1 **The intra- and inter-tester repeatability of radiographic elbow incongruity grading is high in**

2 **chondrodystrophic dog breeds**

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4 Pulkkinen HSM[1], Reunanen VLJ[1], Hyytiäinen HK[1], Junnila JJT[2], Laitinen-Vapaavuori OM[1],

5 Lappalainen AK[1]

6

7 [1]Department of Equine and Small Animal Medicine, University of Helsinki Faculty of Veterinary

8 Medicine. Agnes Sjöberginkatu 2, P.O. Box 66, 00014 University of Helsinki, Finland

9 [2]4Pharma Ltd, Arkadiankatu 7, 00100 Helsinki, Finland

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11 Correspondence: Hanna Pulkkinen, Agnes Sjöberginkatu 2, P.O. Box 66, 00014 University of

12 Helsinki, Finland. hanna.pulkkinen@helsinki.fi

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24 Abbreviations: INC, incongruity grade; PA, proportion of agreement; CI, confidence interval.

Abstract

Elbow incongruity is a form of elbow dysplasia that causes osteoarthritis, pain and lameness, and is common in chondrodystrophic dog breeds. The objective of this retrospective secondary analysis study was to evaluate the intra- and interobserver repeatability of a novel radiographic incongruity grading system for assessing elbow incongruity in three chondrodystrophic dog breeds – the dachshund, Skye terrier and Glen of Imaal terrier. We conducted an observer agreement study that included 220 mediolateral antebrachial radiographs from 110 dogs with the elbow in 90° flexion. The radiographs were independently assessed by three observers at three time points, using a four-stepped grading scale. The proportion of agreement and Kappa coefficient were calculated. Both the intra- and interobserver proportions of agreement were substantial when three grades were required to be identical (0.705–0.777 and 0.609, respectively), and almost perfect for two identical grades (0.991–1.000 and 0.991, respectively). Some differences in repeatability between breeds were noted; specifically, the intraobserver repeatability was higher in the dachshund, and the interobserver repeatability was lower in the Glen of Imaal terrier. Our study showed that the radiographic imaging protocol and INC grading system has high repeatability when assessing elbow incongruity in chondrodystrophic dog breeds.

Introduction

Chondrodystrophy is a breed-characterizing trait caused by a *fgf4* retrogene, which affects dog breeds such as the dachshund, Glen of Imaal terrier and Skye terrier.[1] The characteristic short and curved front legs – which are also included in the breed standards of some of these breeds – is caused by blunted growth of the long bones[1]. Additionally, premature closure of the distal ulnar growth plate is also recognized as a common finding in some chondrodystrophic breeds.[2,3] This causes asynchronous growth of the radius and ulna, which is recognized as an etiology for elbow incongruity. This form of elbow dysplasia[3–5] is common in the Skye terrier, but for most

50   chondrodystrophic breeds the prevalence is unknown.[2,3] In addition to elbow incongruity, the short

51   ulna may cause the radius to bend craniocaudally and mediolaterally during growth, which is

52   clinically described as multiplanar angular deformity of the antebrachium and valgus deformity of

53   the carpal joint.[3–7] Elbow incongruity is associated with osteoarthritis, pain and lameness during

54   growth and adulthood.[2,3]

55

56   Currently, the screening protocol used by the International Elbow Working Group (IEWG) and

57   Orthopedic Foundation for Animals (OFA) is not optimal for detecting elbow incongruity in

58   chondrodystrophic breeds.[8,9] It is only able to detect the most severely incongruent elbows and

59   osteoarthritic changes of the elbows.[8,10,11] Lappalainen et al. (2016) proposed a novel grading

60   system for elbow incongruity in chondrodystrophic dog breeds.[2] The radiographic protocol is based

61   on images obtained with a 90° flexion of the elbow, with the x-ray beam centered mid-radius such

62   that the whole antebrachium (including the carpal joint) is visible in the image.[2] However, the

63   repeatability of this novel grading system has not been tested, although such studies should be

64   carried out to assess the intra- and interobserver agreement. The objective of our study was to

65   evaluate the intra- and interobserver repeatability of the grading system for elbow incongruity in

66   chondrodystrophic dog breeds. We hypothesize that the grading system is repeatable both within

67   and between observers.

