



Hughes, E. C. et al. (2019) *Taenia multiceps* coenurosis in Tanzania: a major and under-recognised livestock disease problem in pastoral communities. *Veterinary Record*, (doi:10.1136/vr.105186).

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Deposited on: 23 November 2018

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1 ***Taenia multiceps* coenurosis in Tanzania: a major and under-recognised livestock**
2 **disease problem in pastoral communities**

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4 Ellen C. Hughes BA MA VetMB MSc^{1*}, Tito K. Kibona BVM MSc^{2*}, William A. de
5 Glanville BVetMed MSc PhD¹, Felix Lankester BVSc MSc PhD³, Alicia Davis BA MA
6 PhD⁴, Ryan W. Carter BSc MSc¹, Rosanne M. F. de Jong¹, Obed M. Nyasebwa BVM
7 MPVM⁵, John R. Claxton BVSc MSc PhD¹, Sarah Cleaveland BSc BA VetMB PhD^{1,2},
8 Kathryn J. Allan BSc BVM&S PhD¹

- 9 1. Institute of Biodiversity, Animal Health and Comparative Medicine, College of
10 Medical, Veterinary and Life Sciences, University of Glasgow, UK
11 2. Nelson Mandela African Institution of Science and Technology, Tanzania
12 3. Paul G. Allen School for Global Animal Health, Washington State University,
13 Pullman, WA, USA
14 4. Institute of Health and Wellbeing, College of Social Sciences, University of Glasgow,
15 UK
16 5. Zonal Veterinary Centre, Ministry of Livestock and Fisheries, Arusha, Tanzania

17
18 * Contributed equally as lead authors

19 **Corresponding author:** Kathryn Allan (Kathryn.Allan@glasgow.ac.uk)

20
21 **Keywords:** Sheep, goats, ruminants, central nervous system, parasitology, cestodes

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23
24 **Funding statement**

25 This research was supported by the Supporting Evidence Based Interventions project,
26 University of Edinburgh (grant number R83537). Additional support was provided through
27 the Zoonoses and Emerging Livestock Systems program (funded through BBSRC, DfID,
28 ESRC, MRC, NERC and DSTL) (grant no: BB/L018926/1) and BBSRC (grant
29 BB/R020027/1).

33 **Abstract:**

34 A neurological syndrome of small ruminants, known locally as ‘ormilo’, has been reported
35 amongst pastoralist livestock keepers in Tanzania. This study was carried out in four affected
36 pastoral communities to determine the prevalence and associated risk factors, characterise the
37 clinical signs and investigate the aetiology of the syndrome. Questionnaires were administered
38 at all households (n=480) within four study villages. Overall, 94% of households reported at
39 least one case in the previous 12 months. By village, the individual-level 12-month period
40 prevalence ranged from 11-34%, equivalent to about 10,000 small ruminants across the four
41 villages. Thirty-eight households were randomly selected for further investigation.
42 Proprioceptive deficits and weakness were the most commonly observed clinical signs in
43 affected animals. Brain and spinal cord cysts consistent with *Taenia multiceps* infection were
44 detected in 32 (82%) of 39 affected animals selected for post-mortem examination. Feeding
45 small ruminant brains to dogs was identified as an important risk factor for the syndrome, even
46 in households that did not own dogs. This study confirms cerebral coenurosis as a major cause
47 of small ruminant neurological disease in northern Tanzania and highlights the urgent need for
48 further investigation to quantify the disease burden and to identify and implement control
49 measures.

50

51

52 **Introduction**

53 A neurological syndrome known locally as ‘*ormilo*’, is reported to be emerging as a major
54 health problem of small ruminants in pastoral livestock settings in northern Tanzania (1).
55 However, little is known about the aetiology of this syndrome, preventing the development of
56 effective control strategies. Differential diagnoses for neurological disease in small ruminants
57 in tropical areas are varied and include bacterial infections such as listeriosis
58 (*Listeria monocytogenes*) and heartwater (*Ehrlichia ruminantium*) (2), viruses such as rabies
59 and maedi-visna, and parasitic infections such as cerebral coenurosis (*Taenia multiceps*), as
60 well as non-infectious causes including nutritional deficiencies (e.g. thiamine deficiency) and
61 toxin ingestion (3). In Tanzania, a recent abattoir study detected cerebral coenurosis in 44%
62 small ruminants brought for slaughter in Ngorongoro District (4), suggesting this may be an
63 important cause of neurological disease in this area. However, animals presented for slaughter
64 may not be representative of the wider population, and further investigation is needed to
65 understand the prevalence of this disease.

66
67 Epidemiological data for cerebral coenurosis is limited in Africa but the disease is thought to
68 occur in small ruminant production systems across the continent (5). Cerebral coenurosis, also
69 known as “gid”, is a progressive neurological disease of sheep and goats, caused by infection
70 with the metacestode stage of the canine tapeworm, *T. multiceps*, a cestode parasite with an
71 indirect life cycle and a worldwide distribution (5). The definitive host is the domestic dog,
72 with adult cestodes inhabiting the canine small intestine and gravid proglottid segments shed
73 into the environment in faecal matter. Following ingestion of embryonated eggs by small
74 ruminants from contaminated pastures, larvae burrow through the intestinal wall and are
75 transported to predilection sites including the brain and spinal cord, where they form cysts,
76 known as coenuri. Clinical signs occur in two phases: firstly, in association with larval
77 migration and acute inflammation in the brain, and secondly, progressive clinical signs are seen
78 as coenurus cysts enlarge over time (5-8). The condition is typically fatal, resulting in direct
79 losses to small ruminant keepers and imposing a significant burden on small ruminant
80 production (9).

81
82 Sheep and goat production is increasingly important to pastoral communities in East Africa
83 that are highly dependent on livestock for household income and food security. A shift towards
84 keeping small ruminants rather than cattle has been reported in response to a complex array of
85 environmental, economic and social challenges, reflecting not only market forces but the
86 greater resilience of sheep and goats in the face of a changing climate, increasing drought

87 frequency and pasture shortages (10-12). Causes of production loss in these species can
88 therefore present an important threat to pastoralist livelihoods and food security (13). In recent
89 surveys conducted as part of participatory community-based studies of zoonotic livestock
90 diseases in northern Tanzania (14), pastoral livestock-keepers expressed high levels of concern
91 about neurological abnormalities in small ruminants and identified this syndrome as the leading
92 animal health concern. In response to these findings, this study was established to: (a)
93 determine the reported 12-month period prevalence and point prevalence of the neurological
94 syndrome in sheep and goats kept by pastoral communities in northern Tanzania; (b)
95 characterise the clinical presentation; (c) investigate the contribution of *T. multiceps* infection
96 and (d) identify risk factors associated with the syndrome.

