ABSTRACT

Poor limb conformation in cattle is believed to be closely associated with claw and limb disorders. Limb conformation is part of genetic evaluation and is assessed visually. In this descriptive study, the assessment of conformation in calves was evaluated objectively using joint angle measurements. A total of 100, 30- to 90-d-old, heifer calves of the Brown Swiss (n = 50) and Holstein (n = 50) breeds were photographed from both sides and the front and rear. Carpal, tarsal, autopodium and fetlock joint angles of the fore- or hind limbs were measured on the images using anatomic reference points and the ImageJ/Fiji® program. Each angle was measured 3 times, and the mean was used for analysis. Values from both sides were pooled. Deviations from defined standard angles were classified as slight or moderate. The positions of the front and hind feet were measured and scored. On average, the calves had moderate “knock-kneed” carpal conformation, and the autopodium of the front limb had a slight lateral deviation. In the rear view, the calves had slight, but close to moderate, “cow-hocked” tarsal conformation, and the autopodium of the hind limbs was parallel, but close to slightly deviated. Holstein calves were moderately, and Brown Swiss calves were slightly “cow-hocked”. A moderate lateral deviation occurred in the metacarpal-digit angle in the front view and a slight lateral deviation occurred in the metatarsal-digit angle in the rear view. The front feet position score was >17° in 69% of the calves, and the hind feet position score was <17° in 90% of the calves. In the side views, the calves were slightly “over at the carpus” and slightly “straight-hocked” and had average fetlock conformation.

In the mean values, most measured joint angles did not correspond to the straight or parallel classifications in our calves; moderate „knock-kneed“ and slight „cow-hocked“, and “toed-out” classifications were most common. The limb angles measured were based on anatomical features and therefore are unlikely to change substantially with increasing age. These aspects should be considered when assessing linear traits and investigating the relationship between limb conformation and claw diseases.

Keywords: Calf, limb angle measurement, „knock-kneed“, „cow-hocked“ conformation

INTRODUCTION

The high prevalence of lameness in dairy cows has a substantial negative effect on their well-being and longevity (EFSA et al., 2023, O'Connor et al., 2023, Thomsen et al., 2023). Selective breeding has long been used in an attempt to improve claw and limb health in dairy cows (Ødegård et al., 2015, Heringstad et al., 2018). However, the prevalence of lameness has continued to increase in parallel with milk production (Distl, 1995, Kolbaum et al., 2023).

A strong relationship is thought to exist between undesired limb conformation, particularly cow-hocked posture, and lameness (Boettcher et al., 1998, Capion et al., 2008, ICAR, 2023). Therefore, optimal limb conformation has traditionally been an important goal in linear assessment of breeding cattle. The criteria used worldwide for the assessment of limb conformation in cattle are similar (Brem, 1998, N.N., 2018, Anon., 2023, ICAR, 2023). Undesirable traits include bow-legged and „knock-kneed“ forelimbs, “bow-legged” and „cow-hocked“ hind limbs, “straight” and “sickled” hind limbs, and low and steep foot angles. Limb conformation is based on visual assessment using linear descriptive traits, but evaluations based on measurements of joint angles are rare in dairy cattle.

Fairly recent studies in calves have shown that deviations from optimal limb conformation appear to be common. According to a textbook, most calves have a mild carpal valgus deformity of approximately 7° (Desrochers et al., 2017). In a study of 712 calves ≤2 mo old, 82.3% were „cow-hocked“ (Capion and Nielsen, 2017).
Walser et al.: Limb conformation measured

122 Holstein Friesian heifers in advanced pregnancy, 81% were „cow-hocked“ (Capion et al., 2008). Earlier investigators reported lower prevalences of „cow-hocked“ conformation in dairy cows (Distl, 1996, Haggman et al., 2013). Increased prevalences of “straight” (Distl, 1996, Haggman et al., 2013) or “sickle-hocked” conformation were also observed (Onyiro and Brotherstone, 2008, Ring et al., 2018). Limb conformation was shown to be affected by management factors; more calves kept on hard surfaces after 6 weeks of age had “straight-hocked” conformation than calves that were moved from a soft to a hard surface at 8 mo of age (Capion and Nielsen, 2017). However, another study found that “straight” tarsi were more common in cows on pasture than in cows housed in other systems (Onyiro and Brotherstone, 2008).

