at the periphery; Stage 4: end-stage appearance, muscle entirely replaced by areas of increased intensity on T1W images [18].

MRI template report

An MRI template report was designed by three neuroradiologists (X3.X3., X4.X4., X15.X15.), all of them experts in interpreting MR examinations in patients with IND, and three neurologists specialized in IND (X12.X12., X13.X13., X14.X14.).

The template was implemented in RIS of the various Institutions in November 1, 2016. For each institution, two neuroradiologists specialized in neuromuscular disease, responsible for reporting MRI of patients with IND in their departments, were trained on how to use the template for two 1-h sessions by the three neuroradiologists who built the SR template.

Key features

All selected reports (SR and NSR) were evaluated by a neuroradiologist not involved in building the SR template (X1.X1.) for the presence of key features deemed necessary for patient management. Each feature was considered present if mentioned in the report, regardless if the finding was positive or negative, and absent if not mentioned.

The key features, in part based on a previous paper describing the pattern of muscular involvement in IND, were: (1) type of sequences acquired (mention of type of sequence and part of body imaged); (2) entity of the subcutaneous tissue relative to underlying muscular bulk (increased, similar, or reduced); (3) fat replacement of single muscle bundles (mention of specific muscle); (4) selective muscular involvement pattern, defined according to literature data; (5) specific muscular involvement at the pelvic girdle (mention of specific muscles); (6) specific muscular involvement at the thigh (mention of specific muscles); (7) specific muscular involvement at the lower leg (mention of specific muscles); (8) specific muscle bundles hyperintense on T2-STIR sequences; (9) overall impression [19]. Figure 1 shows three examples of the key features evaluated on lower limb MRI.

Evaluation of reports and MRI by clinicians

After SR and NSR were selected for neuroradiologists evaluation of key features, a sample of de-identified randomly selected sample of SR and NSR was provided to clinicians for their evaluation. One neurologist for each institute with more than 15 years of experience in IND management evaluated independently the reports and MRI images.

Firstly, clinicians evaluated the reports: for each evaluation, clinicians were asked the following questions: 1. Do you find the report useful to understand disease-specific pattern of muscular involvement? (yes, no); 2. Do you have enough information to decide which genetic tests or which additional diagnostic tests to order? (yes, no); 3. Do you have enough information for making adequate therapeutic decision/to perform a biopsy? (yes, no); 4. Would MRI images be helpful to decide next step in patient care? (yes, no). After 4 weeks, to avoid recall bias, clinicians evaluated reports and MRI images. Then, they were asked the same first three questions.

Statistical analysis

Descriptive statistics were produced for the demographic and clinical characteristics of cases. Mann–Whitney test was used to compare total number of key features for each neuroradiologists in the two groups (NSR vs. SR) for all MRI reports and for the MRI reports produced by neuroradiologists with different level of expertise. Comparison between each key feature was carried out with Chi-square or Fisher's exact test in the two groups for (NSR vs. SR) for all MRI reports and for the MRI reports produced by neuroradiologists with different experience. The Chi-square or Fisher's exact test also was used to compare