97
98

99 **Materials and methods**

100 **Study area**

101 The study was carried out in the Arusha region of northern Tanzania between January and
102 March 2018. The region consists of semi-arid and sub-tropical areas and is divided into seven
103 administrative districts. Study villages were located in Longido and Monduli Districts (Figure
104 1), where livestock keepers operate predominantly extensive pastoralist grazing systems for
105 livestock. Study villages were identified from randomly-selected villages (n = 20) participating
106 in earlier research studies on zoonoses in emerging livestock systems (BBSRC BB/L018926/1)
107 (14). Four villages were selected for further investigation based on previously reported cases
108 of the neurological syndrome, ease of access and good working relationships with local
109 livestock field officers.

110

111 **Ethical clearance**

112 Research clearance for this study was granted by the Tanzania Commission for Science and
113 Technology (No. 2018-48-NA-2005-141) and ethical clearance by the University of Glasgow
114 School of Veterinary Medicine Ethics Committee (REF 43a/17). Informed written consent for
115 livestock examination and sampling was obtained from the head of each household.

116

117 **Study design**

118 The study comprised a cross-sectional survey consisting of three elements. Firstly, a
119 questionnaire survey was administered at all households in each of the four villages to (i)
120 quantify farmer-reported 12-month period prevalence and point prevalence of the neurological
121 syndrome in sheep and goats and (ii) to collect data to identify potential risk factors for the

122 syndrome, including flock size, dog ownership and dog feeding practices. Questionnaires were
123 administered to the head of each household by local livestock field officers in Kiswahili
124 following training and pilot testing.

125

126 Secondly, a target of ten households reporting current cases of neurological syndrome in small
127 ruminants were randomly selected per village for further investigation. At each selected
128 household farmers were asked to identify all animals currently affected with the neurological
129 syndrome. All identified cases were examined by a veterinarian to document clinical signs
130 associated with the syndrome, including assessment of mentation, posture, gait, proprioception
131 and cranial nerve function using standard clinical approaches described in the veterinary
132 neurology literature (15; 16).

133

134 Thirdly, a subset of affected animals were selected for post-mortem examination. Numbers
135 were assigned to affected animals identified by the farmer as destined for slaughter. Up to two
136 animals from each household were selected at random by drawing numbers from a hat. Farmers
137 were compensated for the market value of each selected animal. Animals were then humanely
138 slaughtered by trained livestock officers following international guidelines for slaughter of
139 small ruminant livestock for human consumption (17; 18) At post-mortem examination, the
140 brain and spinal cord were removed from each animal and examined for evidence of gross
141 pathology. Where cysts were identified, sections of cyst wall and protoscoleces were collected
142 into 70% ethanol for DNA preservation and subsequent molecular testing.

143

144 **Laboratory diagnosis**

145 PCR-based amplification and sequencing of a ~470bp fragment of the *Taenia* NADH-1
146 mitochondrial gene was performed to determine the presence of *T. multiceps* and confirm the
147 diagnosis of coenurosis in animals with brain or spinal cord cysts (19; 20). DNA was extracted
148 from cysts preserved in ethanol using the QIAamp DNA Mini Kit spin-column protocol for
149 DNA purification from tissues (Qiagen, Maryland, USA). PCR assays were performed
150 following previously published protocols designed for molecular speciation of *Taenia*
151 infections (19; 20). PCR amplicons were sequenced and compared to published sequences
152 using the BLAST nucleotide alignment search tool available in GenBank to confirm the
153 infecting *Taenia* species (21).

154

155 **Data analysis**

156 Maps of the study area were made using QGIS open access software (version 2.18). National,
157 regional and village-level shape files were obtained from Tanzania National Bureau of
158 Statistics (22). Statistical analyses were performed in R statistical environment, version 3.4.4
159 (<http://cran.r-project.org/>). Household and individual-level point prevalence was determined
160 as the proportion of households or individual animals affected at the time of the survey. Due
161 to the reported high turnover of affected animals, 12-month period prevalence was also
162 calculated to provide a more robust estimate of the scale and impact of the problem. Household
163 12-month period prevalence was calculated as the number of households with at least one
164 reported case in the last year divided by the total number of households. Individual 12-month
165 period prevalence was calculated as the number of animals reported to be affected, over the
166 current flock size, assuming a stable flock size over the same period. Prevalence estimates were
167 calculated for small ruminants as a unit because sheep and goats are typically managed together
168 in this setting, and also by species, to look for differences in susceptibility to the syndrome.

169

170 Statistical significance was set at a value of $p \leq 0.05$. Pearson's chi-squared tests were used to
171 evaluate the difference in point prevalence and 12-month period prevalence between sheep and
172 goats. Regression analysis was performed to investigate risk factors associated with the count
173 of cases at the household over the past 12 months. Explanatory variables included the natural
174 logarithm of flock size, village, dog ownership (yes or no), whether farmers reported feeding
175 small ruminant brains to dogs (yes or no) and an interaction term between dog ownership and
176 brain-feeding. Two models were constructed; firstly, a Poisson regression model for count
177 data and secondly a negative binomial model to account for over-dispersal in the data.
178 Goodness of fit for the two models with and without the addition of the interaction term, was
179 evaluated using a likelihood ratio test.

180

181

182 **Results**

183 **Descriptive data**

184 Questionnaires were administered at 480 households across the four villages. Village size
185 ranged from 83 to 157 households and between approximately 6,000 and 17,000 small
186 ruminants were kept per village. Of the 480 households, 474 (98.8%) currently kept small
187 ruminants and 374 (77.9%) kept at least one dog. Sheep accounted for 58.0% of all small
188 ruminants kept.