Holstein cows, but also cows of other breeds, tend to have toed-out hind feet (Onyiro and Brotherstone, 2008, Haggman et al., 2013, Ring et al., 2018), which has been associated with an increased load on the lateral claws, pain, and claw diseases in general (Toussaint Raven, 1973, van der Tol et al., 2004, Köck et al., 2024). A hind feet position score (HFPS) that estimated the position of both hind digits in relation to the midline of the cow’s body (Bulgarelli-Jiménez et al., 1996) had a sensitivity and specificity of 69.5% and 66.8%, respectively, for detecting lameness defined by a locomotion score ≥ 2 (Köck et al., 2024). A score of 1 (angle of 0° to < 17°) described a balanced heel height of both the medial and the lateral claw, whereas cows with scores of 2 (angle of 17 to 24°) and particularly 3 (angle of > 24°) were assumed to have a higher lateral claw heel and subsequently a higher risk of developing pressure-related claw horn disruption lesions.

Specific information in the literature regarding measurement techniques or optimum joint angles of the limbs of dairy cows is sparse (Herlin and Drevemo, 1997, Phillips and Morris, 2000, Pluk et al., 2012). Therefore, the primary goal of this study was to measure joint angles using anatomical reference points to quantify limb conformation. A secondary goal was to investigate the most common congenital limb position of cattle, and for this reason, the study focused on calves.

MATERIALS AND METHODS

Calves and digital photography

Based on an assumed prevalence of „cow-hocked“ conformation of 70% in dairy cows and a desired power of 90%, power analysis using epitools (https://epitools.ausvet.io/onemean) determined a sample size of a minimum of 81 calves. The calves were selected as convenient samples from herds of the respective breed organizations. A total of 100 heifer calves 58.3 ± 16.2 d of age (range, 30 to 90 d) were used; 50 were Brown Swiss from 3 herds and 50 were Holstein Friesian (42 Holstein and 8 Red Holstein) from one herd. They were kept in straw-bedded group pens or in individual hutches. All calves underwent a clinical examination, and only healthy calves were included in the study. The owners signed a consent form, and the study was approved by the veterinary authority of the canton of Zurich (number 004/20; 32085) with an assigned degree of severity of 0 (observational study, low stress). No calf was harmed during the study.

The limb angles were measured using digital photographs, which were taken in all herds under standardized conditions. The claws and hair coat were cleaned with a brush, and colored pieces of paper were temporarily glued to the hair over defined anatomical reference points. This allowed consistent positioning of the colored markers in all calves.

The pictures were taken with a Canon Eos 600 D and a 50 mm Canon objective (both Canon AG, Öto, Tokyo, Japan) mounted on a tripod (Manfrotto MK190XPRO4–3W XPRO Alu-Stativ, Videndum Media Solutions, Cassola, Italy). The distance from the camera to the joint under investigation was measured using a digital camera rangefinder (Bosch Zamo Typ 0603672400, Robert Bosch GmbH, Stuttgart, Germany).

For photography, the calves were positioned on a horizontal surface and restrained using a halter held by a trained handler. The distance from the camera to the calf was 5 m and from the calf to a wall in the background was 2 m (Figure 1). Ideally, the head of the calf was not supported by the handler, and the calf stood squarely on all 4 legs. Pictures were taken from both sides and from the front and rear. To score the foot position in the front and rear views, 2 wooden wedges were placed at the level of the fore-/hind limbs with attached metal hands indicating the orientation of the interdigital spaces (Figures 2, 3).

Determination of joint angles

Side view of the carpal joint. Three anatomical reference points were defined for measuring the angle of the carpal joint (Figure 1). The proximal point was at the level of the depression between the lateral epicondyle of the humerus and the tuberosity of the radius where the lateral collateral ligament of the elbow joint attaches. The reference point on the carpus was situated at the most lateral part of the joint region at the level of the accessory carpal bone. The reference point on the fetlock was at the level of the proximal border of the dew claw in the middle of the lateral side of the leg. The line connecting the radio-humeral and carpal reference points represented the radial arm of the lateral carpal joint angle, and the line connecting the carpal and the fetlock
reference points represented the metacarpal arm of the lateral carpal joint angle. The angle was measured on the dorsal aspect of the leg.