68

69   **Methods**

70   This was a retrospective secondary analysis evaluating observer agreement[12] using mediolateral

71   antebrachial radiographs of chondrodystrophic dogs, originally taken for another research project

72   that had been approved by The National Animal Experiment Board in Finland

73   (ESAVI/9184/04.10.07/2014). Dachshunds, Skye terriers and Glen of Imaal terriers of 1–10 years

74   of age and no history of orthopaedic surgery or a condition that would increase the risk of sedation

75 were eligible for the study and were approved by a qualified veterinarian. These images had been

76 acquired for the other research project using the imaging protocol introduced by Lappalainen et al.

77 (2016).[2] The images were acquired using computed radiography with an automatic exposure

78 detector, imaging plates and reader (FUJIFILM FCR XG-1 CR-IR 346RU, Fuji Photo Film CO.,

79 LTD. 26-30, Nishiazabu 2-chome Minato-ku Tokyo 106-8620, Japan). S-values of 100-300 were

80 targeted to ensure image quality. One of the observers was involved in supervising the acquisition

81 of the radiographs in the original study and was aware of the dogs signalment and history regarding

82 lameness before the anonymization process was performed for the images. The two other observers

83 were only provided anonymized radiographs. The DICOM-images were anonymized and

84 randomized using computerization. The radiographs were independently graded by three observers

85 (A, B and C) who had 12, 1 and 7 years of experience in veterinary radiology, respectively. Three

86 randomized sets of the radiographs were produced for each observer; each observer graded each

87 image three times. The radiographs were assessed with image analysis freeware (OsiriX MD 9.0 or

88 Horos DICOM viewer v. 2.1.1). Magnification and windowing were allowed as necessary to ensure

89 precise measurements. The grading was performed using the 4-stepped grading system (INC0–

90 INC3) described by Lappalainen et al. (2016; Table 1). Prior to the actual grading, the observers

91 familiarized themselves with the method through discussion with each other. Ten randomly chosen

92 radiographs from the set were then given to each evaluator in order to get accustomed to the

93 grading. Finally, the results were discussed to ensure that all observers were confident with the

94 grading protocol. The first actual grading was done two weeks after the familiarization process. To

95 avoid recall bias, the three gradings were carried out over a 12-week time period, with at least two

96 weeks between gradings. Once a grade was decided, second-look revisions for the image were not

97 allowed.

98

99   All the statistical tests were selected and completed by a professional biostatistician (MSc in

100 biostatistics) with over 10 years' experience conducting clinical and non-clinical trials.

101   Intraobserver repeatability was calculated as the proportion of images in which the observer

102 assigned the same INC grade (proportion of agreement) with 95% confidence intervals (CI). The

103 mode of the three ratings for each individual observer was used to calculate the interobserver

104 agreement (with 95% CIs). The interobserver proportion of agreement was calculated for full

105 agreement (all observers agree), and also for pairwise agreements between each pair of observers.

106 Furthermore, the proportion of radiographs where at least two out of three gradings were identical

107 was calculated for both intra- and interobserver agreement. In addition, Fleiss' Kappa coefficients

108 for the three-way agreement within and between the observers were calculated, and weighted

109 Kappa coefficients (with 95 % CIs) were calculated for the pairwise agreement between the

110 observers. When the Kappa values were evaluated, the following ranges were used: less than zero

111 was considered to have less than a chance agreement; 0.01–0.20 was slight agreement; 0.21–0.40

112 was fair agreement; 0.41–0.60 was moderate agreement; 0.61–0.80 was substantial agreement; and

113 0.81–1.00 was almost perfect agreement.[13] For the purpose of this study, these categories were also

114 applied to the proportion of agreement values. Statistical analyses were performed using

115 commercially available software (SAS® System for Windows, version 9.3, SAS Institute Inc., Cary,

116 NC, USA; and R for Windows, version 3.4.2, R Foundation for Statistical Computing, Vienna,

117 Austria).

118

119 **Results**

120 Digital radiographs from 30 dachshunds, 53 Glen of Imaal terriers and 27 Skye terriers were

121 available for evaluation. The images included both the left and right elbow radiographs of each dog,

122 yielding a total of 220 radiographs from the 110 dogs. All INC grades were represented in the

123 radiographs. INC1 was the most frequent grade for each observer at each time point, and INC3 was

124 the most uncommon. Table 2 reports the frequencies of each grade assigned by each observer at

125 each time point.