189

190 **12-month period prevalence and point prevalence**

191 In total, 445 (93.9%) of the 474 small ruminant-keeping households had experienced at least
 192 one case of neurological syndrome in sheep or goats in the last 12 months (Table 1). By village,
 193 between 10.9% and 34.0% of small ruminants in each village were reported to have been
 194 affected during the same period (Table 1). Overall, the individual-level 12-month period
 195 prevalence was significantly higher in goats than sheep ($\chi^2=26.6$, d.f.=1, $p<0.001$).

196

197 **Table 1: 12-month period prevalence (household and individual) of farmer-reported**
 198 **neurological syndrome in sheep and goats in northern Tanzania**

Village	Number of small ruminant-keeping households reporting \geq one case of neurological syndrome in sheep or goats in the previous 12 months (household 12-month period prevalence %)	Reported number of animals affected in the previous 12 months (individual 12-month period prevalence %)		
		Sheep	Goats	Total
	N (%)	N (%)	N (%)	N (%)
1	140 (91.5)	3043 (24.9)	1990 (39.2)	5033 (29.1)
2	115 (96.6)	1195 (33.4)	970 (34.8)	2165 (34.0)
3	83 (100.0)	1220 (28.0)	1287 (19.8)	2507 (23.1)
4	107 (89.9)	504 (9.9)	475 (12.1)	979 (10.9)
Total	445 (93.9)	5962 (23.6)	4722 (25.8)	10684 (24.6)

199

200 At the time of the survey, 51.1% of small ruminant-keeping households reported current cases
 201 of neurological syndrome in sheep and goats (Table 2). By village, between 0.9% and 2.9%
 202 of small ruminants were reported to be currently affected with neurological syndrome (Table
 203 2). No significance difference was detected in point prevalence between small ruminant
 204 species.

205

206 **Table 2: Point prevalence (household and individual) of farmer-reported neurological**
 207 **syndrome in sheep and goats in northern Tanzania**

Village	Number of small ruminant-keeping households reporting cases of neurological syndrome at the time of survey (household point prevalence)	Reported number of animals affected at the time of survey (individual point prevalence %)		
		Sheep	Goat	Total
	N (%)	N (%)	N (%)	N (%)
1	103 (67.3%)	320 (2.6)	180 (3.5)	500 (2.9)
2	55 (46.2)	81 (2.3)	76 (2.7)	157 (2.5)
3	42 (50.6)	103 (2.4)	140 (2.1)	243 (2.2)
4	42 (35.3)	57 (1.1)	27 (0.7)	84 (0.9)
Total	242 (51.1)	561 (2.2)	423 (2.3)	984 (2.3)

208

209 **Description of affected animals**

210 Across the four villages, 38 households with current cases of neurological syndrome were
 211 randomly selected to participate in clinical investigation (10 households in villages 1 & 4; 9
 212 households in villages 2 & 3). In total, 74 animals were reported to be affected at the time of
 213 the survey. Reported duration of clinical signs at the time of examination ranged from less
 214 than one week (7/74, 9.5%) to 1 year (2/74, 2.7%). Sheep and goats were similarly represented
 215 in affected cases (n=36 (48.7%) and n=38 (51.4%) respectively). The reported age of affected
 216 animals ranged from two months to seven years old, with the 65.5% (38/58 animals with age
 217 data available) of animals recorded as 1 year or under.

218

219 Neurological deficits were detected on clinical examination in 73 (98.6%) of the 74 animals
 220 with reported neurological syndrome. Observed neurological deficits ranged in severity from
 221 subtle gait or proprioceptive abnormalities, to pronounced mentation, postural, gait and cranial
 222 nerve deficits (Figure 2). The most commonly observed neurological signs were
 223 proprioceptive deficits (n=61, 82.4%); weakness, particularly in the hind limbs (n=55, 74.3%)
 224 and gait abnormalities (n=48, 64.9%) which most commonly presented as hindlimb ataxia.
 225 Circling was frequently mentioned by farmers but was only observed in 11 animals (14.9%).
 226 Functional cranial nerve deficits, including reduced or absent menace, palpebral and pupillary

227 light responses, were observed in 38 animals (51.4%). Mentation was normal in most cases
228 (n=65, 87.8%).

229

230 **Post mortem examinations and laboratory diagnosis**

231 Post mortem examinations were carried out on 39 animals (20 sheep, 19 goats) that
232 demonstrated neurological deficits on clinical examination. One or more large, focal or multi-
233 focal, fluid-filled cystic structures (Figure 3) were detected in the brain (n=30) or spinal cord
234 (n=2) of 32 (82.1%) cases examined. Cysts had a bladder-like appearance, filled with clear
235 fluid and multiple small white protoscoleces (Figure 4), and ranged in size from less than 1cm
236 to more than 4cm in diameter. Cysts were found in all regions of the brain (cerebrum,
237 cerebellum and brain stem) and multiple cysts were found in 40.6% (n=13) of cases. Necrotic
238 tracts were observed in the brain parenchyma adjacent to cysts in some cases. In two animals,
239 a single fluid-filled cyst was detected adjacent to and compressing the spinal cord in the
240 lumbar-sacral and thoraco-lumbar regions, respectively. All cysts had a gross appearance
241 consistent with *T. multiceps* coenuri. *T. multiceps* infection causing coenurosis was confirmed
242 by PCR and sequencing in all cases (n=32) (see GenBank accession numbers for representative
243 sequences generated through this study).

244

245 Seven animals showed evidence of neurological deficits but had no evidence of *T. multiceps*
246 coenuri. In one case, hydrocephalus, characterised by distended cerebral ventricles was
247 observed. A second individual had a large, space-occupying cystic structure filled with yellow
248 translucent liquid and surrounded by a wide area of necrotic brain tissue. No evidence of
249 protoscoleces was seen in this cyst, which was also negative by *T. multiceps* PCR. Fly larvae
250 were detected in the frontal sinuses of a third animal. No gross pathology was evident in the
251 remaining four cases.

252

253 **Statistical analysis**

254 Regression analysis was performed to identify risk factors for neurological syndrome in small
255 ruminants in our study villages. A restricted dataset was used that excluded non-livestock
256 owning households and households with missing values for number of cases seen in the last 12
257 months, resulting in a dataset with 467 households. A negative binomial regression model
258 including an interaction between dog ownership and feeding brains to dogs provided the best
259 fit to the data. The final model demonstrated that flock size, dog ownership, feeding brains to
260 dogs, and village were significantly associated with the number of cases of neurological
261 syndrome reported in small ruminants in the previous 12-months (Table 3).