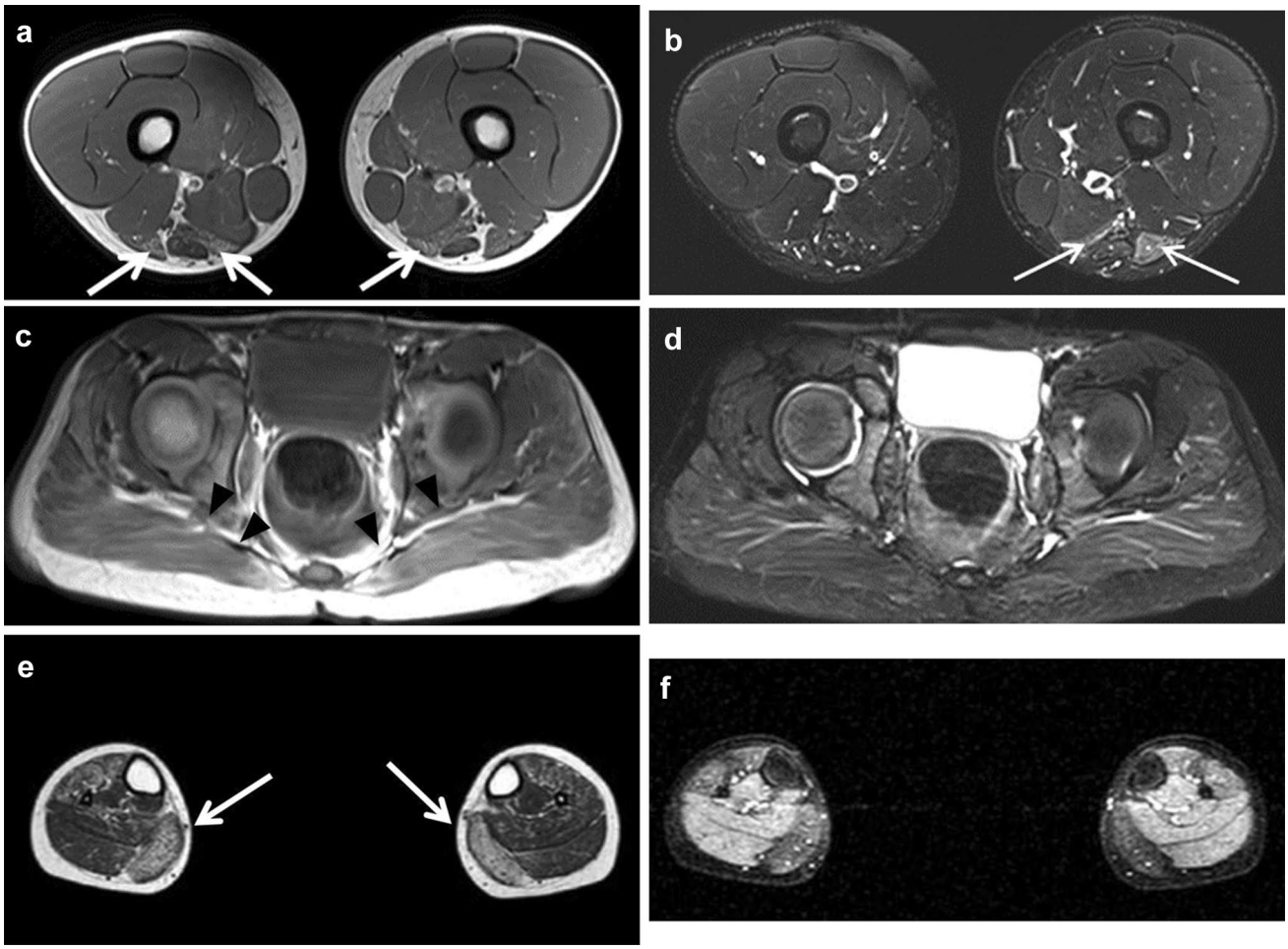

Fig. 1 Representative examples of key features evaluated in muscle MRI. Case 1: 16-year-old male patient with suspected facioscapulohumeral muscular dystrophy (FSHD) presenting with lagophthalmos, horizontal smile, winging scapulae, horizontal clavicula, limited upper limbs abduction and mild steppage gait. **a** T1-weighted image acquired at the level of the thigh shows mild hyperintensity of the right long head of the biceps femoris muscle (arrows) and of both semimembranosus muscles, consistent with fat infiltration. **b** T2/STIR image acquired at the same level of the thigh showing hyperintensity of the left long head of the biceps femoris muscle and mildly of the semimembranosus of the same side, as a radiological sign of intramuscular edema (arrows). These findings were mentioned in structured report. Patient also showed fat infiltration of muscles of the upper girdle on MRI (not shown). Based on the presence of specific clinical symptoms and MRI findings, molecular analysis was performed and showed a D4Z4 allele of 17 Kb, as seen in FSHD. Case 2: 5-year-old male child with suspected Duchenne muscular dystrophy presenting with waddling gait, calf pseudohypertrophy, positive Gowers. Sign, and elevated serum creatine kinase. **c** T1-weighted image acquired at the level of the pelvic girdle shows fat infiltration of the bilateral gluteus maximus and gluteus medius muscles (black arrowheads). **d** T2/stir image acquired at the level of the pelvic girdle shows hypointensity of the same muscles, with no hyperintensity to suggest edema. Both findings were mentioned in structured report. Molecular analysis of DMD gene, on the basis of clinical symptoms, was performed, demonstrating exons 44–55 deletion. Case 3: 11-year-old male child with suspected limb-girdle muscular dystrophy presenting with positive Gowers' sign, waddling gait, prominent calf, winging scapulae and hyperlordosis. **e** T1-weighted image acquired at the level of the leg demonstrates hyperintensity of the soleus (arrows). **f** T2/STIR image acquired at the same level, shows T2-hypointensity suggesting advanced fat infiltration and no sign of intramuscular edema. Both findings were mentioned in structured report. No biopsy was performed, as Beta Sarcoglycan gene mutation (homozygous duplication of 8 exons (377_384duplCAGTAGGA) in exon 3 determining frame shifting (G129_R130insQX) in Beta Sarcoglycan gene) found in his older brother confirmed the diagnosis. This case has been previously described in [26]

