Review of data on hoof growth in normal and laminitic equines suggests a new aetiology for acute laminitis.

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Abstract

Background. To gain a greater insight into normal and laminitic hoof growth and to be able to make comparisons between the two groups.

Methods. Ten normal and three laminitic equines completed the survey, each hoof was marked with a horizontal file mark in three places, the dorsal wall and each medial and lateral quarter at about 1cm below the coronary band. Measurement of the progression of the file mark was made every 28 days, a total of 1,872 measurements were made.

Results. Equine hoof growth rates showed seasonal variation with greater rates of growth during the summer months and slower rates during the winter. In normal horses growth was slower at the quarters compared to the dorsal region but the difference was not statistically significant ($p>0.05$).

During the summer months laminitic hoof growth at the quarters was significantly faster than at the laminitic dorsal region ($p< 0.05$). The rate of accelerated growth at the laminitic quarters reduced during the winter months and was not statistically significant ($p>0.05$).

Discussion. The results of this measurement survey highlighted that laminitic hoof growth is remarkably different at the quarters. This raises the question of when the transition from normal to laminitic hoof growth takes place. Traditionally changes in hoof shape during laminitis have been assumed to be a consequence of the acute phase but this has never been confirmed. The possibility exists that abnormal hoof growth could commence early in the developmental phase, the implications of abnormal hoof growth commencing at this stage are profound. A new aetiology for equine laminitis then becomes possible, based on accelerated hoof growth at the quarters inducing the hoof capsule to change in shape; this process would have the capacity to subject the underlying dorsal dermal laminae to forces of extension which would be capable of destroying the laminal interface.

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Introduction

The equine hoof wall has three structural layers, *stratum externum, stratum medium and stratum internum*. Structural strength is complemented by tubules of horn which are most densely populated in the stratum externum and become less dense towards the stratum internum (Reilly J D 1998).

Studies on the hoof wall have mostly focused on the way it reacts to loading and locomotion, Douglas reported that the hoof wall has a comparatively rigid external surface with a less stiff inner lining; the quarter regions are more flexible than the dorsal wall allowing the quarters to facilitate flaring of the quarters during weight bearing (Douglas J E 1996). Other studies have shown that hoof behaves as a multidirectional composite, capable of tolerating operating strains in all directions, this mechanical behaviour also allows the hoof wall to withstand compressive loading in many unpredictable situations, particularly when the equine foot contacts irregular substrata (Thomason J J 1992).

A study of hoof growth in Konik horses in Poland reported variations in the rate of horn growth between young mares, older mares and stallions. A seasonal variation was also observed with growth being slowest during the winter months and most rapid during the period of elongated solar day (Frackowiak H 2006). With the exception of Frackowiak and this study, other studies on equine horn growth have been over comparatively short time periods and have not recognised underlying seasonal variations in horn growth. Shannon and Butler found that hoof growth was faster in young horses than in adults, they also commented on a change in growth rate which was fastest in warmer temperatures and greater rainfall (Shannon R O 1979). Glade and Saltzman concluded that the angle to which the hoof was trimmed could also affect growth rates, reporting growth rates at the toe ranged between .19 and .28mm per day, over the period of 126 days of their survey (Glade M J 1985).

Abnormal hoof growth associated with chronic laminitis has been commented on in many equine veterinary text books and is usually identified by divergent growth ridges at the quarters (O'Grady 2002). No other studies have been found to date that have measured the rate at which laminitic hooves grow or the possible consequences this may have on the equine foot.

The original data for this paper was collected in 1984/5 and published in Forge 89, a British farrier's magazine (Ryan 1989). The significance of the data in relation to the possible onset of laminitis was not recognised at the time but is presented in this paper.