262

263 **Table 3: Rate ratios, 95% confidence intervals and P values for explanatory variables in**
 264 **final negative binomial regression model for neurological syndrome in small ruminants**

Variable	Rate ratio (95% confidence intervals)	P value
(Intercept)	1.1 (0.70-1.73)	0.676
Dog ownership	2.0 (1.26-3.08)	0.003
Feed brains to dogs	2.6 (1.71-3.81)	<0.001
Log (flock size)	1.7 (1.58-1.84)	<0.001
Village 1	Baseline	
Village 2	0.7 (0.59-0.86)	<0.001
Village 3	0.8 (0.67-1.01)	0.057
Village 4	0.3 (0.26-0.38)	<0.001
Dog ownership*Feed brains to dogs	0.6 (0.37-0.97)	0.036

265

266 Across all households, a large proportion of respondents (n=383, 79.8%) reported having fed
 267 sheep or goat brains to dogs, including in 65 (61.3%) out of 106 households that did not own
 268 dogs. Both dog ownership and the practice of brain-feeding were statistically significant, but
 269 the effect for each of these two variables modified that of the other. The greatest risk of
 270 neurological syndrome was associated with households that both owned dogs and fed brains,
 271 when compared to households that did neither (rate ratio 3 (95% CI 2.1 – 4.4), estimated from
 272 the regression co-efficients (β) derived from the model shown in Table 3, i.e. $\beta_{fed} + \beta_{own} +$
 273 $\beta_{own*fed}$). However, even in households that did not own dogs, the practice of brain-feeding
 274 alone was associated with a rate ratio of 2.6 (95% CI 1.7 – 3.8). In households that did not
 275 report brain-feeding, owning dogs was associated with a rate ratio of 2.0 (95% CI 1.3 – 3.1),
 276 whereas in households that fed brains to dogs, owning dogs was associated with a small, non-
 277 significant increase in risk (rate ratio 1.17 (95% CI 0.95 – 1.45), $\beta_{own\ dogs} + \beta_{own\ dogs*fed}$
 278 dogs).

279

280

281 Discussion

282 Our study, investigating the problem of a severe neurological syndrome in small ruminants in
 283 pastoral communities of northern Tanzania, demonstrates several key findings. Firstly,

284 neurological abnormalities are widely reported in small ruminants in our study villages with
285 almost all flocks (94%) affected. The individual-level 12-month period prevalence is also high,
286 with 11-34% of sheep and goats in each village reported to have been affected over the last
287 year. Secondly, post mortem findings revealed that cerebral coenurosis is a major contributing
288 cause of this neurological syndrome in sheep and goats in these villages, with brain cysts
289 detected in 82% of clinically-affected animals and *T. multiceps* confirmed through PCR and
290 sequencing. Finally, our risk factor analysis identified dog ownership and the practice of
291 feeding small ruminant brains to dogs as significant risk factors for this neurological syndrome.
292 Our study provides important insights into the prevalence and aetiology of neurological disease
293 in sheep and goats in this area and identifies risk factors that could be targeted to help control
294 this important animal health problem.

295

296 Period prevalence estimates obtained from this study indicate that the neurological syndrome
297 reported by farmers is common and poses a major burden for small ruminant production in this
298 setting. Although the point prevalence of neurological syndrome reported in our study (2.3%)
299 is relatively low, point prevalence estimates are limited, as the rapid sale or slaughter of
300 affected animals reported in our system means that point prevalence is likely to be highly
301 dynamic and therefore may not be representative of the true scale of the problem. The use of
302 12-month period prevalence in our study allowed us to improve our estimates of losses and
303 highlighted the scale of the problem over time. In this small-scale study of four villages, almost
304 10,000 small ruminants were reported to be affected by this neurological syndrome over a 12-
305 month period. Given the typically fatal outcome of the syndrome, both directly (e.g. through
306 death or predation) and via premature slaughter of affected animals resulting in a loss of market
307 value, this syndrome is resulting in substantial financial and production losses for livestock-
308 dependent communities in northern Tanzania.

309

310 Cerebral coenurosis appears to be a major contributing cause of the neurological syndrome of
311 small ruminants reported in northern Tanzania. Evidence of *T. multiceps* coenuri were found
312 in more than 80% of cases at post mortem examination and clinical signs were consistent with
313 those reported in outbreaks of cerebral coenurosis described elsewhere (23-25). Further
314 investigations, such as histopathology on brain tissue or testing for other infectious agents,
315 were not performed as part of this study hence other causes of neurological disease could not
316 be ruled out. However, gross pathology is considered pathognomonic for the diagnosis of
317 cerebral coenurosis in the presence of compatible clinical signs.

318

319 In our study, the majority of affected animals were one year old or less which is consistent with
320 reports in the literature (9; 26). Infection was also seen in several animals under 6 months,
321 including a two-month old lamb that had several small multifocal parasitic cysts scattered on
322 the cerebral surface and necrotic tracts in the cerebral tissue. The very young age of some of
323 the animals in our study was surprising as the interval between infection and onset of clinical
324 signs has previously been estimated as two to six months (25) and maternally derived
325 antibodies could be expected to still provide protection at this age (27; 28). Early onset cases
326 have been described where naïve animals have been exposed to a very high burden of *T.*
327 *multiceps* eggs, but appear to be rare (24; 29). In these cases progression to clinical signs, and
328 even death, can occur in less than a week (30). It remains unclear whether the young age profile
329 seen in this study reflects a particularly high environmental burden of *T. multiceps*, intrinsic
330 host factors such as immuno-compromise, or pathogen strain characteristics, and further work
331 is needed to understand the early onset of disease in this setting.