clinicians' answers in the two groups. A p value of less than 0.05 was considered significant. All statistical analyses were conducted using JMP version 13.0.0 for Windows (JMP®, Version 13.0.0 SAS Institute Inc., Cary, NC, 1989–2007).

Results

Study population

A total of 149 MRI reports were initially retrieved. Reports were initially screened for the presence of artifacts,

completeness, and the presence of positive findings. MRI reports mentioning the presence of artifacts ($n=2$), interruption of the MRI examination ($n=1$), and MRI reports with the absence of any positive findings ($n=14$) were excluded. A total of 132 reports of lower limbs MRI with indication of suspected/known IND created by a total of 6 neuroradiologists were included; of these 101 were NSRs, 31 were SRs. Sixty-eight MRI reports were produced by neuroradiologists with more than 15 years of experience in IND diagnosis (48 NSR and 20 SR), and 64 MRI reports by less experienced neuroradiologists (53 NSRs and 11 SRs). A sample of 56 reports was evaluated by clinicians. Of these, 48 had images available for clinicians' review.

Key features

The presence of key features in all SR and NSR are presented for MRI reports in Table 1.

Regarding single key features, entity of the subcutaneous tissue relative to underlying muscular bulk (p value: <0.0001), fat replacement of single muscle bundles (p value: <0.0001), the specific muscular involvement at the thigh (p value: <0.0001), at the lower leg (p value: 0.0003), and the presence of specific muscle bundles hyperintense on STIR sequences ($p<0.0001$) were significantly more often reported in SR than NSR. Overall impression was significantly more often present in NSR than SR (p value: 0.0140).

No significant difference between SR and NSR was observed for other key features evaluated: the type of sequences acquired (p value: 0.5908); the selective muscular involvement pattern (p value 0.5908); and the specific muscular involvement at the pelvic girdle (0.0663) (Table 1).

A significant difference in terms of number of key features was observed for MRI reports, with median of 8 key features [lower quartile ($Q1$)–upper quartile ($Q3$): 8–9] in SR and median of 6 key features [$Q1$–$Q3$: 4–7] in NSR ($p<0.0001$).

When MRI reports were grouped according to neuroradiologists' level of expertise, there was significant difference in number of key features reported in SR and NSR, with median of 9 key features [$Q1$–$Q3$: 8–9] in SR and 7 key features [$Q1$–$Q3$: 6–8] in NSR for experienced neuroradiologists (p value <0.0001); and median of 8 key features [$Q1$–$Q3$: 8–8] in SR and 4 key features [$Q1$–$Q3$: 4–5] in NSR for less experienced neuroradiologists (p value <0.0001).

Evaluation of reports and MRI by clinicians

Clinicians' answers when reading reports and reports and images are reported in Table 2. In summary, when all MRI reports were evaluated, a statistically significant difference was observed in answers to question 1, as neurologists could understand disease-specific pattern of muscular involvement more often reading SR than NSR (p value: 0.0029) and in answer to question 3 (Do you have enough information for making adequate clinical decision/to perform a biopsy?) (p value: 0.0437). Regarding question 2 (Do you have enough information to decide which genetic tests or which additional diagnostic tests to order?), no significant difference was observed when NSR and SR were evaluated (p value: 0.1765). Clinicians needed to evaluate images significantly more often when reading NSR than SR (p value: 0.0437).

