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EULAR points to consider for the use of big data in rheumatic and musculoskeletal diseases

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1 **European League Against Rheumatism points to consider for the use of big**
 2 **data in rheumatic and musculoskeletal diseases**

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8

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9

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12

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17

18 **RUNNING TITLE**

19 EULAR points to consider for the use of big data in RMDs

20

21 **Word count:** 3817 words, 4 tables, 78 references

22 **Key words for journal submission:** recommendations, big data, artificial
23 intelligence, machine learning, biostatistics, data management, EULAR,
24 epidemiology, health services research, outcomes research.

25 **Contributorship statement** All authors have contributed to this work and have
26 approved the final version.

27

28 **Key messages**

29

30 ***What is already known about this subject?***

31 The use of big data by artificial intelligence, computational modelling and machine
32 learning is a rapidly evolving field with the potential to profoundly modify RMD
33 research and patient care.

34 ***What does this study add?***

35 These are the first European League Against Rheumatism (EULAR)-endorsed ‘points
36 to consider’ for the use of big data in RMDs. These points address key issues
37 including: ethics, data sources, data storage, data analyses, artificial intelligence
38 (e.g., computational modelling, machine learning), the need for benchmarking,
39 adequate reporting of methods, and implementation of findings into clinical practice.

40 ***How might this impact on clinical practice or future developments?***

41 These points to consider will promote advances and homogeneity in the field of big
42 data in RMDs, and may be useful as guidance in other medical fields.

43

44

45 **Abstract** (238 words)

46

47 **Background:** Tremendous opportunities for health research have been unlocked by
48 the recent expansion of big data and artificial intelligence. However, this is an
49 emergent area where recommendations for optimal use and implementation are
50 needed. The objective of these European League Against Rheumatism (EULAR)
51 points to consider is to guide the collection, analysis and use of big data in rheumatic
52 and musculoskeletal disorders (RMDs).

53 **Methods:** A multidisciplinary taskforce of 14 international experts was assembled
54 with expertise from a range of disciplines including computer science and artificial
55 intelligence. Based on a literature review of the current status of big data in RMDs
56 and in other fields of medicine, points to consider were formulated. Levels of
57 evidence and strengths of recommendations were allocated and mean levels of
58 agreement of the taskforce members were calculated.

59 **Results:** Three overarching principles and 10 points to consider were formulated.
60 The overarching principles address ethical and general principles for dealing with big
61 data in RMDs. The points to consider cover aspects of data sources and data
62 collection, privacy by design, data platforms, data sharing, and data analyses, in
63 particular through artificial intelligence and machine learning. Furthermore, the points
64 to consider state that big data is a moving field in need of adequate reporting of
65 methods and benchmarking, careful data interpretation and implementation in clinical
66 practice.

67 **Conclusion:** These EULAR points to consider discuss essential issues and provide a
68 framework for the use of big data in RMDs.

69

70

71 INTRODUCTION

72

73 The recent expansion of big datasets and advanced computational techniques lead
74 to tremendous opportunities for health research.[1] As elegantly elaborated by E.
75 Topol the use of big data in medicine is going to disrupt the medical system as we
76 know it.[2] Big data include both clinical data (e.g. originating from electronic health
77 records, healthcare system claims data or patient-generated data such as from
78 Apps), biological data issued from the development of molecular research leading to
79 multi-omics complex molecular data,[3] social data (e.g. originating from social
80 networks, Internet Of Things, physical social connections or economic data
81 repositories), imaging data, and environmental data (e.g. urbanistic data, pollution or
82 atmospheric conditions).[4, 5] In parallel, artificial intelligence-based methodologies
83 allowing computer systems to "learn" from data (i.e., progressively improve
84 performance on a specific task without being explicitly programmed) are more and
85 more accessible.[6, 7] The collection of big data combined with such information
86 processing techniques (computational modelling, machine learning) lead to an
87 opportunity for progress in medical research, which should ultimately modify patient
88 care and clinical decision making.