**Side view of the tarsal joint.** The proximal anatomical reference point was at the widest part of the stifle joint at the level of the insertion of the middle patellar ligament in the tibia, which was identified using the index and middle fingers and thumb. The middle reference point was at the widest part of the tarsus at the level of the medial malleolus (Figure 1). The reference point on the fetlock was at the level of the proximal border of the dew claw in the middle of the lateral side of the leg, similar to the forelimb. The line connecting the stifle and tarsal reference points represented the tibial arm of the lateral tarsal joint angle, and the line connecting the tarsal and fetlock reference points represented the metatarsal arm of the lateral tarsal joint angle. The angle was measured on the dorsal aspect of the leg (Figure 1).

**Side view of the fetlock joint.** For measurement of the lateral fetlock joint angle, the previously described metacarpal/metatarsal lines were used as the proximal arm. A distal third reference point was created using ImageJ/Fiji, which generated a line along the lateral claw running parallel to the coronet. The middle of this line represented the distal reference point. The line connecting the reference points at the fetlock and at the coronet represented the phalangeal arm of the fetlock joint angle, which was measured on the dorsal aspect of the leg (Figure 1).

**Front view of the carpal joint angle.** The proximal reference point was the cephalic vein at the level of the lateral radial tuberosity where the collateral ligament attaches (Figure 2). The middle reference point was the tendon of the radial extensor muscle of the carpus at the level of the accessory carpal bone. The distal reference point was the dorsal end of the interdigital space.

The line connecting the proximal and middle reference points represented the radial arm of the carpal joint angle, and the line connecting the middle and distal reference points represented the autopodial arm (autopodium = carpal joint, metacarpus and digits) of the carpal joint...
The carpal joint angle was measured on the medial aspect of the leg (Figure 2).

Tarsal joint rear view. The middle reference point was the calcaneal tuberosity. No proximal reference point was selected but instead a straight line was drawn along the middle of the Achilles tendon to the stifle region. The distal reference point was in the middle of the digital axis at the transition from skin to horn tissue at the plantar end of the interdigital space. The tarsal joint angle was measured on the medial aspect of the leg.

Angle between the autopodium of the fore- and hind limbs and the ground surface. For determining the angle of the autopodium (i.e., the axis of the carpus/tarsus-metacarpus/metatarsus-digits) to the ground surface, the deviation of the front or hind feet from a vertical line drawn from the middle reference point of the carpus or tarsus to the ground surface was measured. Fiji/ImageJ was used to draw a horizontal line on the ground surface (Figure 2 and 3). The deviation of the autopodia from a vertical line was defined by a line from the middle reference point to the interdigital space, and the angle was measured on the lateral aspect at the intersection of this line with the horizontal line on the ground.

Angle between the metapodium axis and the digit axis. The autopodium axis of the front limbs was further divided into a metacarpal arm and a digit arm, resulting in a metacarpal-digit angle in the frontal view. The proximal reference point for this angle was the reference point on the cranial aspect of the carpus. The middle of a horizontal line drawn at the level of the metacarpal physis served as the middle reference point (Figure 4). The distal reference point was located on the dorsal aspect.
and in the middle of the start of the interdigital space. The line between the proximal and middle reference points represented the metacarpal part of the metacarpal-digit angle. The line between the middle and distal reference points represented the phalangeal part of the metacarpal-digit angle. The angle between both lines was measured on the medial side.

In the hind limbs, the metatarsal-digit angle was measured similarly. The midway point of the rear view tarsal joint angle at the calcanean tuber served as the proximal reference point. The middle of a horizontal line drawn at the level of the 2 dew claws represented the middle reference point (Figure 4). The distal reference point was on the plantar aspect and in the middle of the start of the interdigital space. The line between the proximal and middle reference points represented the metatarsal part of the rear view metatarsal-digit angle. The line between the middle and distal reference points was the phalangeal part of this angle. The angle between both lines was measured on the medial side.

Measurement of joint angles and assessment of feet position. For measurement of the joint angles, the pictures from both sides and from the front and rear of the calves were imported into the ImageJ/Fiji program (Java 18.0_172 [64-bit], v1.53f51). Lines were drawn digitally between the colored reference points, and the calculated angles were recorded. Some angles could not be calculated in 100 calves (Tab. 3) because the colored pieces of paper on the anatomical reference points had fallen off or could not be seen clearly enough on the photographs. Each joint angle was measured 3 times, and the calculated average was used for analysis. Angles of corresponding joints were measured on both sides of the calves, and the means for the left and right sides were pooled for analysis.