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Materials and Methods

Twenty horses and ponies were selected from the author's client base, four of which had chronic laminitis. All the horses and ponies involved were privately owned and kept at different locations in Bedfordshire, England. The criterion for selection of the animals was the reliability of the owner to have the animal available for measurement on a regular 28 day basis. During the period of this survey 7 animals were withdrawn from the survey being sold, moved away from the area or not made available for measurement by the client, so final results are based on 13 animals divided into two groups, 10 normal and 3 of which had naturally occurring chronic laminitis but no signs of displacement of the distal phalanx. Measurements were made on all four feet of each animal, measuring the growth rate of each quarter and dorsal surface. In order to obtain measurements a horizontal groove was filed into the hoof wall on the dorsal surface and at each quarter approximately 1 cm distal to the coronary band. Measurements were then made from this file mark to the proximal hoof at the coronary band in alignment with the direction of growth. As the file mark grew out of the foot it was replaced by a new file mark distal to the coronary band and measurements made accordingly. Measurements were taken every 28 days. Initial marks and baseline measurements commenced on 25th April 1984, resulting in the first growth measurements being obtained on 23rd May 1984 and concluding on 27th March 1985. All measurements were made in millimetres.

A total of 1,872 measurements were made in the course of the study. A mean growth rate was plotted for each group and comparisons were made regarding overall growth in each group and rates of growth between dorsal and quarter regions of the hoof capsule. Statistical significance was designated at a probability value of $p<=0.05$ using the two-tailed test in MS Excel 2007. All owners gave their consent to file makes being made in the hoof wall and were present each time the recording of the hoof growth took place. The file marks made in the hoof had no adverse effect on the animals welfere.

Fig 1, Measurement file marks on a normal hoof, as the distal marks are nearing the ground surface, new marks have been inserted near the proximal hoof wall, (Photo Credit: T P Ryan).

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Table 1, Equines with normal hooves				
Equine No.	**Height cm**	**Type**	**Gender**	**Age(at start)**
1	150	Cob	Gelding	9
2	147	X Cleveland Bay	Gelding	2
3	150	Pony	Mare	10
4	157	X Thoroughbred	Mare	5
5	137	Pony	Gelding	10
6	157	Cob	Gelding	16
7	150	Pony	Mare	8
8	147	Cob	Gelding	20
9	152	Cob	Gelding	20
10	147	Arab X Pony	Gelding	2

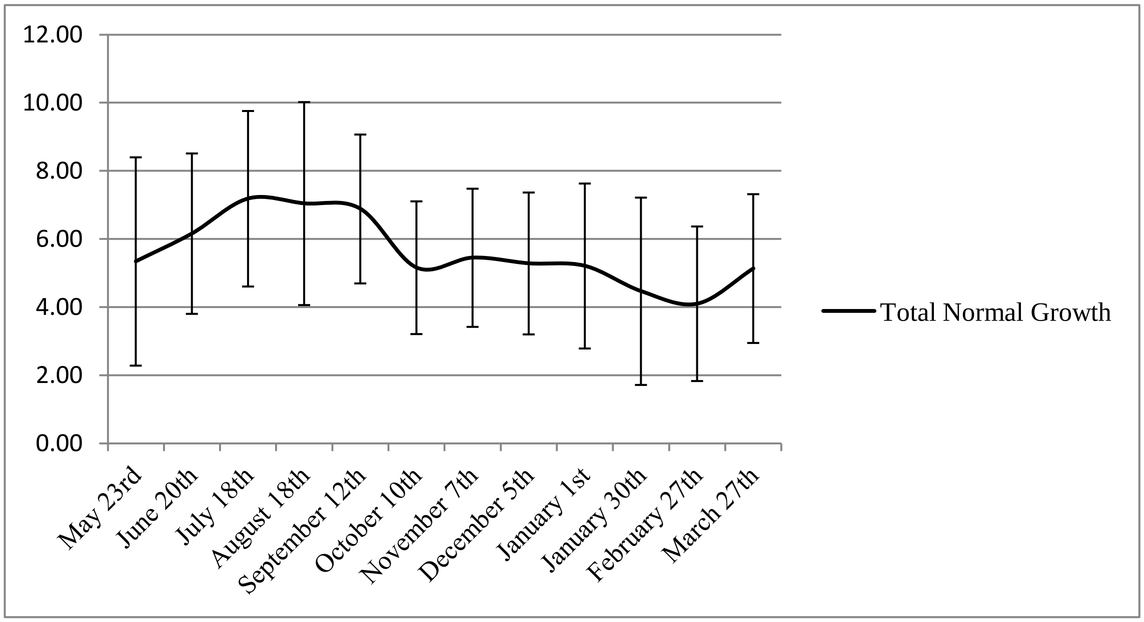
Table 2, Equines with chronic laminitic hooves				
Equine No.	**Height cm**	**Type**	**Gender**	**Age(at start)**
11	122	Pony	Mare	15
12	99	Shetland pony	Gelding	8
13	124	Pony	Mare	11