89 Some recent applications of big data show interesting potential. These include the
90 correct detection of skin lesions suspect of melanoma,[8-10] prediction of cancer
91 treatment response based on imaging,[11] and the correct interpretation of eye
92 fundus pathologies.[11] However, big data is an emergent area in need of guidelines
93 and general recommendations on how to move this field forward in a collaborative
94 and ethical way. Some of the challenges presented by big data and artificial
95 intelligence include data sources and data collection: how to collect and store the
96 data, while guaranteeing ethics and data privacy;[12] how to interpret data models of
97 complex analyses;[13, 14] and what are the clinical implications of big data: how to
98 go from big data to clinical decision making.[3, 15, 16]

99 To our knowledge, no academic societies have developed consensus guidelines
100 dealing with big data.[17] Very recently, the European Medicines Agency (EMA)
101 released recommendations focused on the acceptability of evidence derived from big
102 data in support of the evaluation and supervision of medicines by regulators;[18]
103 however, these recommendations deal mainly with the interpretation of drug-related
104 big data. The European League Against Rheumatism (EULAR) has recently

105 formulated as one of its key strategic objectives, the advancement of high-quality
106 collaborative research and comprehensive quality of care for people living with
107 rheumatic and musculoskeletal disorders (RMDs).[19] Thus, EULAR naturally takes
108 an interest in big data and its applications.

109 The objective of this project was to develop EULAR 'points to consider' (PTC) for the
110 collection, analysis and use of big data in RMDs.

111

112

113

114 **METHODS**

115

116 After approval by the EULAR Executive Committee, the convenors (LG, TR) and the
117 project fellow (JK) led a multidisciplinary taskforce guided by the 2014 updated
118 EULAR Standardised Operating Procedures, [20] which were modified for this
119 specific taskforce. In October 2018, the main questions to be addressed in the
120 preparatory work for the taskforce were defined as: 1) data sources and collection; 2)
121 data analyses; and 3) data interpretation and implementation of findings. These
122 questions were addressed in subsequent months leading up to the face-to-face
123 meeting by the project fellow and the convenors. A systematic literature review (SLR)
124 was performed between November 2018 and February 2019, regarding publications
125 employing big data in RMDs, with a comparison in other medical fields.[21]
126 Additionally, a narrative review of unpublished data on websites on big data and
127 artificial intelligence was performed to inform the taskforce [12, 17,18, 22-26] and
128 expert opinions were obtained from four selected persons through individual
129 telephone interviews.

130 In February 2019, during a one-day face-to-face task force meeting, overarching
131 principles and PTC were developed. The process was both evidence-based and
132 consensus-based, through discussions of the international task force of experts from
133 a range of disciplines including computer science and artificial intelligence. The task
134 force consisted of 14 individuals from 8 European countries: 6 rheumatologists, 4
135 data scientists/big data experts, 1 cardiologist specialized in systems medicine, 1
136 patient research partner, 1 health professional with expertise in outcomes research
137 and 1 fellow in rheumatology. Furthermore, feedback was obtained after the meeting
138 from 2 additional experts. This inclusive approach aimed to obtain broad consensus

139 and applicability of the PTC. During the one-day meeting, the preparatory work was
140 presented and discussed, the target audience of the PTC was defined, then the PTC
141 were formulated and extensively discussed. The PTC were finalised over the
142 subsequent 2 weeks by online discussions, taking into account the publication the
143 same week of an EMA consensus document on big data.[18]
144 During the meeting and through online discussions, based on the gaps in evidence
145 and the issues raised among the task force, a research agenda was also formulated.
146 After the PTC were finalised, the level of evidence and strength of each PTC were
147 ascertained according to the Oxford system.[27] Finally, each task force member
148 voted anonymously on their level of agreement with each PTC via email (numeric
149 rating scale ranging from 0=do not agree to 10=fully agree). The mean and standard
150 deviation of the level of agreement of taskforce members were calculated.
151 The final manuscript was reviewed and approved by all task force members and
152 approved by the EULAR Executive Committee.

153

154

155

156 **RESULTS**

157

158 **Target audience**

159 The target audience of these PTC includes researchers in the field of big data in
160 RMDs, researchers outside the field of RMDs; data collection organisations and/or
161 groups collecting data (e.g. registries, hospitals, telecom operators, search engines,
162 genetic sequencing teams, institutions which collect images etc.); data analysts and
163 organisations; people with RMDs, people at risk of developing RMDs, patient
164 associations; clinicians involved in the management of people with RMDs; other
165 stakeholders such as research organisations and funding agencies, policy makers,
166 authorities, governments and medical societies outside of RMDs.

167

168 Overarching principles and PTC were formulated, which are shown in **Table 1** and
169 are discussed in detail below.