332

333 Dog ownership and the practice of feeding livestock brains to dogs were both identified as
334 significant risk factors for reported cases of neurological syndrome, which is consistent with
335 our conclusion that cerebral coenurosis is a major cause of neurological disease in small
336 ruminants in our study area. Feeding brains of small ruminants to dogs is a common practice,
337 reported by 79.8% of households in this study and observed elsewhere in northern Tanzania
338 (1,2). Our results show that disease risk is more strongly associated with brain-feeding
339 behaviour than dog ownership *per se* suggesting that preventing this behaviour may be more
340 important than changing dog ownership practices in affected communities. Education and
341 changing behavioural practices related to the disposal of infected offal, which have been
342 important elements in *T. multiceps* control and prevention elsewhere (25), could therefore be
343 highly effective in these communities. Other preventive measures could be considered in
344 combination with behavioural interventions, include anthelmintic (praziquantel) treatment of
345 dogs, which is an important mainstay of control programmes in other parts of the world and
346 can also be used to control other zoonotic cestode parasites such as *Echinococcus granulosus*,
347 which is also reported in livestock in northern Tanzania (31). Our results emphasise that
348 intervention strategies, especially behavioural interventions, will need to engage the whole
349 community, not only dog owners, to encourage the collective action needed to break
350 transmission cycles.

351

352 The study presented here was conducted as an initial investigation as such is limited in scope,
353 with only four purposely-selected pastoral study sites. The data presented in this study was

354 dependent upon farmer reporting, which may have introduced bias into the selection of cases
355 for further investigation. Furthermore, the extent of this disease problem in other livestock-
356 keeping communities in Tanzania, or indeed elsewhere in East Africa, remains unclear and is
357 an important question for further investigation. Previous research in Tanzania has shown that
358 dogs kept in pastoralist households are more likely to carry *Taenia* spp. cestodes than those in
359 agro-pastoralist households (22), suggesting that sheep and goats kept by pastoral communities
360 may be at higher risk of disease than in other farming systems. Further work is needed to
361 understand the extent to which this disease problem is occurring elsewhere in Tanzania and to
362 characterise the burden of small ruminant neurological disease in different farming systems.

363

364 It is also unclear whether the high prevalence of coenurosis detected in this study represents an
365 emerging disease problem in Tanzania or whether the extent of the problem has only recently
366 become apparent as a result of detailed participatory and community-studies carried out as part
367 of other livestock disease research (14). Although coenurosis has previously been highlighted
368 as a concern in pastoral communities of Ngorongoro District in Tanzania (4) and in Ethiopia
369 (9; 32), the disease is rarely prioritised by national veterinary services or international animal
370 health agencies and surveillance data is lacking to compare temporal trends in disease patterns.
371 However, the scale of the problem identified by this study raises urgent questions about the
372 economic, health and social impacts of coenurosis in these communities, as well as the
373 sustainability of livestock-based livelihoods in the East African region in the face of such
374 sustained losses. The issue is particularly acute in the wake of a recent succession of droughts,
375 with the disease posing an additional threat to the small ruminant production base on which
376 pastoralists increasingly depend for food security and survival (11; 12; 33; 34).

377

378 Human disease surveillance is also important as *T. multiceps* is a potentially zoonotic infection
379 and may be of particular concern in livestock-dependent communities with limited access to
380 health care. Zoonotic cases of cerebral coenurosis, although rare, have been reported in North
381 America, Europe and the Middle East (35-37) and may occur alongside another zoonotic
382 cestode infection, *E. granulosus*, the cause of human hydatid disease (cystic echinococcosis).
383 Hydatid disease, which has a similar lifecycle to *T. multiceps* with dogs as the definitive host
384 and livestock as the intermediate host, is recognised as an important zoonotic disease problem
385 in pastoralist communities in East Africa (38). It is possible that the factors driving the high
386 prevalence of cerebral coenurosis in small ruminants may also drive a concurrent increase in
387 zoonotic cestode infections in humans. Progression of *E. granulosus* cysts in people is
388 generally much longer (months to years) (39) than the progression of *T. multiceps* coenuri in

389 sheep and goats so an increase in human disease may not be immediately apparent. Therefore,
390 public health authorities should be aware of the risk of human coenurosis and other cestode
391 infections such as cystic echinococcosis as emerging health problems in pastoral communities.
392 Improved surveillance of both animal and human health is recommended to monitor the burden
393 and to identify potential drivers of these two important parasitic infections.