94 **Results**

95 **Total normal growth**

Total normal growth

	Mean measurement	S.D.
May 23rd	5.34	3.06
June 20th	6.16	2.36
July 18th	7.18	2.58
August 15th	7.04	2.98
September 12th	6.88	2.19
October 10th	5.16	1.95
November 7th	5.45	2.03
December 5th	5.28	2.08
January 1st	5.21	2.42
January 30th	4.47	2.75
February 27th	4.10	2.27
March 27th	5.13	2.18



Graph of total normal growth

There was a marked seasonal variation of growth showing in all four feet of the normal group with the fastest rate recorded on 18th July, the slowest growth rate was recorded on 27th February. This represents a peak monthly growth rate of 7.18mm (0.25mm per day) for July and a minimum monthly rate of 4.10mm (0.14mm per day) for February.

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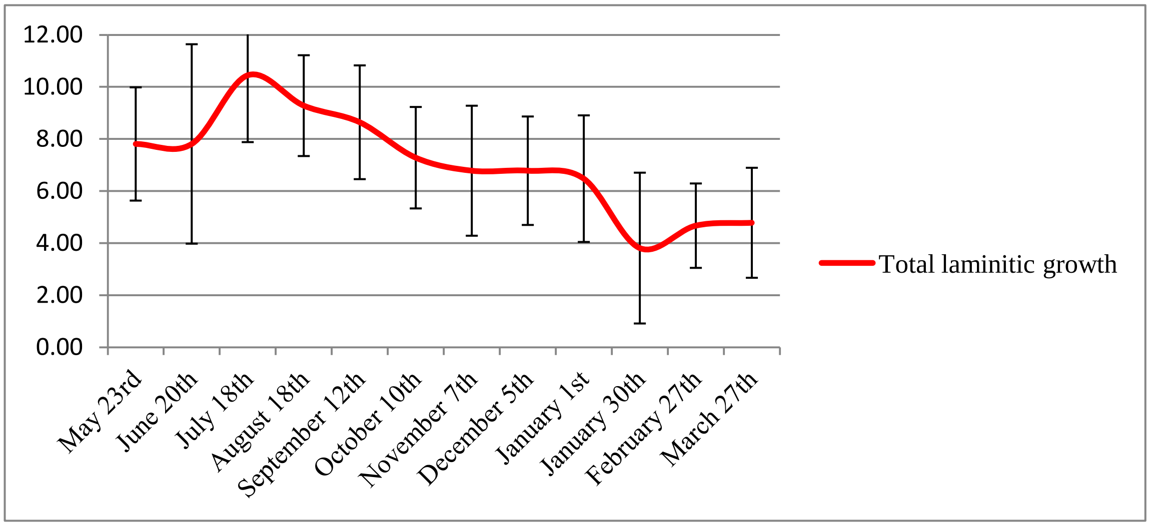
100 **Total laminitic growth**