Five criteria were used for the classification of limb conformation. In addition to an “optimal” value (score 3, also: standard/average, straight, parallel or vertical), there were 2 scores (1, 2 and 4, 5) for opposite divergences that deviated slightly or moderately from score 3 (Table 1).

To determine the FFPS and HFPS, the direction of the metal hands relative to the line on the ground surface (yellow line in Figure 2 and 3) was quantified using a digital protractor (Measurist app® for Mac, Takuto Nakakamura) and entered into a scoring system (Bulgarelli-Jiménez et al., 1996).

The measured joint angles were divided into 5 categories (Table 2) corresponding to the definitions in Table 1 to facilitate the allocation of the calves to different classifications. A value of 180° with a tolerance of ± 3° was set as the ideal angle for the carpal joint in front
RESULTS

Joint angles

The carpal joint angle in side view (ideal value 177–183°) was a mean of 183.1° (SE 0.3, range 175.7 to 195.2°, Table 1). The mean overall forelimb conformation was therefore considered slightly “over at the carpus” (Table 2, 3). The tarsal joint angle in side view (ideal value 150°) was a mean of 153.3° (SE 0.4, range 144.7 to 167.9°). The mean overall tarsal joint conformation was therefore considered slightly straight.

The fetlock joint angle of the forelimbs in side view (standard value 90 ± 3°) was a mean of 96.8° (SE 0.3, range 91.2 to 105.6°), which corresponded to an average conformation (Table 2). The fetlock joint angle of the hind limbs in side view (ideal value 161°) was a mean of 161.4° (SE 0.4, range 152.7 to 171.5°), which was also considered an average conformation.

The carpal joint angle in front view (ideal value 177–183°) was a mean of 191.9° (SE 0.2, range 186.7 to 196.8°). This corresponded to the moderately „knock-kneed“ classification. None of the 91/100 measured calves had a straight classification; 11 were slightly „knock-kneed“ and 80 were moderately „knock-kneed“ (Table 3). Thus, the latter was the predominant forelimb conformation in our sample of calves.

The autopodium angle of the front feet in front view (ideal value 90 ± 3°) was a mean of 96.8° (SE 0.3, range 91.2° to 105.6°), which was a slight lateral deviation (Table 3). Seven of 99 calves had straight front autopodium conformation, 74 had slight lateral deviation, and 18 had moderate lateral deviation.

The tarsal joint angle in rear view (straight angle 180 ± 3°) was a mean of 188.7° (SE 0.5, range 179.3° to 204.6°), which corresponded to slightly „cow-hocked“ but was close to moderately „cow-hocked“ (>189°). According to the measurements of this angle, 11 calves had

Table 1. Classification of limb conformation

<table>
<thead>
<tr>
<th>Limb angle/position</th>
<th>1 moderate</th>
<th>2 slight</th>
<th>3 optimal</th>
<th>4 slight</th>
<th>5 moderate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpal joint; Side view</td>
<td>Back at the carpus</td>
<td>Back at the carpus</td>
<td>straight</td>
<td>Over at the carpus</td>
<td>Over at the carpus</td>
</tr>
<tr>
<td>Tarsal joint;</td>
<td>Sickle-hocked</td>
<td>Sickle-hocked</td>
<td>standard/average</td>
<td>Straight</td>
<td>Straight</td>
</tr>
<tr>
<td>Fetlock joint; Side view</td>
<td>Low</td>
<td>Low</td>
<td>standard/average</td>
<td>Steep</td>
<td>Steep</td>
</tr>
<tr>
<td>Carpal/tarsal joint;</td>
<td>Bow-legged</td>
<td>Bow-legged</td>
<td>straight/vertical</td>
<td>knock-kneed, cow-hocked</td>
<td>knock-kneed, cow-hocked</td>
</tr>
<tr>
<td>Front/rear view</td>
<td>Medial deviation</td>
<td>Medial deviation</td>
<td>vertical</td>
<td>Lateral deviation</td>
<td>Lateral deviation</td>
</tr>
<tr>
<td>Autopodium;</td>
<td>Medial deviation</td>
<td>Medial deviation</td>
<td>straight</td>
<td>Lateral deviation</td>
<td>Lateral deviation</td>
</tr>
<tr>
<td>Metapodium-digit;</td>
<td>Medial deviation</td>
<td>Medial deviation</td>
<td>straight/parallel</td>
<td>Toed-out</td>
<td>Toed-out</td>
</tr>
<tr>
<td>Front or rear view</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fore-/hind limb position</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(FFPS, HFPS); Front/rear view</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
parallel hind legs, 48 were slightly „cow-hocked“, and 41 were moderately „cow-hocked“.