394

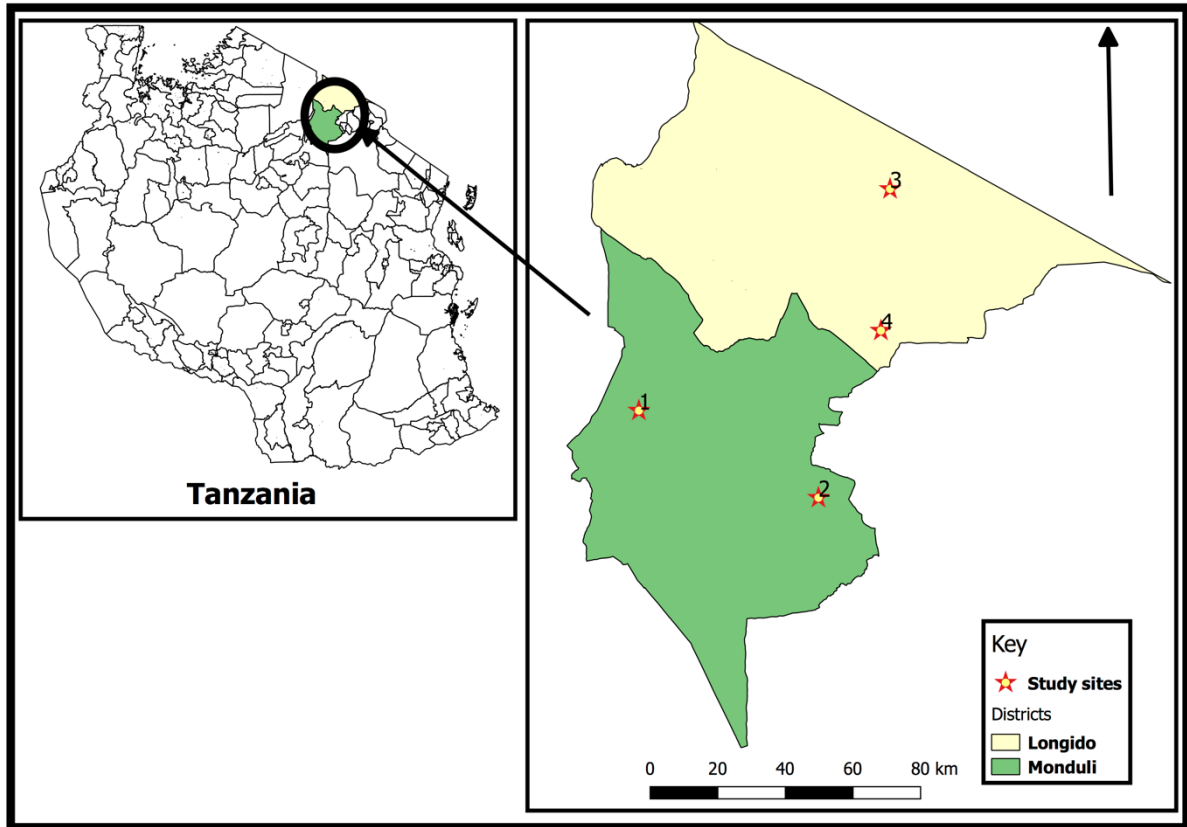
395 **Conclusion**

396 This study indicates that cerebral coenurosis is a predominant cause of a neurological syndrome
397 of small ruminants commonly reported in pastoral communities in northern Tanzania. The
398 point and 12-month period prevalence of farmer-reported cases demonstrates that *T. multiceps*
399 coenurosis, although rarely mentioned as a national veterinary priority, is a major disease of
400 small ruminants in the region. Further work is needed to better quantify the prevalence and
401 incidence of the disease at a wider scale, to understand the economic and social impacts on
402 livestock-keeping communities, and to identify and implement appropriate measures for
403 disease control and prevention.

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405 **Figures**

406 **Figure 1: Map showing Arusha region with (inset) study village locations. Maps made**
407 **using QGIS open access software (version 2.18). Shape files were obtained from Tanzania**
408 **National Bureau of Statistics.**



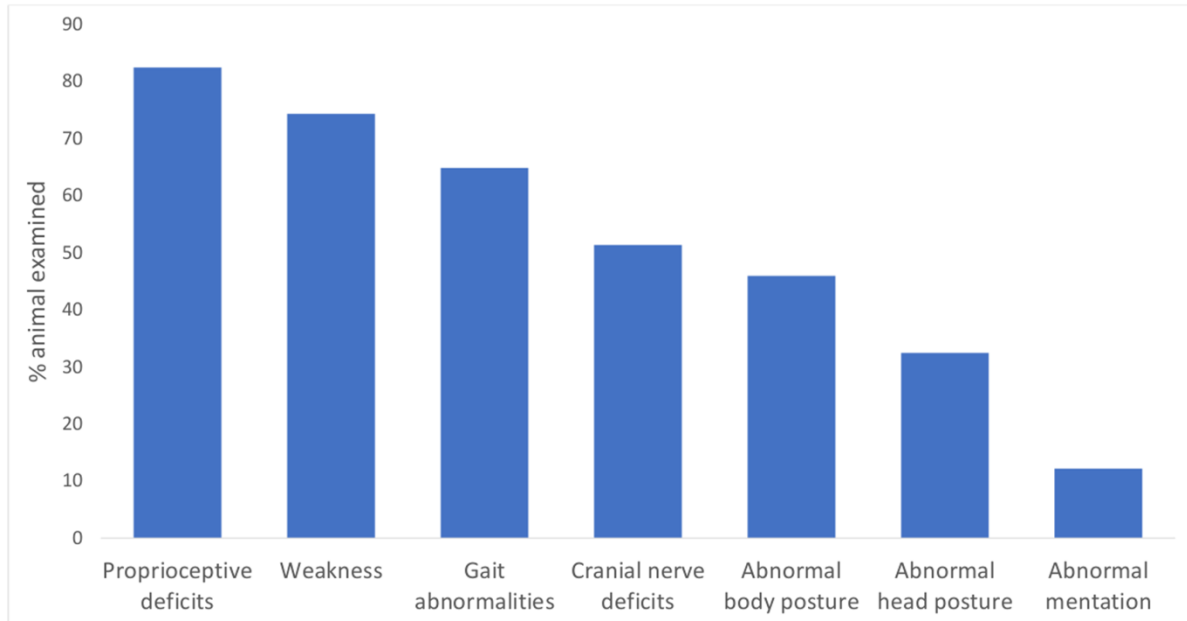
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413 **Figure 2: Percentage of affected animals showing different neurological abnormalities.**



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416 **Figure 3: Brain of a goat with multiple fluid-filled cysts and evidence of associated**
417 **cerebral parenchymal loss.**

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422 **Figure 4: Cyst removed from the brain of a sheep, showing multiple protoscoleces**
423 **consistent with *Taenia multiceps* coenurus.**

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Acknowledgments

We thank field teams for support of data collection in Tanzania, including Hussein Hassan, Matayo Malambo and Fadhili Mshana, and thank Kate Thomas and Victor Mosha for laboratory support. Finally, we would like to thank the livestock field officers and livestock owners for their participation in this study.

Author contributions

Conceptualisation of the study and acquisition of funding - ECH, TKK, WAdG, FL, AD, OMN, JRC, SC, KJA. Field investigation - ECH, TKK, FL, OMN, KJA. Laboratory analysis - RWC, RMFdJ, KJA. Data analysis and interpretation - ECH, WAdG, SC, KJA. Manuscript writing - ECH, TKK, WAdG, FL, AD, JRC, SC, KJA. All authors were involved in critical review and editing of the final manuscript