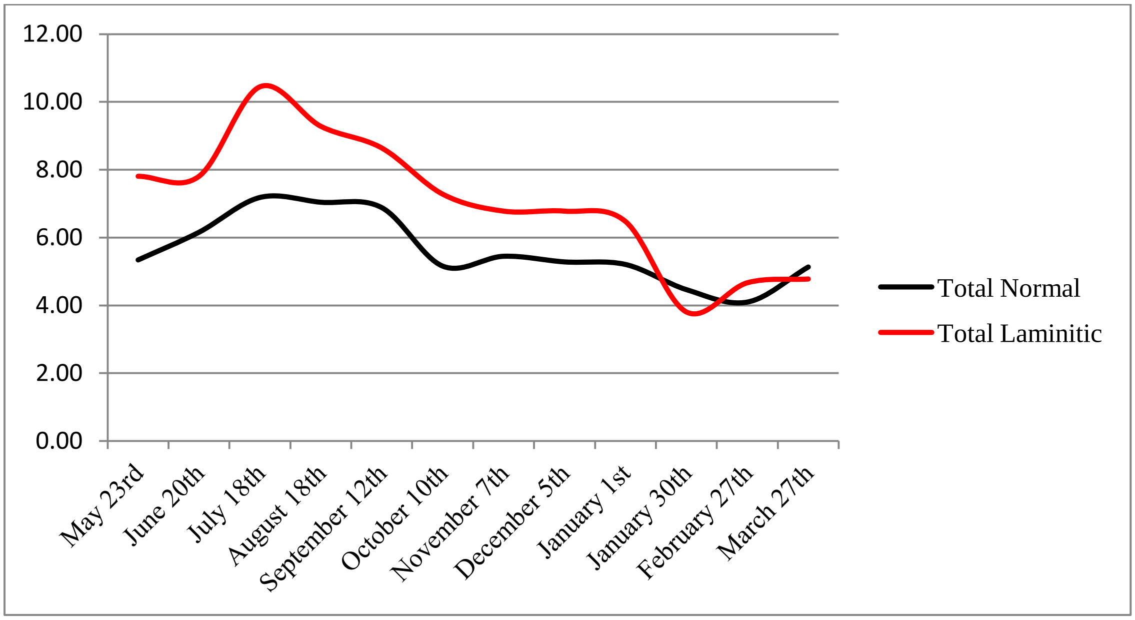
Total laminitic growth

	Mean measurement	S.D.
May 23rd	7.81	2.18
June 20th	7.81	3.83
July 18th	10.44	2.57
August 15th	9.28	1.94
September 12th	8.64	2.19
October 10th	7.28	1.95
November 7th	6.78	2.50
December 5th	6.78	2.08
January 1st	6.47	2.43
January 30th	3.81	2.90
February 27th	4.67	1.62
March 27th	4.78	2.11



Graph of total laminitic growth

The pattern of growth for all four feet in the laminitic growth also peaked on 18th July at 10.44mm (0.37mm per day) and the lowest value of 3.81mm (0.13mm per day) on 30th January.



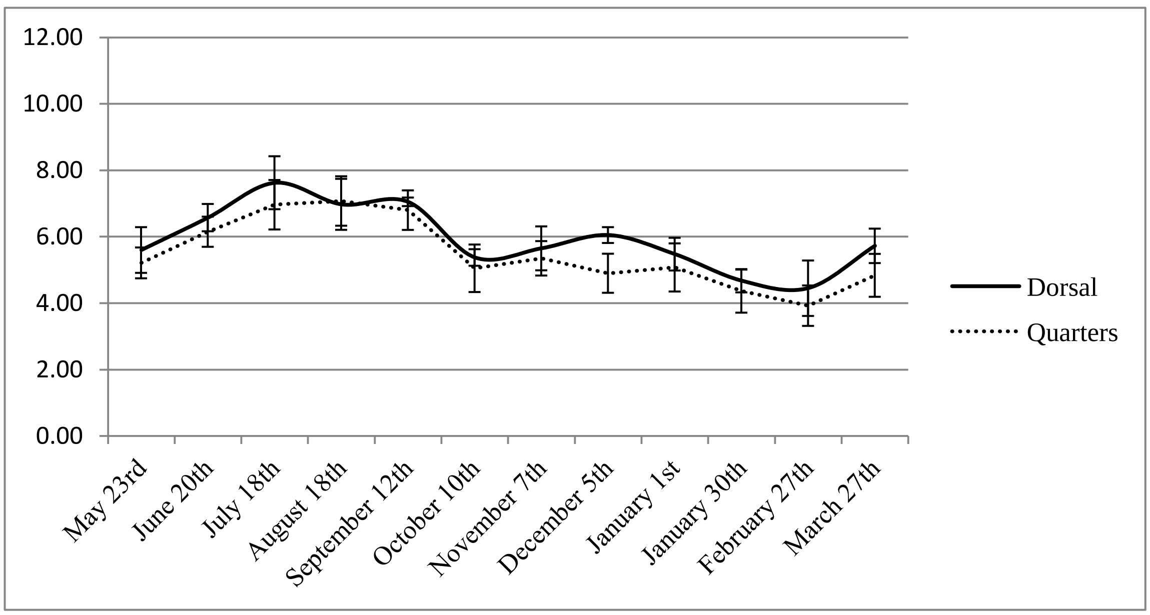
Comparison of normal and laminitic growth