When reports and images were evaluated together, statistically significant difference was observed in answers to question 1 (p value: 0.0415) and question 3 (p value: 0.0013). No significant difference for question 2 was observed when reports and images were evaluated together (0.3412).

Clinicians' answers when reading reports and reports with images grouped according to neuroradiologists experience

Table 1 Key features in non-structured (NSR) and structured (SR) reports

Key features evaluated in MRI reports	NSR (101)	SR (31)	*P* value
1. Sequences acquired	96 (95%)	31 (100%)	0.5908
2. Entity of the subcutaneous tissue relative to muscle	35 (34.6%)	31 (100%)	**< 0.0001**
3. Fat replacement of single muscle bundles	29 (28.7%)	31 (100%)	**< 0.0001**
4. Selective muscular involvement pattern	96 (95%)	31 (100%)	0.5908
5. Specific muscular involvement at the pelvic girdle	90 (89.1%)	31 (100%)	0.0663
6. Specific muscular involvement at the thigh	46 (45.5%)	29 (93.5%)	**< 0.0001**
7. Specific muscular involvement at the lower leg	56 (55.4%)	28 (90.3%)	**0.0003**
8. Specific muscle bundles hyperintense on T2-WI	43 (42.6%)	27 (87%)	**< 0.0001**
9. Overall impression	84 (83.1%)	19 (61.3%)	**0.0140**
Total (median; $Q1$–$Q3$)	**6 (4–7)**	**8 (8–9)**	**< 0.0001**
Experienced neuroradiologists	7 (6–8)	9 (8–9)	**< 0.0001**
Less experienced neuroradiologists	4 (4–5)	8(8–8)	**< 0.0001**

SR Structured report, *NSR* non-structured report, *T2-WI* T2 weighted/STIR images

Bold value represents clinically significant *P* value

Table 2 Neurologists evaluation of MRI reports and MRI reports with images

Neuroradiologists expertise Type of MRI report	Question evaluated (positive/total answers)						
	MRI reports				MRI reports with images		
	1. Pattern of muscular involvement	2. Genetic/diagnostic tests to order	3. Sufficient information for therapeutic decision/biopsy	4. Need to review images	1. Pattern of muscular involvement	2. Genetic/diagnostic tests to order	3. Sufficient information for therapeutic decision/biopsy
More than 15 years							
SR	10/18	9/18	13/18	4/18	5/14	9/14	12/14
NSR	7/18	6/18	14/18	3/18	7/14	5/14	11/14
P value	0.5051	0.4998	0.148	0.177	0.7036	0.2568	1
Less than 15 years							
SR	9/10	10/10	10/10	1/10	10/10	10/10	10/10
NSR	10/10	7/10	1/10	10/10	0/10	10/10	0/10
P value	**< 0.0001**	0.2105	**0.0001**	**0.0001**	**< 0.0001**	1	**< 0.0001**
Total							
SR	19/28	19/28	23/28	5/28	15/24	19/24	22/24
NSR	7/28	13/28	15/28	13/28	7/24	15/24	11/24
P value	**0.0029**	0.1765	**0.0437**	**0.0437**	**0.0415**	0.3412	**0.0013**

SR Structured report, *NSR* non-structured report

Bold value represents clinically significant *P* value

are reported in Table 2. When reports and reports with images produced by experienced neuroradiologists were evaluated, no significant difference in clinician answers was observed for all questions. When reports produced by neuroradiologists with less than 15 years of experience in reading IND-MRI were evaluated, a statistically significant difference was observed in answers to question 1 (p value: $0 < 0.0001$) and question 3 (p value: < 0.0001). No significant difference in answer to question 2 was observed (p value: 0.1765). Clinicians needed to evaluate images significantly more often when reading NSR than SR produced by neuroradiologists with less than 15 years of experience in reading IND-MRI (p value: 0.0001). Specifically, clinicians needed images to decide which step to take in patient care in all cases when reading NSR. When reports and images were evaluated together, statistically significant difference was again observed in answers to question 1 (p value: < 0.0001), and question 3 (p value < 0.0001). No significant difference for question 2 was observed when reports and images were evaluated together (p value: > 0.99).