170

171 **Definitions of terms**

172 This first point in **Table 1** proposes a definition of terms relating to big data. Although
173 the term big data is widely utilised, there is not one commonly accepted definition.
174 When performing the literature review, several definitions were found (**Table 2**).[6,
175 21] The first overarching principle defines the term big data, largely based on the
176 EMA definition.[18] Big data is defined by its size and diversity– it is diverse,
177 heterogeneous and large and incorporates multiple data types and forms; but also by
178 the specific complexity and challenges of integrating the data to enable a combined
179 analysis.[18] The second half of the definition refers to artificial intelligence (AI). AI is
180 defined as the ability of a machine to mimic "cognitive" functions that humans
181 associate with human minds, such as "learning" and "problem solving".[6] New
182 computational techniques, such as AI (which includes machine-learning and deep
183 learning) are often (but not necessarily) applied to big data.[18]
184 This next sentence is informative and aims to present the diversity of data sources
185 leading to big data; we listed in a non-exhaustive way some of the sources of big
186 data. The most common sources of big healthcare data found in the SLR were
187 clinical; these include electronic health records, studies and registries, billing and
188 healthcare system claims databases.[21, 28, 29] A more recent source of clinical big
189 data, currently underused in RMDs is the Internet of Things (e.g. wearables, apps,
190 medical devices and sensors), but also social media, behavioural and environmental
191 data.[18, 30, 31] Imaging is also a growing field of application of big data.[10, 32, 33]
192 Regarding basic and translational research results, -omics such as genomics and
193 bioanalytical omics are an important and rapidly growing field for big data.[18, 34]

194

195 **Overarching principles**

196 ***Overarching principle A – Ethical aspects***

197 This overarching principle addresses ethical issues with big data. The collection,
198 analysis and implementation of big data in RMDs must adhere to all applicable
199 regulations. This covers privacy, confidentiality and security, ownership of data, data
200 minimalization, and flow of data within the EU and with third countries.[22, 35] This is
201 both a regulatory and legal requirement, and an ethical one.[12] In terms of legal
202 requirements, the General Data Protection Regulation (GDPR) has set standards
203 which apply across Europe but for health-related data, national rules could also apply
204 on top of these.[12]

205 In this overarching principle, we also raise the question of the role of the patient
206 and/or carer in big data. Big data enables active participation of patients, but this is
207 not always the case. Participation of patients and patient research partners can be
208 helpful in data interpretation; for big data, the active participation of patients is still a
209 field to be explored.[36] This principle highlights not only issues around information,
210 consent and responsibilities, but also patient rights and participation.[35]

211

212 ***B – Potential of big data***

213 Big data provides unprecedented opportunities which we wished to highlight in this
214 overarching principle. Maybe even more than other types of data, big data benefits
215 from transversal thinking, by both original ‘outside the box’ approaches and cross-
216 fertilization approaches taking into account other medical fields and aspects such as
217 comorbidities, psychological, sociological and environmental findings.[18] In this
218 regard, collaboration both within the RMD field and in particular with patients, and
219 outside of RMDs, is key, as will be addressed later in these PTC.[15, 24, 37]

220

221 ***C – Ultimate goal***

222 This overarching principle states that the ultimate goal is to be of benefit to people
223 with RMDs. This is always a key priority of EULAR and is in keeping with the EULAR
224 Strategic Objectives and Roadmap.[19, 38]

225

226 **Points to consider**

227 **Table 1** provides the level of evidence, strength of recommendation and level of
228 agreement for each of the 10 PTC.[20, 27]

229

230 ***PTC 1: Data collection - use of standards***

231 As the amount of big data increases, the need for data harmonisation becomes more
232 apparent, with the possibility for using different data sources through application of
233 global standards. It is essential to ensure that existing and future datasets can be
234 utilised and in particular, pooled, for big data approaches. To this end, they must be
235 harmonised/aligned to facilitate interoperability of data.[18] Where possible,
236 minimising the number of standards and using global data standards would be
237 helpful; as stated by the EMA, standards should be transparent, open to promote
238 widespread uptake and globally applicable.[18]

239 In that regard, international consensus efforts such as data standards, developed by
240 groups such as the International Consortium for Health Outcomes Measures,
241 International Council for Harmonisation, Health Level Seven International,
242 International Organization for Standardization and Clinical Data Interchange
243 Standards (to name a few) are useful.[39-42] Some of these groups have developed
244 standards for rheumatology.[40]. The EULAR dataset for rheumatoid arthritis (RA)
245 registries, or other core sets, are also helpful in this regard.[43, 44] While these
246 standards regulate the way in which the data are recorded and stored, they do not
247 control how efficient the data collection is at the care team level.