126

127 The intraobserver proportion of agreement was substantial (0.705–0.777) when the requirement was

128 for three grades to be identical. When the requirement was for two grades to be identical, the

129 agreement was almost perfect (0.991–1.000). The intraobserver Fleiss' Kappa values also suggested

130 substantial agreement (0.623–0.690) for each of the observers when three identical grades were

131 required (Table 3). The interobserver proportion of agreement was substantial (0.609; 95% CI 0.54–

132 0.67) when all three observers were included; if at least two observers were required to agree on the

133 same grade, the proportion was almost perfect (0.991). The interobserver Fleiss' Kappa value was

134 moderate (0.502; 95% CI 0.45–0.56) when all three observers were required to agree, and moderate

135 to substantial (0.568–0.617) for the pairwise analyses between observers (Table 4). An example of

136 an elbow with high intra and interobserver agreement is shown in Figure 1 and an example of an

137 elbow with low agreement is shown in Figure 2.

138

139 When analyzed by breed, the intraobserver proportion of agreement was highest for the dachshund

140 (0.767–0.850) for all observers. The agreement was lower, and roughly similar for the Glen of

141 Imaal terrier (0.651–0.745) and Skye terrier (0.667–0.759; Table 5). The interobserver proportion of

142 agreement by breed was moderate to substantial, ranging from 0.557–0.717. Based on the Fleiss'

143 Kappa coefficient, agreement was moderate for both the Skye terrier (0.528) and dachshund

144 (0.570), but only fair for the Glen of Imaal terrier (0.400; Table 6).

145

146 **Discussion**

147 Our study showed that the novel grading method for assessing elbow incongruity among

148 chondrodystrophic dogs had excellent intraobserver proportion of agreement. When two grades (out

149   of the three grading time points) were required to be identical, two of the observers had a perfect

150   intraobserver agreement, and the third observer reached an almost perfect agreement (Table 3). The

151   intraobserver agreement was substantial even when grades from all three time points were assessed.

152   The interobserver agreement was almost perfect between two observers, and substantial among all

153   three observers.

154

155   Based on our review of the literature, there are no repeatability studies available for comparisons of

156   radiographic grading of elbow dysplasia in dogs. However, according to repeatability studies of

157   another prevalent radiographic screening method – the Fédération Cynologique Internationale (FCI)

158   hip dysplasia scoring system – proportions of agreement have ranged from 46.3 to 71.3%, and

159   Kappa values from 0.46 to 0.76.[14–16] Thus, the interobserver consistency of INC found in our study

160   appears to be higher than what has been reported for hip dysplasia. The high agreement for the INC

161   grading system noted in our study may reflect the objectivity of the measurement-based protocol,

162   compared to the subjective nature of the hip dysplasia measurement and FCI score.

163

164   Regarding the observer-related factors that may contribute to the grading consistency, prior

165   experience in radiology could be assumed to affect repeatability, as supported by Verhoeven et al.

166   (2009).[17] In our study, however, the intraobserver repeatability and pairwise analyses were almost

167   similar between all observers, regardless of experience. This may be a result of the observers having

168   the opportunity to get accustomed to the grading system before applying it. As subjectivity can

169   never be completely eliminated, there is always some inherent fluctuation within and between

170   individuals, leading to a higher likelihood of disagreement with increased grading repetitions.

171   Accordingly, we observed a slightly lower repeatability when all three grades were required to be

172   identical, compared to when only two were required.

173

174   When the images were grouped by breed, the agreement was lower in the Glen of Imaal terrier in

175   the intraobserver agreement analyses in two of the observers (A and B). The agreement was also

176   lower for the Glen of Imaal terrier in the breed-specific interobserver analysis. It is possible that this

177   is due to the slightly larger size – and thus longer limbs – of the Glen of Imaal terrier. Specifically,

178   as the x-ray beam is centered to the mid-radius, the longer antebrachium requires the beam to be

179   positioned farther away from the joint. As this study aimed to assess the repeatability of a

180   previously established imaging protocol, we did not make changes to the positioning of the patient

181   or the radiographic beam regarding the protocol described in the earlier study by Lappalainen et al.