The autopodium angle of the hind feet in rear view (ideal value 90 ± 3°) was a mean of 93.0° (SE 0.3, range 87.0 to 102.9°), which was in the parallel classification but close to the slight lateral deviation classification (Table 1 and 2). The metapodium-digit angles showed moderate lateral deviation in the front limbs and slight lateral deviation in the hind limbs (Table 3).

The pooled FFPS was a mean of 20.6° and clearly deviated from the ideal value of < 17° (Table 3). Thirty-one of 100 calves had an FFPS of < 17°. The mean HFPS was 8.6°; 90 of 100 calves had a score of < 17°.

Effect of age on conformation
Age had a minor effect on joint angles. The prevalence of „cow-hocked“ conformation tended (p < 0.07) to increase with increasing age of the calves. The tarsal joint angle viewed from the side became straighter with increasing age of the calves (p < 0.05); however, the increase was small and did not appear to be clinically significant. Metapodium-digit angles and FFPS and HFPS did not increase with increasing age.

### Table 2. Classification of joint angles below and above the optimal value (in bold). The definitions of the 5 classes are shown in Table 1

<table>
<thead>
<tr>
<th>Limb angle</th>
<th>1 moderate</th>
<th>2 slight</th>
<th>3 optimal</th>
<th>4 slight</th>
<th>5 moderate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpal joint side view</td>
<td>&lt;171°</td>
<td>171–176.9°</td>
<td>177–183° (180°)</td>
<td>183.1–189°</td>
<td>&gt;189°</td>
</tr>
<tr>
<td>Tarsal joint side view</td>
<td>&lt;141°</td>
<td>141–146.9°</td>
<td>147–153° (150°)</td>
<td>153.1–159°</td>
<td>&gt;159°</td>
</tr>
<tr>
<td>Fetlock joint, forelimbs side view</td>
<td>&lt;152°</td>
<td>152–157.9°</td>
<td>158–164° (161°)</td>
<td>164.1–170°</td>
<td>&gt;170°</td>
</tr>
<tr>
<td>Fetlock joint, hind limbs side view</td>
<td>&lt;152°</td>
<td>152–157.9°</td>
<td>158–164° (161°)</td>
<td>164.1–170°</td>
<td>&gt;170°</td>
</tr>
<tr>
<td>Carpal joint front view</td>
<td>&lt;171°</td>
<td>171–176.9°</td>
<td>177–183° (180°)</td>
<td>183.1–189°</td>
<td>&gt;189°</td>
</tr>
<tr>
<td>Autopodium front or rear view</td>
<td>&lt;81°</td>
<td>81–86.9°</td>
<td>87–93° (90°)</td>
<td>93.1–99°</td>
<td>&gt;99°</td>
</tr>
<tr>
<td>Tarsal joint rear view</td>
<td>&lt;171°</td>
<td>171–176.9°</td>
<td>177–183° (180°)</td>
<td>183.1–189°</td>
<td>&gt;189°</td>
</tr>
<tr>
<td>Metapodium-digit front or rear view</td>
<td>&lt;171°</td>
<td>171–176.9°</td>
<td>177–183° (180°)</td>
<td>183.1–189°</td>
<td>&gt;189°</td>
</tr>
</tbody>
</table>

### Table 3. Joint angles (°, mean, standard error, minimum, maximum) and feet position scores measured in digital pictures of standing calves. The mean values for the left and right corresponding joints were pooled