248

249 ***PTC 2: Data collection and storage - FAIR principle***

250 The FAIR (Findable, Accessible, Interoperable, and Reusable) data principles are a
251 measurable set of principles intended to act as a guideline to enhance the reusability
252 of their data.[45] The FAIR principles are recognised by many actors, including the
253 EMA and the EU Commission.[18, 22, 24,46] The FAIR principles are strongly linked
254 to PTC 1 and 3, referring to standardisation, interoperability and data storage. Efforts
255 are ongoing to promote the FAIR principles, such as those of the EU commission
256 through the development of the EU eHealth Digital Service Infrastructure.[47]

257

258 ***PTC 3: Data storage - data platforms***

259 Several platforms have been developed to facilitate big data projects. These
260 platforms are independent, standardised, collaborative, and not at all limited to use
261 for RMDs.[48-50] These platforms have been developed with financial support from
262 the EU and therefore adhere to necessary standards. Hence, the use of such
263 platforms should be promoted as recently stated by the EMA.[18] In these PTC, we
264 refer to the use of such platforms for RMD big data, but of course this would also
265 apply to other groups of big data.

266 Public access to data is an important point, which raised much debate within the task
267 force. Internationally, several groups emphasised the principle that big data should
268 be made publicly available to promote open and reproducible research; in particular
269 when the data is publicly funded.[18, 26, 51, 52] On the contrary, downsides of public
270 access to data are the potential loss of momentum to secure intellectual property and
271 scientific publications from the researchers who initially generated the data [53] Given
272 this controversy, data sharing should be achieved in a way that is sustainable for all

273 parties involved.[53] How to make data but also algorithms openly available is very
274 complex.[54, 55] The task force consensus was in favour of accessible data, but in
275 the current situation, with limited and supervised access; we also felt that pilot
276 projects to assess the impact of data sharing are needed and that such data sharing
277 should be evidence-based. [56] This consensus will need to be revised as the
278 situation evolves. The topic of data sharing was also added to the research agenda.

279

280 ***PTC 4: Privacy by design***

281 Privacy by design is an important approach which should be followed when
282 managing big data projects. This point insists on the importance of privacy by design
283 at the different levels of big data use; including the collection, processing, storage,
284 analysis and interpretation of big data.[17, 57] Privacy by design is directly quoted in
285 EU law about personal data [12]. This approach prompts thinking on the reasons why
286 you collect/gather, process, store and protect data, from inception to final deletion.
287 Privacy by design also prompts individuals to self-assess the potential risks or
288 weaknesses relating to data, and how best to manage such risks. This PTC is a
289 major challenge for researchers in big data but it appeared to the task force to be not
290 only a legal requirement or an ethical one; but also an educational one, since this
291 practice is not widely understood. For big data projects, the data source is key: either
292 the data is collected for the purpose of the project, or data is re-used from existing
293 sources. In the first case, obtaining consent is mandatory and must involve a data
294 officer and follow a transparent and effective process in terms of data
295 governance.[35] When data is re-used, the national laws on consent, data sharing
296 and governance must be applied. In this context, the development of common
297 principles for data anonymisation would facilitate data sharing, including regulations
298 for sharing, de-identifying, securely storing, transmitting and handling personal health
299 information.[18]

300 The European regulatory framework around data is currently undergoing change:
301 from May 2019, the circulation of non-identifying data will be facilitated.[47] The
302 implications of this change will have to be assessed.

303

304 ***PTC 5: Collaboration***

305 While interdisciplinary collaboration is beneficial and required for all research
306 projects, it is even more important in big data projects where expertise is dispersed

307 among different stakeholders. The task force insisted on the importance of
308 collaboration between appropriate stakeholders, not only at the analysis stage, for
309 example, where AI methods require appropriate expertise, but at all phases of a big
310 data project.[25] Interdisciplinary collaborations should intervene at different times
311 across a project, to enable the most appropriate design to be chosen, while ensuring
312 that data collection and the type of analysis are fit for purpose. Of note, the statistical
313 methods may be based on AI or may include more traditional statistics and/or
314 computational methodologies, as appropriate. Further knowledge is needed on the
315 comparison of statistical methods, which discussed in more detail in PTC 7.[21, 58]
316 The appropriate individuals to collaborate include clinical/biological scientists,
317 computational/data scientists, health professionals and patients: proposals for
318 respective roles are shown in **Table 3**.