182   2016. However, the effect of beam centering for recognizing elbow incongruity has been studied by

183   Murphy et al. (1998), who found that a congruent joint will not appear incongruent even if the

184   radiographic beam is not centered directly on the elbow.[18] This was further supported in a later

185   study by Blond et al. (2005), who showed that only a proximal displacement affected the

186   recognition of normal elbows – a beam misalignment as large as 3 cm away from the center of the

187   joint did not affect the recognition of incongruity.[10] Thus, it is unlikely that the larger size of the

188   Glen of Imaal terrier would explain the lower repeatability in this breed, but can be considered a

189   limitation of the imaging protocol for non-chondrodystrophic dog breeds. However, one breed-

190   related factor that could explain the noted difference in repeatability might be the amount of angular

191   deformity in the forelimb, which is likely to vary between breeds. The deformity may make it

192   difficult to position the joint in such a way that the medial and lateral border of the ulnar joint

193   surface would overlap perfectly in the image. The resulting double silhouette could have an effect

194   on measuring the joint space. Additionally, if the joint space measures very close to the boundary of

195   two grades, very small variations (such as a tenth of a millimeter) between the measurements may

196   result in a different INC grade. Subjectively, this could be the case especially between grades 0 and

197   1. The breeds selected for our study may represent different frequencies of these borderline cases of

198   the INC grades.

199

200 Although this study highlighted the importance of repeatability in INC grading, it is not without

201 limitations. For example, the frequencies of the different INC grades were not distributed equally.

202 The most dominant grade was INC1, comprising over half of the samples. Subjectively, among the

203 cases where demarcation between grades may have caused uncertainty, the most common were

204 borderline cases between INC0 and INC1. In the more severely affected cases, the joint space might

205 be easier to measure even in the presence of other deformities, especially when the joint space

206 would be wider than 3 mm. Therefore, it could be argued that if the study population would have

207 included a larger proportion of more severe cases (i.e. INC2 and INC3), the repeatability could

208 possibly be higher than what we report in the current study.

209

210 The INC grading as such does not take into account possible signs of osteoarthritis, which should

211 obviously be added to the protocol if used for screening purposes. Actually, the screening protocol

212 of the Finnish Kennel Club has incorporated osteoarthritis into the protocol, and a dog with signs of

213 degenerative joint disease cannot get INC grades 0 or 1.

214

215 In conclusion, our study showed that the radiographic grading of elbow incongruity by the INC

216 grading system had good intra- and interobserver repeatability in chondrodystrophic breeds such as

217 the dachshund, Glen of Imaal terrier and Skye terrier. This would make the INC grading system a

218 suitable method for screening elbow incongruity in these breeds. However, as this study only aims

219 to assess repeatability of the grading system, any recommendations on which grades should be

220 considered acceptable for each breed would require further investigations.

221

222 **List of author contributions**

223 Category 1

243

244   **References**

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310   Table 1. The incongruity-grading system used for scoring elbow incongruity (as described by

311   Lappalainen et al. 2016).[2]

Grade	Definition
INC0 (normal)	Even and narrow joint space; the width of the humeroulnar joint space measures < 1 mm.
INC1 (mild)	The width of the humeroulnar joint space measures 1–2 mm.
INC2 (moderate)	The width of the humeroulnar joint space measures 2–3 mm.
INC3 (severe)	The width of the humeroulnar joint space measures > 3 mm.

312   *INC, incongruity grade.*

313   Table 2. Frequencies of incongruity grades, by observer and measurement time point, for 220 elbow

314   joint images (110 dogs) in three chondrodystrophic dog breeds.

Grade	Observer	A			B			C		
	Measurement time point	1	2	3	1	2	3	1	2	3
INC0		51	32	26	66	60	64	25	22	34
INC1		138	157	166	121	125	120	132	156	135
INC2		25	25	23	26	28	29	54	38	45
INC3		6	5	5	7	7	7	9	4	6

315   *INC, incongruity grade.*

316 Table 3. Intra-observer proportion of agreement and Fleiss' Kappa of incongruity grades for 220

317 images of elbow joints from 110 dogs representing three chondrodystrophic dog breeds.