<table>
<thead>
<tr>
<th>Angle/position</th>
<th>Ideal angle</th>
<th>Mean</th>
<th>Standard error</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpal joint, side view (n = 98)</td>
<td>180° (177–183°)</td>
<td>183.1°</td>
<td>0.3</td>
<td>175.7</td>
<td>195.2</td>
<td>Slightly over at the carpus</td>
</tr>
<tr>
<td>Tarsal joint, side view (n = 95)</td>
<td>150° (147–153°)</td>
<td>153.3°</td>
<td>0.4</td>
<td>144.7</td>
<td>167.9</td>
<td>Slightly straight</td>
</tr>
<tr>
<td>Front fetlock joint, side view (n = 98)</td>
<td>161° (158–164°)</td>
<td>161.5°</td>
<td>0.4</td>
<td>152.4</td>
<td>176.1</td>
<td>Standard</td>
</tr>
<tr>
<td>Hind fetlock joint, side view (n = 99)</td>
<td>161° (158–164°)</td>
<td>161.4°</td>
<td>0.4</td>
<td>152.7</td>
<td>171.5</td>
<td>Standard</td>
</tr>
<tr>
<td>Carpal joint, front view (n = 91)</td>
<td>180° (177–183°)</td>
<td>191.9°</td>
<td>0.2</td>
<td>186.7</td>
<td>196.8</td>
<td>Moderately knock-kneed</td>
</tr>
<tr>
<td>Autopodium front, frontal view (n = 99)</td>
<td>90° (87–93°)</td>
<td>96.8°</td>
<td>0.3</td>
<td>91.2</td>
<td>105.6</td>
<td>Slight abduction</td>
</tr>
<tr>
<td>Metacarpal-digit angle (n = 99)</td>
<td>180° (177–183°)</td>
<td>192.4°</td>
<td>0.4</td>
<td>183.2</td>
<td>202.8</td>
<td>moderate lateral deviation</td>
</tr>
<tr>
<td>Tarsal joint angle, rear view (n = 100)</td>
<td>180° (177–183°)</td>
<td>188.7°</td>
<td>0.5</td>
<td>179.3</td>
<td>204.6</td>
<td>Slightly cow-hocked</td>
</tr>
<tr>
<td>Autopodium hind feet, rear view (n = 100)</td>
<td>90° (87–93°)</td>
<td>93.0°</td>
<td>0.3</td>
<td>87</td>
<td>102.9</td>
<td>vertical</td>
</tr>
<tr>
<td>Metatarsal-digit angle, rear view (n = 100)</td>
<td>180° (177–183°)</td>
<td>186.9°</td>
<td>0.4</td>
<td>177.4</td>
<td>197.6</td>
<td>Slight lateral deviation</td>
</tr>
<tr>
<td>Front feet position score (n = 100)</td>
<td>&lt;17°</td>
<td>20.7°</td>
<td>0.6</td>
<td>5.5</td>
<td>29.0</td>
<td>Score 2</td>
</tr>
<tr>
<td>Hind feet position score (n = 100)</td>
<td>&lt;17°</td>
<td>8.6°</td>
<td>0.6</td>
<td>0.5</td>
<td>29.0</td>
<td>Score 1</td>
</tr>
</tbody>
</table>
**Effect of breed on conformation**

The 2 breeds did not differ with respect to the front view carpal joint angle and the front view autopodium angle of the front feet; all the calves tended to have the same degree of “knock-kneed” conformation and none of the calves had “straight” conformation.

Brown Swiss calves were more frequently ($P < 0.01$) slightly “over at the carpus” than Holstein calves, and Brown Swiss calves had straighter tarsal joint angles ($P < 0.05$) and steeper fetlock joint angles in the hind feet ($P < 0.05$) than Holstein calves.

The 2 breeds differed significantly ($P < 0.01$) with respect to the tarsal angle in the rear view. On average, Brown Swiss calves were slightly “cow-hocked” (mean 186.8°, SE 0.7) and Holstein calves were moderately “cow-hocked” (mean 190.6°, SE 0.7). Likewise, the hind leg autopodium angles of the Holstein calves were significantly larger than those of the Brown Swiss calves ($p < 0.01$). The metapodium-digit angles were also significantly different, whereby a significantly larger angle occurred in the front limbs of Brown Swiss calves and in the hind limbs of Holstein calves.

With respect to the FFPS and HFPS, Brown Swiss calves were significantly ($P < 0.01$) more toed-out in the front feet (mean 23.1°, SE 0.8 vs. mean 18.3°, SE 0.8) and significantly less toed-out in the hind feet (mean 6.7°, SE 0.8 vs. mean 10.6°, SE 0.8; $P < 0.01$).