319

320 ***PTC 6: Data analyses reporting***

321 The methods, parameters and tools used in big data processing must be reported
322 explicitly in any scientific paper. This is pivotal to allow comparison and interpretation
323 of findings. Our SLR found that 8% of papers using AI did not report in any way what
324 artificial intelligence methods were being used.[21] Proper reporting is important for
325 all research, but even more so when innovative methods such as artificial intelligence
326 are used, to avoid confusion and to promote reproducibility.[14, 18, 30, 59]

327

328 ***PTC 7: Benchmarking of data analyses***

329 AI encompasses several techniques which are intended to solve the most difficult
330 problems in computer science: search and optimisation (heuristics), logic (fuzzy
331 logic), uncertain reasoning and learning (machine learning).[60]. In our SLR, machine
332 learning methods were the most used artificial intelligence techniques, in RMDs and
333 in other medical fields (98% and 100% of artificial intelligence papers, respectively).
334 The most used machine learning algorithms were artificial neural networks (with deep
335 learning as the most advanced version), representing 48% of AI articles.[21 , 61]
336 In addition, comparison of artificial intelligence methods within RMDs should be
337 promoted. [17, 18, 24, 62] This is particularly needed because AI is a rapidly growing
338 field; there is an ongoing and unsolved debate, as to which methods within artificial
339 intelligence perform best.[63, 64] The comparison of AI methods was also added to

340 the research agenda, since it was felt that this particularly topic was difficult to
341 perform at this moment in time, and was more aspirational.

342

343 ***PTC 8: Validation of big data findings***

344 Although there may be a perception that big data are more valid or less subject to
345 bias than traditional studies, model overfitting, inappropriate generalisation of the
346 results and/or bias can in fact lead to inappropriate conclusions. [14, 18, 28]. Thus, it
347 is important both to assess and benchmark the quality of the generated data and the
348 methods used to avoid over-interpretation of results, overfitting of the models, and
349 generalisation of the results when using big data. The task force also felt that it was
350 important to validate results in independent datasets. [24, 28] Overall, the task force
351 agreed that conclusions drawn from big data need independent validation (in other
352 datasets) to overcome current limitations and to assure scientific soundness.
353 However, a specific challenge for big datasets and the validation of results is the
354 need for other (similar) big datasets – thus, feasibility of validation is a key issue
355 which was discussed at length within the taskforce

356

357 ***PTC 9: Implementation of findings***

358 The clinical implementation of big data findings should be considered at the earliest
359 opportunity. The SLR and from literature showed that this implementation is currently
360 mostly lacking.[21, 65] The task force consensus was that researchers using big data
361 should consider implementation of their results in clinical practice; this would include
362 for example, discussing implementation of findings in clinical practice in the original
363 papers. The task force is well aware that this is a difficult task; such implementation
364 being both complex to set up, costly, and potentially not within the scope of the
365 primary study.[66] In this regard, the EMA states that regulatory guidance is required
366 on the acceptability of evidence derived from big data sources.[18, 67] However,
367 taking all these limitations into account, the task force consensus was that
368 implementation of findings should be proactively considered early on.

369

370 ***PTC 10: Training***

371 Interdisciplinary training for clinical, biological or imaging researchers, healthcare
372 professionals and computational biologists/data scientists in the field of big data is
373 important and links closely with the need for collaborations in the field of big data