Total laminitic hoof growth was faster than total normal hoof growth during most of the recorded period and confirms that hoof growth associated with chronic laminitis is not impeded but is actually accelerated compared to normal hoof growth.

Normal dorsal & quarter hoof growth

Normal dorsal and quarter growth

	Dorsal	S.D.	Quarters	S.D.
May 23rd	5.60	0.69	5.21	0.46
June 20th	6.58	0.41	6.15	0.45
July 18th	7.63	0.80	6.96	0.74
August 15th	6.98	0.77	7.08	0.74
September 12th	7.05	0.13	6.80	0.60
October 10th	5.38	0.25	5.05	0.72
November 7th	5.65	0.66	5.35	0.52
December 5th	6.05	0.24	4.90	0.59
January 1st	4.68	0.49	5.08	0.72
January 30th	4.45	0.35	4.36	0.65
February 27th	4.45	0.83	3.93	0.61
March 27th	5.73	0.52	4.84	0.65



Graph normal dorsal and quarter growth

A comparison of the rates of growth between the dorsal and quarter surfaces in the normal group shows slower growth at the quarters when compared to the dorsal surface but this was not statistically significant ($p>0.05$).

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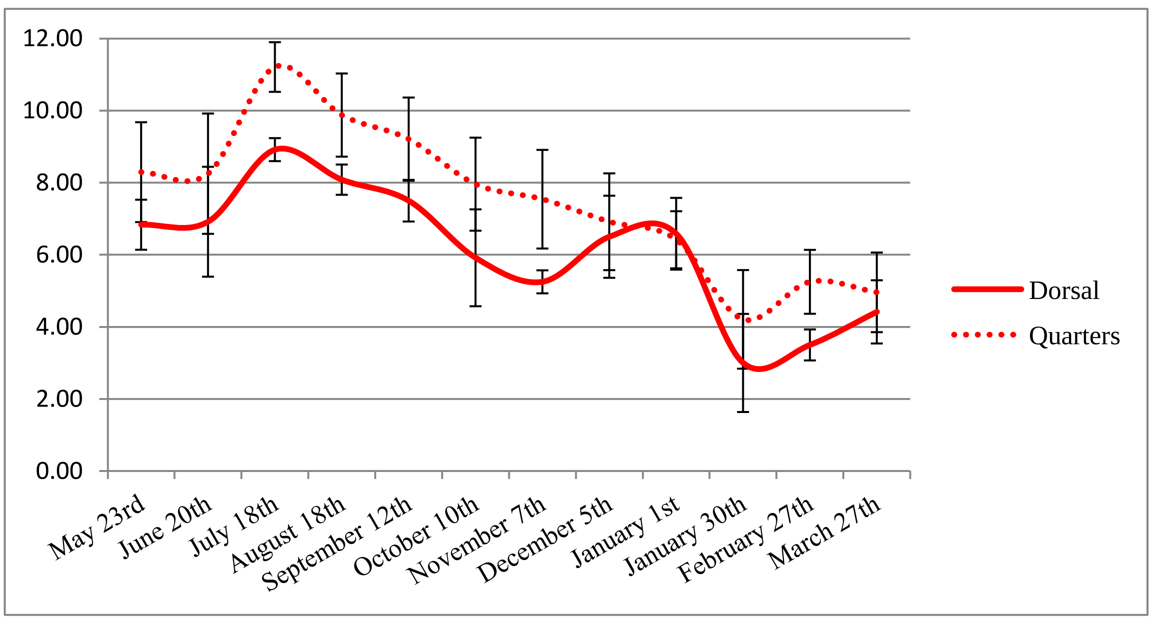
Laminitic dorsal & quarter growth