**DISCUSSION**

The ability to quantify limb conformation in dairy cows may be advantageous for calculating linear traits. Considering the increasing use of automation in dairy farming, it is likely that locomotion and lameness monitoring will soon be automated using artificial intelligence techniques (Russello et al., 2022, Sahar et al., 2022, Nejati et al., 2023). Knowing the standard angulation of limb joints is therefore important. In addition, quantifying limb conformation has possible practical and clinical implications for claw trimming.

The present study attempted to objectively evaluate limb conformation by using joint angle measurements based on defined anatomical landmarks. However, the development of a practical tool for the objective evaluation of linear traits was not a goal. The anatomical reference points could be reliably identified in all calves regardless of body size. Standard or average joint angle measurements from the literature were used for reference when available, and ideal angles were otherwise proposed. For instance, the ideal angle for straight or parallel legs in front and rear view was set at 180 ± 3°, and the angle of the autopodium to the ground at 90 ± 3°. A tolerance of ± 3° was used for all angles because visual assessment of linear type traits requires some flexibility. Rotation of the limb axis or the effect of weight bearing on the angulation (e.g., 3-dimensional measures) could not be correctly assessed by our 2-D limb angle measurements.

The principal finding of our study was the observation that moderate „knock-kneed“ conformation of the forelimbs and slight „cow-hocked“ conformation of the hind limbs was most common; no calves had straight front legs in front view and only 12.1% had parallel hind limbs in rear view. Moreover, the mean tarsal joint angle (188.7°) in the rear leg rear view was close to the cut-off value (189°) for the moderately „cow-hocked“ classification. Therefore, the vast majority of the calves did not have the desired ideal limb conformation i.e., straight or parallel.

In our opinion, the limb conformations in our calves should be considered inborn because they are based on characteristic anatomical features in cattle. These anatomical features and their development during later life have not received much attention in research, which shows that basic anatomical knowledge is still needed.

We also hypothesized that the pronounced congenital outward rotation of the front feet plays a role in the development of corkscrew claw syndrome (Cook et al., 2019, Capion et al., 2024) of the medial claw of the forelimbs. This is especially applicable to cows standing in head gates, where outward rotation of the front limbs is increased; this results in overloading of the heel and abaxial wall of the medial claw (Lüchinger et al., 2021), which then causes the latter to bend inwards toward the sole.

The toed-out position of the hind limbs also has an anatomical basis; flexion of the stifles and tarsal joints is associated with some degree of outward rotation so...
that the legs can be advanced along the trunk (Reinsfeld, 1932, Hagenbuch, 1938, Schmid et al., 2009). The outward rotation of the digits was less pronounced in the hind legs (HFPS <17°) compared with the front legs as well as the results of clinical examinations (Köck et al., 2024) suggesting that the asymmetry of the hind-limb increases with age because of housing conditions, and infrequent claw trimming.

The notion that „cow-hocked“ conformation appears to be most common in calves and even in older cattle is supported by other studies (Capion et al., 2008, Capion and Nielsen, 2017). In one study, the majority (82.3%) of 122 Danish Holstein calves were born with „cow-hocked“ conformation that remained unchanged in the following 12 to 16 months; with increasing age, > 95% of these cattle were „cow-hocked“ (Capion and Nielsen, 2017). A significant age effect on conformation was not seen in the present study, most likely because the age range of the calves was too small, or, there is no age effect. Interestingly, „cow-hocked“ and “splay-footed” hind limb conformation have also been described in horses (Holmström and Back, 2013) and donkeys (Abdelgalil et al., 2018) at frequencies that led the authors to conclude that the condition should be considered “normal”.

The „cow-hocketed“ conformation of cows has been associated with lameness and claw horn lesions (van der Tol et al., 2004, Nuss et al., 2020). The toed-out conformation with a high HFPS (>17°) appears to have changed over time, most probably because of differences in measurement techniques. An angle ≥ 145° was considered normal in 1981, and > 160° was considered straight (Greenough et al., 1981). Measurements a few years later showed considerably straighter tarsal joint angles in dairy heifers (167.3°, mean; 0.7, standard error) (Vermunt and Greenough, 1996). National breed associations (https://www.nordicebv.info/wp-content/uploads/2015/05/Conformation_recording_pictures.pdf) defined the optimum tarsal angle as 150 to 155°, or published guidelines (160° = straight, 147° = intermediate, 134° = “sickle hocked”) (https://www.holstein-uk.org/media/legacyhw/Breeding%20for%20