374 **(Table 3)**. Indeed, machine learning methods are becoming ubiquitous, and have
375 major implications for scientific discovery;[26] however, healthcare professionals are
376 not perfectly aware of the correct use of these methods, whereas data scientists may
377 lack the clinical knowledge to design studies and interpret the findings **(Table 3)**.
378 Given the current relative lack of expertise related to big data in the field of RMDs,
379 and given the rapid changes in this field, certain organisations should set up or
380 facilitate training sessions.[18, 37] This may include academic institutes, public
381 research bodies and international organisations, such as EULAR. The training is
382 needed for both sides: the healthcare professionals needing to learn about the basics
383 of big data, and the data scientists needing to better understand the clinical questions
384 and context within which big data has been collected, and/or is being applied.[68]
385 The training can be performed separately for the different stakeholders but, in some
386 instances, it will require an interdisciplinary educational setting in order to engage
387 multidisciplinary teams and their unique dynamics (e.g. the need to set a common
388 vocabulary). The training process should detect skills gaps, identify individuals with
389 bioinformatics/biostatistics/analytics/data science expertise within or outside the field
390 of RMDs, and implement appropriate training. The training should also aim for
391 different levels of education provision, ranging from academic taught modules
392 (undergraduate and postgraduate), academic research modules (PhD) and
393 continuous professional development opportunities (for example, through seminars
394 and workshops). Similar efforts can be observed in Systems Biology and Systems
395 Medicine.[18, 68-70]

396

397

398 **Research agenda**

399

400 Based on the discussions among the task force and the areas of uncertainty
401 identified within the SLR and discussions among expert stakeholders, a research
402 agenda has been proposed, depicted in **Table 4**. This research agenda covers
403 issues related to data collection, data analyses, training, interpretation of findings and
404 implementation of findings.

405

406

407

408 **DISCUSSION**

409

410 These are the first EULAR-endorsed PTC for the use of big data within the field of
411 RMDs, which could well be applied by other medical disciplines. These PTC address
412 the core aspects of big data, namely data sources and storage, including ethical
413 aspects, data analyses, data interpretation and implementation. Legal aspects are
414 not clearly mentioned, but these points to consider were meant to cover principles
415 and practical aspects of big data; however, the law, and in particular GDPR, applies
416 first. (12) For the update of these points to consider in a few years, participants with
417 legal and ethical expertise should be considered.

418 This consensus effort is original and should help to promote growth and alignment in
419 the field of big data. However, we are aware that this is a rapidly moving field and
420 that the present PTC may quickly become outdated. It is reassuring that our
421 proposals were not in contradiction to other recent recommendations, such as those
422 of the EMA or the National Health Service in the United Kingdom.[17, 18]

423 To our knowledge, no other non-governmental organisation representing patients,
424 healthcare professional and scientific societies to date has developed
425 recommendations for big data. While the American College of Rheumatology has not
426 published specific guidance relating to big data, it has developed an online patient
427 registry from electronic health records which could potentially be used as a big data
428 source.[71]

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430 The use of big data is rapidly expanding as witnessed by the increasing number of
431 organisations, companies and publications/books dealing with this topic.
432 Undoubtedly, the exploration, use and implementation of big data provide
433 opportunities to improve healthcare but it is also clear that this field is in need for
434 guidelines and criteria. These PTC are a first tool to set those guidelines. With the
435 growth of big data in RMDs, we expect that these PTC inspire governmental and
436 research organizations, health care providers, researchers and patients to increase
437 relevant training of the stakeholders, promotes research on interpretation and clinical
438 applications of big data results, and develop benchmarks/guidelines for reproducible
439 research.

440 Points 8 and 9 referring to validation and implementation raised much debate within
441 the taskforce since we felt it was important to both insist on the importance of these
442 steps, and at the same time aim for applicability/feasibility of the points to consider.
443 The final formulation of the points was thought to encourage progress without being
444 too directive, to allow researchers to move forward as needed. Such elements will
445 have to be updated as more data becomes available.

446 The grading of the evidence was a challenge in the present work as the Oxford level
447 of evidence (27) which is used in EULAR taskforces is better adapted to therapeutic
448 evidence than to observational or prognostic evidence as is often obtained in big data
449 work. However, according to EULAR Standardized Operating Procedures (20), levels
450 of evidence and strength of recommendations should be rated by the Oxford Levels
451 of Evidence. Moreover, in the case where there is little data-driven evidence, EULAR
452 Standardized Operating Procedures recommend to downgrade the recommendations
453 to the level of “points to consider”, which is what was performed here.

454 This work has several limitations: the main one is that the present PTC are not
455 specific to RMDs. However, they are not specific because the aspects of big data that
456 they address are universal, and at present, there is no specific issue related to big
457 data in RMDs, as is also the case in any other medical speciality. Moreover, the
458 experts we consulted consider big data as an opportunity to go beyond the traditional
459 division of medical specialties and allow multidisciplinary approaches. The other main
460 limitation was the extremely low level of evidence for all the PTC, raising the question
461 of the interest of evidence in this specific field where the PTC were expert-driven.
462 This is often the case on subjects where recommendations are formulated before
463 supportive data are produced.[72] It is linked to the novelty of the subject.