Laminitic dorsal and quarter growth

	Dorsal	S.D.	Quarters	S.D.
May 23rd	6.83	0.69	8.29	1.39
June 20th	6.92	1.52	8.29	1.67
July 18th *	7.63	0.80	11.21	0.47
August 15th	8.08	0.77	9.88	0.74
September 12th	7.05	0.58	9.21	0.60
October 10th	5.92	0.25	7.96	1.29
November 7th	5.25	0.32	7.54	1.37
December 5th	6.50	1.14	6.92	1.34
January 1st	6.58	1.00	6.42	0.79
January 30th	3.00	1.36	4.21	1.37
February 27th	3.50	0.43	5.25	0.89
March 27th	4.42	0.88	4.96	1.10



Graph of laminitic dorsal and quarter growth

A comparison of rates of growth between the dorsal and quarter regions in the laminitic group revealed the laminitic quarters to be growing at a faster rate than the dorsal surface by a

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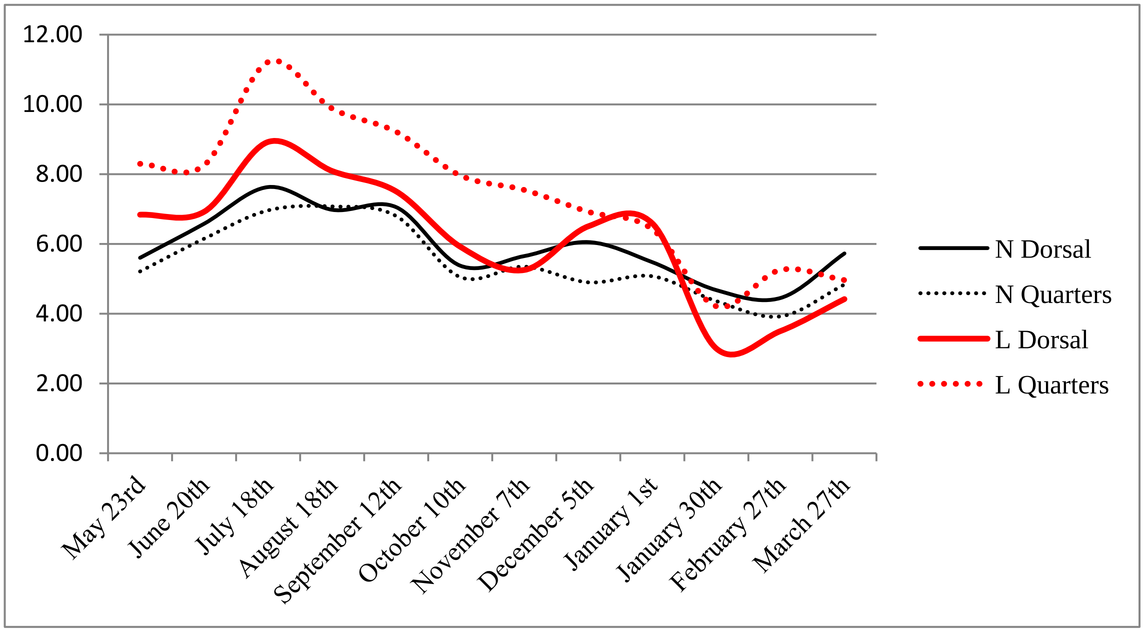
statistically significant amount ($p<0.05$) during the period of maximum differential hoof growth from May 23rd to September 12th.