According to our measurements, 69 of 100 calves had an FFPS of >17° and 90 of 100 calves had an HFPS < 17°. Another study that involved weight and pressure measurements of claw soles in dairy calves (Zimmermann et al., 2018) found that the medial front claws bore considerably higher loads than the lateral front claws (65.9 vs. 34.1%), whereas in the hind feet, the load distribution between the medial and lateral claws was similar but less pronounced (55.1 to 44.9%). This means that a distinctly uneven claw load distribution that puts a larger load on the lateral hind claw may only occur in older calves and adult cows. The toed-out conformation with a high FFPS (>17°) points to an uneven load distribution between the paired claws, which itself is thought to have a significant effect on the etiology of claw diseases (ICAR, 2023, Köck et al., 2024). A high HFPS was associated with increased lateral heel height and increased risk of developing lameness; a low score was linked to a balanced heel height in both the medial and lateral claws (Köck et al., 2024). However, functional foot trimming was only partially successful in establishing load balance between the paired hind claws in earlier studies (Kehler and Gerwing, 2004, van der Tol et al., 2004, Nuss et al., 2020). The observation that „cow-hocked“ conformation is most common for many cows nevertheless has practical implications for foot trimming. One goal of functional foot trimming is to establish a more parallel rear leg rear view; however, attempts to achieve this will be futile if the „cow-hocked“ conformation has a genetic anatomical basis. It is conceivable that there is some evidence that „cow-hocked“ conformation serves to offload the lateral claw (Toussaint Raven, 1973, Nuss et al., 2020) by shifting the load to the medial claw. At the phenotypic level, HFPS was found to be of limited value in identifying individual lame cows (Köck et al., 2024). Our measurements for determining feet position scores were in agreement with other authors (Köck et al., 2024) but only approximated the correct angles because only angles measured from a dorsal view would have been accurate.
HW/Breeding-Linear-Assessment.pdf) without elaborating on the measuring techniques. Target values for specific joint angles are no longer published in the guidelines for linear evaluation of dairy cows (ICAR, 2023).

We chose an age range of 30 to 90 d for the calves for 2 reasons. We assumed that after the first month of life, conformation features would be established, and therefore calves with congenital deformities such as contracted tendons (Sato et al., 2021) could be excluded from analysis. Calves older than 3 mo were excluded to avoid conformation traits caused by husbandry conditions. However, husbandry conditions such as hard and soft floor surfaces had no significant effect on the development of hind limb conformation (Capion and Nielsen, 2017). A large proportion of 712 Danish Holstein calves that were assessed periodically over several months (Capion and Nielsen, 2017) were “cow-hocked”, regardless of the type of floor surface. This observation and certain anatomical features of limb joints and bones suggest that limb conformation in cattle does not change fundamentally with increasing age. However, this notion suggests that limb conformation in cattle does not change substantially from birth to weaning (Robert et al., 2013).

Mature cattle above 3 years of age generally have moderate “knock-kneed” and slight “cow-hocked” conformation. The autopodium and the digits of the forelimbs had moderate lateral deviation, and those of the hind limbs had slight lateral deviation. We recommend that these apparent misalignments, which in fact appear to correspond to the anatomical features, be considered in the genetic evaluation of breeding animals or when investigating the relationship between limb conformation and lameness.

CONCLUSIONS

The most common findings in the calves of this study were moderate „knock-kneed“ and slight „cow-hocked“ conformations. The autopodium and the digits of the forelimbs had moderate lateral deviation, and those of the hind limbs had slight lateral deviation. We recommend that these apparent misalignments, which in fact appear to correspond to the anatomical features, be considered in the genetic evaluation of breeding animals or when investigating the relationship between limb conformation and lameness.

ACKNOWLEDGMENTS

The authors thank Laura Pieper for conducting the power analysis and Michael Haessig, Chris Winder and Ruedi Waechli for helpful comments. We also wish to thank Michelle Aimée-Oesch for helping with the photography, the agricultural technicians for assisting with the calves, and the participating herd owners for providing us with the calves. Lastly, we want to thank the reviewers for their valuable comments.

Conflict of interest statement: None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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