464
465 In conclusion, it is anticipated that new data in this rapidly moving field will emerge
466 over the next few years and that some of the questions formulated in the research
467 agenda will be answered. Therefore, we will consider an update of these PTC as
468 needed in a few years.

469

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Table 1. EULAR-endorsed overarching principles and points to consider for the use of big data in RMDs, with levels of agreement and for the specific points, levels of evidence and strength

Definitions				
The term 'big data' refers to extremely large datasets which may be complex, multi-dimensional, unstructured and from heterogeneous sources, and which accumulate rapidly. Computational technologies, including artificial intelligence (e.g. machine learning), are often applied to big data. Big data may arise from multiple data sources including clinical, biological, social and environmental data sources.				
Overarching principles			LoA, mean (SD)	
A. For all big data use, ethical issues related to privacy, confidentiality, identity and transparency are key principles to consider.			9.6 (0.7)	
B. Big data provides unprecedented opportunities to deliver transformative discoveries in RMD research and practice.			9.5 (1.2)	
C. The ultimate goal of using big data in RMDs is to improve the health, lives and care of people including health promotion and assessment, prevention, diagnosis, treatment and monitoring of disease.			9.6 (0.5)	
Points to consider		LoA, mean (SD)	LoE	SoR
1. The use of global, harmonised and comprehensive standards should be promoted, to facilitate interoperability of big data.		9.7 (0.6)	4	C
2. Big data should be Findable, Accessible, Interoperable, and Reusable (FAIR principle).		9.6 (0.9)	5	D
3. Open data platforms should be preferred for big data related to RMDs.		8.7 (1.2)	5	D
4. Privacy by design must be applied to the collection, processing, storage, analysis and interpretation of big data.		9.6 (0.5)	4	C
5. The collection, processing, storage, analysis and interpretation of big data should be underpinned by interdisciplinary collaboration, including biomedical/health/life scientists, computational and/or data scientists, relevant clinicians/health professionals and patients.		9.7 (0.6)	4	C
6. The methods used to analyse big data must be reported explicitly and transparently in scientific publications.		10 (0)	4	C
7. Benchmarking of computational methods for big data used in RMD research should be encouraged.		9.4 (1.2)	5	D
8. Before implementation, conclusions and/or models drawn from big data should be independently validated.		9.1 (0.7)	4	C
9. Researchers using big data should proactively consider the implementation of findings in clinical practice.		9.3 (0.8)	5	D
10. Interdisciplinary training on big data methods in RMDs for clinicians/health professionals/health and life scientists and data scientists must be encouraged.		9.7 (0.6)	5	D

481 LoA, level of agreement; LoE, level of evidence, SoR: strength of recommendation
482 Numbers in the column 'LoA' indicate the mean and SD (in parentheses) of the LoA, as well as the
483 mean agreement of the 14 task force members on a 0-10 scale. LoE and strength based on the
484 Oxford Centre for Evidence-Based Medicine classification, with 'Level 1' corresponding to meta-
485 analysis or randomized controlled trials (RCT) or high quality RCTs; 'Level 2' to lesser quality RCT or
486 prospective comparative studies; 'Level 3' to case-control studies or retrospective studies; 'Level 4' to
487 case series without the use of comparison or control groups; 'Level 5' to case reports or expert
488 opinion[27]
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491 **Table 2.** Some definitions of the terms ‘big data’ in the literature

Extremely large sets of information which require specialised computational tools to enable their analysis and exploitation. These data might come from electronic health records from millions of patients, genomics, social media, clinical trials or spontaneous adverse reaction reports[18]
Data sets that are too large or complex for traditional data-processing application software to adequately deal with[73]
Defined by volume, if $\text{Log}(n \cdot p)$ is superior or equal to 7, where n is number of rows and p is number of columns[74]
Data sets that are large or complex (multidimensional and/or dynamic) enough to apply complex methods e.g. Artificial intelligence [75]
Information assets characterized by such high velocity, variety, and volume that specific data mining methods and technology are required for its transformation into value[76]
A generic and comprehensive definition of big data is based on the five V paradigm i.e., volume of data, variety of data, velocity of processing, veracity, and value[77]
The term big data refers to the emerging use of rapidly collected, complex data in such unprecedented quantities that terabytes (10^{12} bytes), petabytes (10^{15} bytes) or even zettabytes (10^{21} bytes) of storage may be required[78]