445 **References**

- 446 1. QUEENAN, K., MANGESHO, P., OLE-NESELLE, M., KARIMURIBO, E.,
447 RWEYEMAMU, M., KOCK, R. & HASLER, B. (2017) Using local language syndromic
448 terminology in participatory epidemiology: Lessons for One Health practitioners among the
449 Maasai of Ngorongoro, Tanzania. *Preventive Veterinary Medicine* 139, 42-49,
450 doi:10.1016/j.prevetmed.2017.02.003
- 451 2. BEDELIAN, C., NKEDIANYE, D. & HERRERO, M. (2007) Maasai perception of
452 the impact and incidence of malignant catarrhal fever (MCF) in southern Kenya. *Preventive*
453 *Veterinary Medicine* 78, 296-316, doi:10.1016/j.prevetmed.2006.10.012
- 454 3. KUSILUKA, L. & KABARAGE, D. (1996) *Common Diseases of Sheep and Goats*
455 *in Sub-Saharan Africa*. Roslin, Scotland, VETAID
- 456 4. MIRAN, M. B., NZALAWAHE, J., KASSUKU, A. A. & SWAI, E. S. (2015)
457 Prevalence of coenurosis in sheep and goats at three slaughter slabs in Ngorongoro District,
458 Tanzania. *Tropical Animal Health and Production* 47, 1591-1597, doi:10.1007/s11250-015-
459 0903-7
- 460 5. SHARMA, D. K. & CHAUHAN, P. P. S. (2006) Coenurosis status in Afro-Asian
461 region: A review. *Small Ruminant Research* 64, 197-202,
462 doi:10.1016/j.smallrumres.2005.05.021
- 463 6. ORYAN, A., MOAZENI, M., AMRABADI, O., AKBARI, M. & SHARIFIYAZDI,
464 H. (2015) Comparison of distribution pattern, pathogenesis and molecular characteristics of
465 larval stages of *Taenia multiceps* in sheep and goats. *Small Ruminant Research* 132, 44-49,
466 doi:10.1016/j.smallrumres.2015.10.008
- 467 7. EVANGELISTI, M. A., VARCASIA, A., DEIANA, R., ZOBBA, R., PASSINO, E.
468 S., SCALA, A., MELOSU, V., PIPIA, A. P., TAMPONI, C. & MANUNTA, M. L. (2016)
469 Clinical evolution of cerebral coenurosis from invasive to chronic infection in sheep and a
470 goat. *Journal of Infection in Developing Countries* 10, 1151-1155, doi:10.3855/jidc.8719
- 471 8. SCALA, A., CANCEDDA, G. M., VARCASIA, A., LIGIOS, C., GARIPPA, G. &
472 GENCHI, C. (2007) A survey of *Taenia multiceps* coenurosis in Sardinian sheep. *Veterinary*
473 *Parasitology* 143, 294-298, doi:10.1016/j.vetpar.2006.08.020
- 474 9. ALIYE, J. & DERESSA, F. B. (2017) Prevalence and economic importance of
475 *Coenurus Cerebralis* in sheep and goats in and around “Legahida” district of bale zone, south
476 eastern Ethiopia. *Comparative Clinical Pathology* 26, 483-492, doi:10.1007/s00580-017-
477 2404-8
- 478 10. WESTERN, D. & NIGHTINGALE, D. L. M. (2003) *Environmental Change and the*
479 *Vulnerability of Pastoralists to Drought: A Case Study of the Maasai in Amboseli, Kenya.*
480 *Africa Environmental Outlook Report*. Nairobi: UNEP,
481 <http://www.amboseliconservation.org/recommendation-for-planning-and-conservation.html>

- 482 11. GOLDMAN, M. J. & RIOSMENA, F. (2013) Adaptive capacity in Tanzanian
483 Maasailand: Changing strategies to cope with drought in fragmented landscapes. *Global*
484 *Environmental Change* 23, 588-597, doi:10.1016/j.gloenvcha.2013.02.010
- 485 12. LEAL FILHO, W., NZENGYA, D., MUASYA, G., CHEMULITI, J. & KALUNGU,
486 J. W. (2017) Climate change responses among the Maasai Community in Kenya. *Climatic*
487 *Change* 145, 71-83, doi:10.1007/s10584-017-2087-9
- 488 13. GALVIN, K. A. (2009) Transitions: Pastoralists Living with Change. *Annual Review*
489 *of Anthropology* 38, 185-198, doi:10.1146/annurev-anthro-091908-164442
- 490 14. RYAN, M. R. & CLEAVELAND, S. (2017) Zoonotic diseases: sharing insights from
491 interdisciplinary research. *Veterinary Record* 180, 270-271, doi:10.1136/vr.j1261
- 492 15. ABRAMSON, C. J. (2009) The neurological examination: how to describe what you
493 see & know if it is normal,. AAHA Phoenix 2009 Proceedings: Scientific, Management and
494 Technician Programs : American Animal Hospital Association. Phoenix, Arizona. March 26-
495 29, 2009
- 496 16. CONSTABLE, P. D. (2004) Clinical examination of the ruminant nervous system.
497 *Veterinary Clinics of North America: Food Animal Practice* 20, 185-214, v,
498 doi:10.1016/j.cvfa.2004.02.011
- 499 17. SHIMSHONY, A. & CHAUDRY, M. M. (2005) Slaughter of animals for human
500 consumption. *REVUE SCIENTIFIQUE ET TECHNIQUE-OFFICE INTERNATIONAL*
501 *DES EPIZOOTIES* 24, 693-710
- 502 18. OIE (2018) Slaughter of animals In: *Terrestrial animal health code*. 27th edn. Paris,
503 World Organisation for animal health. pp 369-386. [http://www.oie.int/en/standard-](http://www.oie.int/en/standard-setting/terrestrial-code/access-online/)
504 [setting/terrestrial-code/access-online/](http://www.oie.int/en/standard-setting/terrestrial-code/access-online/)
- 505 19. GASSER, R. B., ZHU, X. Q. & MCMANUS, D. P. (1999) NADH dehydrogenase
506 subunit 1 and cytochrome c oxidase subunit I sequences compared for members of the genus
507 *Taenia* (Cestoda). *International Journal for Parasitology* 29, 1965-1970, doi:10.1016/s0020-
508 7519(99)00153-8
- 509 20. AL-RIYAMI, S., IOANNIDOU, E., KOEHLER, A. V., HUSSAIN, M. H., AL-
510 RAWAHI, A. H., GIADINIS, N. D., LAFI, S. Q., PAPADOPOULOS, E. & JABBAR, A.
511 (2016) Genetic characterisation of *Taenia multiceps* cysts from ruminants in Greece.
512 *Infection Genetics and Evolution* 38, 110-116, doi:10.1016/j.meegid.2015.12.008
- 513 21. BENSON, D. A., KARSCH-MIZRACHI, I., CLARK, K., LIPMAN, D. J., OSTELL,
514 J. & SAYERS, E. W. (2012) GenBank. *Nucleic Acids Research* 40, D48-D53,
515 doi:10.1093/nar/gkr1202
- 516 22. Tanzania National Bureau of Statistics (2013) 2012 Population and Housing Census
517 of Tanzania Shapefiles (Levels 1, 2 and 3) Tanzania National Bureau of Statistics, Tanzania,