Observer	PA	Lower 95 % CI	Upper 95 % CI	Kappa	Lower 95 % CI	Upper 95 %CI
Three ratings identical						
A	0.777	0.72	0.83	0.690	0.635	0.745
B	0.714	0.65	0.77	0.678	0.623	0.733
C	0.705	0.64	0.76	0.623	0.568	0.677
At least two ratings identical						
A	1.000	0.98	1.00			
B	1.000	0.98	1.00			
C	0.991	0.97	1.00			

318 *INC, incongruity grade; PA, proportion of agreement; CI, confidence interval.*

319   Table 4. Interobserver proportion of agreement and weighted Kappa of incongruity grades for 220

320   images of elbow joints from 110 dogs representing three chondrodystrophic dog breeds.

Agreement in question	PA	Lower 95 % CI	Upper 95 % CI	Kappa	Lower 95 % CI	Upper 95 % CI
All three agree	0.609	0.54	0.67	0.502*	0.448	0.557
At least two agree	0.991	0.97	1.00			
A vs. C	0.759	0.70	0.81	0.583	0.481	0.686
A vs. B	0.755	0.69	0.81	0.617	0.526	0.708
B vs. C	0.695	0.63	0.76	0.568	0.477	0.660

321   *Fleiss' Kappa; INC, incongruity grade; PA, proportion of agreement; CI, confidence interval.

322   Table 5. Intra-observer proportion of agreement and Fleiss' Kappa of incongruity grades for three

323   identical gradings of 220 images of elbow joints from 110 dogs representing three

324   chondrodystrophic dog breeds, analyzed by breed.

Observer	Breed	PA	Lower 95 % CI	Upper 95 % CI	Kappa	Lower 95 % CI	Upper 95 % CI
A							
	Glen of Imaal terrier	0.745	0.65	0.82	0.614	0.515	0.714
	Dachshund	0.850	0.73	0.93	0.727	0.619	0.835
	Skye terrier	0.759	0.62	0.87	0.727	0.611	0.844
B							
	Glen of Imaal terrier	0.651	0.55	0.74	0.562	0.463	0.662
	Dachshund	0.800	0.68	0.89	0.763	0.657	0.868
	Skye terrier	0.741	0.60	0.85	0.720	0.613	0.828
C							
	Glen of Imaal terrier	0.689	0.59	0.78	0.570	0.486	0.653
	Dachshund	0.767	0.64	0.87	0.663	0.555	0.772
	Skye terrier	0.667	0.53	0.79	0.595	0.464	0.726

325   *PA, proportion of agreement; CI, confidence interval.*

326   Table 6. Interobserver proportion of agreement and Fleiss' Kappa of incongruity grades for three

327   identical gradings for 220 images of elbow joints from 110 dogs representing three

328   chondrodystrophic dog breeds, analyzed by breed.

Breed	PA	Lower 95 % CI	Upper 95 % CI	Kappa	Lower 95 % CI	Upper 95 % CI
Glen of Imaal terrier	0.557	0.46	0.65	0.400	0.306	0.495
Dachshund	0.717	0.59	0.83	0.570	0.465	0.675
Skye terrier	0.593	0.45	0.72	0.528	0.410	0.645

329   *INC, incongruity grade; PA, proportion of agreement; CI, confidence interval.*

330   Figure 1A. Mediolateral radiograph of the antebrachium showing an example of an elbow with high intra

331   and intertester agreement of incongruity grade showing a single measurement made with the imaging

332   software. All three observers graded the elbow as INC1 on each of the three gradings. The image was

333   acquired using computed radiography with an automatic exposure detector (FUJI imaging plates, FUJIFILM

334   reader, 44 kV; 4,0 mAs, S-values of 100-300).

335   Figure 1B. Zoomed and cropped version of the same radiograph as Fig. 1A, centered over the

336   humeroulnar joint space.

337 Figure 2A. Mediolateral radiograph of the antebrachium showing an example of an elbow with low

338 intra and intertester agreement of incongruity grade. The elbow was graded INC0 three times and

339 INC1 six times. The image was acquired using computed radiography with an automatic exposure

340 detector (FUJI imaging plates, FUJIFILM reader, 44 kV; 4,0 mAs, S-values of 100-300).

341   Figure 2B. Zoomed and cropped version of the same radiograph as Fig. 2A, centered over the

342   humeroulnar joint space.