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Table 3. Stakeholders involved in big data research: Proposal of potential roles

Stakeholder	Characteristics	Potential role in big data research
Clinicians/health professionals, biomedical/health/life scientists	Knowledge of the diseases, prognosis and treatments	Clinically relevant question, study protocol, data collection, interpretation and implementation of findings
Data scientist	To analyse and interpret complex digital data, should be proficient in a broad spectrum of analytical methodologies that encompass traditional (biostatistics, epidemiology, discrete-event simulation, and causal modeling) as well as emerging methods (67).	Provide early guidance on the best tools or algorithm to analyze the data. Analyses of data and interpretation
Computational biologist	Involved in the development and application of data-analytical and theoretical methods, mathematical modeling and computational simulation techniques to the study of biological, ecological, behavioral, and social systems. Has domain knowledge in biology.	Provide early guidance on the best tools or algorithm to analyze the data. Analyses of data and interpretation
Data Protection Officer	Expert on data privacy	Orient the project team in privacy by design practice
Patients, carers, patient research partners and patient associations	People living with RMDs who have knowledge of day-to-day life with RMDs, from diagnosis to treatment and long-term management	Participation in all stages of the study, from the protocol to the interpretation of the findings
Database expert	Expert of the data in a database	Help the project team to understand the real “value” of data in a database, and provide guidance on data selection
Computer sciences Expert	Expert in computer sciences solutions	Provide guidance on the best technical solution to manage the Big data, from its collection to massive calculation solutions

496 **Table 4.** Research agenda.

Theme	Research point
Data sources	Leverage EULAR legacy initiatives around core datasets that should be collected in research (and usual care) as foundations for successful big data projects in the field of RMDs.
	Determine the optimal use of eHealth data through digital traces and patient-generated/patient-reported data.
	Determine the potential use of database linkages, such as healthcare system claims databases.
Data access	Identify the mechanisms supporting and implications following open access to, and sharing of, big data.
	Assess positive and negative aspects of data sharing in terms of article impact (academic/social) and translational success
	Identify the challenges, opportunities and solutions for international data sharing.
	Develop a repository of privacy rules in different European countries.
	Identify public platforms for data, and how the public can access their own data within big data sets for knowledge/education/self-management purposes
Analyses	Evaluate and compare statistical methods and benchmarking of big data.
	Develop methods of assessment and minimization of bias and of generalisation / reproducibility.
	Determine the most appropriate open source tools to improve reproducibility of the results.
	Perform a critical assessment of statistical significance vs clinical relevance of the results obtained from medical big data.
Reporting	Stimulate consistent reporting of big data studies using validated reporting guidelines.
	Stimulate and facilitate open sharing of codes/scripts.

Implementation	Determine the value of algorithms and big data findings in terms of quality of care and cost effectiveness.
	Assess levels of evidence in evidence-based medicine when based on big-data studies.
	Manage the potential rapid and frequent changes of outcomes when implementing big data findings.
Training	Identify opportunities for training via the EULAR School of Rheumatology and other relevant organisations.
	Assess the importance of inter and cross-disciplinarity.
	Assess the place of multidisciplinary training at specific stages of individual careers and/or at specific stages of specific projects
	Consider introducing a basic big data/systems biology/bioinformatic course at bachelors' levels for healthcare professionals.
Collaborations	Stimulate national and international interest among the data scientist community in relation to RMDs.
	Promote the integration of RMD fluent "ethical experts" in collaborative teams working on big data.
Ethics and roles	Stimulate ethical and moral discussions with patients and 'data donors' specifically in the context of big data, addressing topics such as informed consent/assent, confidentiality, anonymity, and privacy concerns, particularly with regards to the re-use of
	Discuss the roles and responsibilities of healthcare professionals, scientists/researchers and patients in relation to big data.
	Assess issues pertaining to commercial use of big data, particularly involving public-private consortiums and the use of multiple datasets
	Assess the effects of big data results on use of drugs including in unauthorized/ compassionate use cases
	Define the role, modalities and rules of patient engagement in the generation and exploitation of big data.

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