- 518 June 2013. [http://www.nbs.go.tz/nbstz/index.php/english/statistics-by-subject/population-](http://www.nbs.go.tz/nbstz/index.php/english/statistics-by-subject/population-and-housing-census)
519 [and-housing-census](http://www.nbs.go.tz/nbstz/index.php/english/statistics-by-subject/population-and-housing-census)
- 520 23. AMER, S., ELKHATAM, A., FUKUDA, Y., BAKR, L. I., ZIDAN, S., ELSIFY, A.,
521 MOHAMED, M. A., TADA, C. & NAKAI, Y. (2017) Prevalence and Identity of *Taenia*
522 *multiceps* cysts "*Coenurus cerebralis*" in Sheep in Egypt. *Acta Tropica* 176, 270-276,
523 doi:10.1016/j.actatropica.2017.08.012
- 524 24. GIADINIS, N. D., PSYCHAS, V., POLIZOPOULOU, Z., PAPADOPOULOS, E.,
525 PAPAIOANNOU, N., KOMNENOU, A. T., THOMAS, A. L., PETRIDOU, E. J.,
526 KRITSEPI-KONSTANTINOY, M., LAFI, S. Q. & BRELLOU, G. D. (2012) Acute
527 coenurosis of dairy sheep from 11 flocks in Greece. *New Zealand Veterinary Journal* 60, 247-
528 253, doi:10.1080/00480169.2012.665343
- 529 25. SCOTT, P. R. (2012) Diagnosis and treatment of coenurosis in sheep. *Veterinary*
530 *Parasitology* 189, 75-78, doi:10.1016/j.vetpar.2012.03.034
- 531 26. TAVASSOLI, M., MALEKIFARD, F., SOLEIMANZADEH, A. & TAJIK, H.
532 (2011) Prevalence of *Coenurus cerebralis* in sheep in Northwest of Iran. *Veterinary Research*
533 *Forum* 2, 274-276
- 534 27. ABO-SHEHADA, M. N., JEBREEN, E., ARAB, B., MUKBEL, R. &
535 TORGERSON, P. R. (2002) Prevalence of *Taenia multiceps* in sheep in northern Jordan.
536 *Preventive Veterinary Medicine* 55, 201-207, doi:10.1016/s0167-5877(02)00056-9
- 537 28. GEMMELL, M. A., LAWSON, J. R. & ROBERTS, M. G. (1987) Population
538 dynamics in echinococcosis and cysticercosis: evaluation of the biological parameters of
539 *Taenia hydatigena* and *T. ovis* and comparison with those of *Echinococcus granulosus*.
540 *Parasitology* 94 161-180, doi:10.1017/s0031182000053543
- 541 29. PINTUS, D., VARCASIA, A., DESSI, G., TAMPONI, C., MANUNTA, M. L.,
542 CARBONI, G. A., CANCEDDA, M. G., LIGIOS, C. & SCALA, A. (2018) Atypical
543 outbreak of acute coenurosis by *Taenia multiceps* in a sheep flock. *Parasitology Research*
544 117, 1985-1988, doi:10.1007/s00436-018-5873-z
- 545 30. DOHERTY, M. L., BASSETT, H. F., BREATHNACH, R., MONAGHAN, M. L. &
546 MCERLEAN, B. A. (1989) Outbreak of acute coenuriasis in adult sheep in Ireland
547 *Veterinary Record* 125, 185-185, doi:10.1136/vr.125.8.185
- 548 31. MIRAN, M. B., KASUKU, A. A. & SWAI, E. S. (2017) Prevalence of
549 echinococcosis and *Taenia hydatigena* cysticercosis in slaughtered small ruminants at the
550 livestock-wildlife interface areas of Ngorongoro, Tanzania. *Vet World* 10, 411-417,
551 doi:10.14202/vetworld.2017.411-417
- 552 32. ACHENEF, M., MARKOS, T., FESEHA, G., HIBRET, A. & TEMBELY, S. (1999)
553 *Coenurus cerebralis* infection in Ethiopian highland sheep: Incidence and observations on
554 pathogenesis and clinical signs. *Tropical Animal Health and Production* 31, 15-24,
555 doi:10.1023/a:1005125316275

- 556 33. OGUTU, J. O., PIEPHO, H. P., SAID, M. Y., OJWANG, G. O., NJINO, L. W.,
557 KIFUGO, S. C. & WARGUTE, P. W. (2016) Extreme Wildlife Declines and Concurrent
558 Increase in Livestock Numbers in Kenya: What Are the Causes? PLOS ONE 11, e0163249,
559 doi:10.1371/journal.pone.0163249
- 560 34. BOLLIG, M. (2016) Adaptive cycles in the savannah: pastoral specialization and
561 diversification in northern Kenya. *Journal of Eastern African Studies* 10, 21-44,
562 doi:10.1080/17531055.2016.1141568
- 563 35. EL-ON, J., SHELEF, I., CAGNANO, E. & BENIFLA, M. (2008) *Taenia multiceps*:
564 a rare human cestode infection in Israel. *Veterinaria Italiana* 44, 621-631
- 565 36. ING, M. B., SCHANTZ, P. M. & TURNER, J. A. (1998) Human coenurosis in North
566 America: Case reports and review. *Clinical Infectious Diseases* 27, 519-523,
567 doi:10.1086/514716
- 568 37. SERGIO SABATTANI, ANNA FEDERICA MARLIANI, FEDERICO
569 RONCAROLI, MINO ZUCHELLI, ANDREA ZINI, FABIO CALBUCCI &
570 FRANCESCO CHIODO (2004) Cerebral coenurosis. *Journal of Neurosurgery* 100, 964-964,
571 doi:10.3171/jns.2004.100.5.0964
- 572 38. TORGERSON, P. R. & MACPHERSON, C. N. L. (2011) The socioeconomic burden
573 of parasitic zoonoses: Global trends. *Veterinary Parasitology* 182, 79-95,
574 doi:10.1016/j.vetpar.2011.07.017
- 575 39. MCMANUS, D. P., ZHANG, W., LI, J. & BARTLEY, P. B. (2003) Echinococcosis.
576 *The Lancet* 362, 1295-1304, doi:10.1016/S0140-6736(03)14573-4
577
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