119 **Comparison between normal and laminitic dorsal & quarter growth**

Normal & laminitic dorsal and quarter growth

	Normal		Laminitic	
	Dorsal	Quarters	Dorsal	Quarters
May 23rd	5.60	5.21	6.83	8.29
June 20th	6.58	6.15	6.92	8.29
July 18th	7.63	6.96	7.63	11.21
August 15th	6.98	7.08	8.08	9.88
September 12th	7.05	6.80	7.05	9.21
October 10th	5.38	5.05	5.92	7.96
November 7th	5.65	5.35	5.25	7.54
December 5th	6.05	4.90	6.50	6.92
January 1st	4.68	5.08	6.58	6.42
January 30th	4.45	4.36	3.00	4.21
February 27th	4.45	3.93	3.50	5.25
March 27th	5.73	4.84	4.42	4.96
Total growth	70.20	65.70	71.68	90.13



Comparison of normal & laminitic dorsal and quarter growth

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Comparisons between normal and laminitic growth revealed a significant variation in growth at the quarters of the laminitic group (p< =0.05), while laminitic growth at the dorsal surface was not significantly different to the normal group. This indicates that chronic laminitic hoof growth is not a reduction of growth at the dorsal surface but acceleration at the quarters.

Discussion

Normal hoof growth shows a seasonal variation between summer and winter, with faster growth being recorded during the summer months and the slowest during the winter months. The need for a greater rate of hoof growth during the summer period could be attributed to the harder and more abrasive ground conditions found at this time of year. During the winter months the ground conditions would be wetter, softer or even snow covered, which would be less abrasive to the hoof capsule, thus the rates of hoof growth recorded would match the seasonal demands of the horse's environmental conditions. The seasonal growth pattern presented here is confirmed by similar the results obtained in hoof growth measured by Frackowiak & Komosa (Frackowiak H 2006). Slower growth at the quarters in the normal group should be viewed as a normal feature which induces the hoof capsule to curve in a similar way to claws in other mammals and would add structural strength to the hoof capsule; it also shows that the normal equine foot has the capacity to naturally grow horn at differential rates.

Laminitic hoof also shows a similar seasonal variation but with much faster growth rates during the peak growth period in the summer months, returning to a similar rate to the normal group in the winter months. This seasonal variation in abnormal growth coincides with the seasonal incidence of laminitis reported by Luthersson (Luthersson N 2016). The comparison of growth rates between normal and laminitic hooves revealed a statistically significant pattern ($p<0.05$) of accelerated growth at the quarters in the laminitic hooves during the periods of maximum growth. The accelerated pattern of growth seen in laminitic hooves explains why growth rings are observed to be divergent at the quarters when compared to normal hooves as illustrated in the photo of a chronic laminitic hoof (Fig. 2).

The contrasting patterns of hoof growth between normal and laminitic quarters raises the questions of when in the progression of this disease does the transition from normal to laminitic hoof growth take place and what initiated this change? These are crucial questions which have not previously been addressed; hoof distortion has traditionally been associated with the post acute stages of laminitis, probably because it's clearly visible by this stage. It has been hypothesised that the trauma of the acute phase and subsequent movement of the distal phalanx causes the dorsal hoof capsule to grow abnormally slow at the dorsal surface, this is probably true in foundered cases where the dorsal coronary corium becomes compressed by the prolapsed distal phalanx, but many laminitis cases do not founder and the results of this study clearly shows horn growth at the dorsal surface in non foundered laminitic hooves to be comparable to normal rates.

The transition in growth rates from a normal to laminitic pattern will act on the whole hoof capsule due to the rigid nature of mature horn (Thomason J J 1992) and (Douglas J E 1996), faster growth rates in the quarters will cause the existing hoof capsule to be deflected forward at a similar rate to the increase of rate of growth at the quarters over the dorsal area, this forward movement places forces of extension onto the distal dorsal laminal structures, which subsequently becomes visible as a distended 'laminar wedge' several months later (Fig. 3). The highest rate of differential laminitic growth was recorded on the 18 July (* Laminitic dorsal and

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quarter growth), when dorsal hoof growth was 7.63mm while growth at the quarters was11.21mm, resulting in the quarters growing 3.58mm faster for the period or 0.12 mm faster per day. Forward deflection of the hoof capsule calculated with these values would result in the distal dorsal wall being displaced by 0.48mm within four days of the commencement of abnormal growth and 3.58mm after 28 days, (Table 3).

Day	Forward deflection of the distal dorsal hoof wall
1	0.12mm
2	0.24mm
3	0.36mm
4	0.48mm
......28	3.58mm

Table 3, Deflection of the hoof capsule as a result of differential hoof wall growth

Fig 2, A chronic laminitic hoof with a dark stripe which highlights the forward displacement of the distal hoof capsule and also illustrating diverging hoof growth at the quarters, (Photo Credit: T P Ryan).