Discussion

Although no specific guidelines on MRI reporting of IND exists, evidence from the literature has shown a growing role of MRI in patients with IND given that MRI, delineating the extent and localization of muscle pathology, provides useful information for the diagnostic workup of patients, can guide genetic testing, and allows optimal targeting of muscle biopsy [5–8, 20]. The application of SR in various fields of radiology, from mammography to neuroradiology to have shown that this system has been useful to improve completeness and clarity of reports, facilitate data mining, and improve communications of results to the referring physician [11, 21, 22].

Our study showed that SR of MRI in patients with IND contained more clinically relevant and important information for disease management compared with NSR. Specifically, the entity of the subcutaneous tissue relative to underlying muscular bulk, the fat replacement of single muscle bundles, the specific muscular involvement at the thigh and lower leg and the T2-STIR hyperintensity of specific muscle bundles, were significantly more often reported in SR than in NSR. Even though these findings are considered crucial for MRI diagnosis of IND, our multi-institutional study shows these are not always mentioned in the MRI reports, and the clinical practice varies widely according to neuroradiologists' experience. A potential bias of this study is that the clinicians were often involved in the multidisciplinary discussion of the MRI findings and that the reports may not always reflect the multidisciplinary discussion. Nevertheless, since radiologic reports are formal documents that should be made available for patients, clinicians and other radiologists, our findings suggest that more attention should be paid to make sure that clinically relevant information is consistently present in the report.

Neurologists understood disease-specific pattern of muscular involvement and had enough information for making adequate clinical decision or to perform a biopsy more often when reading SR rather than NSR. Furthermore, neurologists needed to evaluate images significantly less often to make decisions in patient care, when reading SR rather than NSR.

These findings are in agreement with previous studies reporting that SR conveys adequate clinical information on imaging studies more often than NSR in other areas of neuroradiology and musculoskeletal radiology [11, 12, 23–25]. In a different field of neurology, a recent multi-institutional study on brain MRI reports in patients with known or suspected multiple sclerosis, Dickerson et al. [11] demonstrated that SR contained more often key features deemed important for management of multiple sclerosis. Our study confirmed that also for MRI reports of suspected/known IND, SR more often contains more often a significantly higher number of key features affecting management of this condition.

Similarly, regarding neurologist evaluation of reports, a previous study of our group showed that when evaluating brain MRI reports of patients with known/suspected multiple sclerosis, experienced neurologists found that SR had more often sufficient information for clinical decision-making than NSR and needed to evaluate images to make clinical decision significantly more often with NSR [12].

This study has some limitations, including its retrospective nature. We divided radiologists in only two categories based on their experience, more than 15 years or less than 15 years of experience, clustering together novices and radiologists with moderate experience in reading MRI for IND. Furthermore, reports were created by six radiologists from different institution, increasing variability of reports. Nonetheless, we purposely performed a multi-institutional study to reflect the current clinical practice and increase the applicability of the study. Lastly, we did not evaluate difference between NSR performed in different years. More recent NSR might have been more informative than NSR performed years before, both for increased radiologist experience, and for the potential improvement related to peer-review of the cases. In this study, we did not evaluate this aspect, as we focused in comparing NSR with SR, although it is reasonable to predict that more recent NSR, might have been more complete than the NSR performed years before.

Our results clearly showed that the MRI reports produced by neuroradiologists with more than 15 years of experience in IND diagnosis, gave neurologists adequate information for patient care both when SR as when NSR, whereas when the report was produced by a radiologist with less than 15 years of experience, only the SR gave the clinician sufficient information to understand the pattern of muscular involvement to make clinical decisions/to perform a biopsy. This does not suggest that muscle MRI should be performed or interpreted only by very experienced neuroradiologists but rather that less experienced neuroradiologists should use SR as it will provide a structured approach to fill the MRI report with all the relevant information. Further studies are needed to establish the compliance to the use of SR within the same institution or across different institutions.

In conclusion, our study suggests that SR can facilitate communication of findings and support neurologists in medical or therapeutic decisions and provide more complete information in patients with IND especially when reported by neuroradiologists with lower level of expertise.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent For this type of study formal consent is not required.

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