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The link between endocrine diseases and laminitis has been recognised for some time, but how these diseases lead to laminal failure has been difficult to explain, the possibility arises that diseases or events that are known to be associated with laminitis as summarised by Katz (Katz and Bailey 2012) could be influencing the way normal hoof grows and initiating faster hoof growth at the quarters. In a recent study, a correlation between dorsal hoof wall curvature and cell proliferation in epidermal papillae at the quarters was revealed, indicating that there may be a difference in the overall growth rate between the various capsular shapes. Further analysis showed that there was a regional variation of cell proliferation between the epidermal dorsal and quarter coronary regions. Cell proliferation increased at the quarters as a function of the hoof curvature (i.e. for dished hooves) but no variations were noticed at the dorsal regions whatever the dorsal curvatures involved. The same study also measured the fluorescence intensity of the cell proliferation marker Ki-67 and cytokeratin protein K14, which revealed clear response with an increased expression of Ki-67 and K14, as a function of time and insulin concentrations (Al-Agele 2018).

Hoof capsule distortion has the capacity to cause direct physical injury to the underlying laminal structures, observations during experimentally induced laminitis by insulin infusion has shown the secondary epidermal laminae to be lengthened, attenuated with pointed tips within 48 hours of the induction of laminitis (Laat de M. A. 2010), these observations would also be consistent with the forward movement of the dorsal hoof capsule stretching the secondary epidermal laminae. The pursuit by research for an explanation for the failure of the laminal bond during an episode of experimentally induced laminitis has primarily been based on insult within the cells which form the dermal laminae and has not recognised that there may be other pathways that could cause the same level of injury.

The distended laminae on the solar surface which subsequently becomes visible are effectively mapping the movement of the hoof capsule as it distorts around the distal phalanx (Fig. 3). The full extent of hoof capsule distortion is often disguised by corrective farriery where the concave dorsal surface is rasped back to a straight profile.

Fig 3, Distorted hoof capsule and 'stretched' laminar wedge, (Photo Credit: T P Ryan).

If abnormal hoof growth can be shown to commence early in the developmental phase then a new explanation for laminar destruction becomes possible, caused merely by hoof capsule distortion. The earliest stages of hoof capsule distortion would commence at the distal border of the dorsal hoof wall, as the dorsal wall becomes elevated it would traumatise the underlying laminal bond, exerting a peeling effect on the dorsal laminae, distortion would progress in a proximad direction up the dorsal laminal bond. If laminal destruction is extensive this would lead to prolapse of the distal phalanx. Laminae can withstand huge forces when uniformly applied over its entire surface but is vulnerable to separation by peeling, this vulnerability has been demonstrated during surgical procedures for the removal of keratoma (Honnas 1997) and in the removal of portions of the dorsal hoof wall to examine how the foot recovers after laminitis (Pollitt C. C. 2004). By proposing that the commencement of abnormal growth occurs before the acute phase a new and viable biomechanical aetiology for equine laminitis becomes possible, one in which the laminae are merely victims of abnormally rapid hoof growth at the quarters which causes a change in the orientation of the distal hoof capsule, this alone has the capacity to have a devastating affect on the structures which form the laminal bond in the dorsal hoof wall.

Conclusions

This review of the hoof growth data confirms that normal hoof growth is seasonal and also highlights the difference between laminitic and normal hoof growth. That chronic laminitic hoof growth is not a reduction of growth at the dorsal surface but an abnormal increase at the quarters.

The commencement of abnormal hoof growth has previously been assumed to occur after the acute phase; however this has never been established, a biomechanical aetiology for equine laminitis involves a simple re-evaluation of the events that are known to take place during an episode of acute laminitis. The hoof wall has previously been considered to be inert during laminitis and therefore has been overlooked as a possible antagonist, the fact that it is intimately connected with the dermal laminae has previously been considered unimportant but its close proximity to the site of injury indicates that the external hoof wall should not be excluded from future investigation.

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