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The Effect of Joint Angle on Measurements of Equine Metacarpophalangeal Radiographs

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Abstract: Radiology is an important, minimally invasive, diagnostic tool used to identify and treat pathological cases. Metacarpophalangeal joint (MCPJ) radiographic parameters have been developed to evaluate equine MCPJ conformation, but the effect of MCPJ angle on these radiographic parameters has not been reported. This experiment was aimed at studying the effect of MCPJ angle on 27 (12 angular and 15 ratio) MCPJ parameters and also to determine the acceptable range at which minimal changes occurred in those parameters. Six forelimbs from six different horses with no MCPJ abnormalities or visible pathology were collected. Each MCPJ was positioned vertically and digitally radiographed dorsopalmarly at seven different MCPJ angles within the normal range and with 5.5° intervals. MCPJ angles were achieved by applying different loads using a load cell. All parameters were measured on the 42 radiographs using EponaTech Metron software. Differences were estimated per 5.5° change in MCPJ angle for all parameters. The ratio parameters were generally less affected than the angular parameters. The amount of change was small in the majority of the angular parameters and very small in all the ratio parameters. MCPJ angles ranging between 146° and 157° would be considered acceptable ranges for all these parameters.

Keywords: Equine, Metacarpophalangeal joint, Morphometry, Rotation, Radiographs.

تأثير الزاوية المشتركة على قياسات الصور الشعاعية السنعية السلامية للخيول

المستخلص: يعد الطب الإشعاعي أداة تشخيصية مهمة ذات تدخل جراحي بسيط تستخدم لتحديد الحالات المرضية وعلاجها. تم تطوير المعلمات الشعاعية للمفصل السنعي السلامي (MCPJ) لتقييم تشكيل MCPJ للخيول، ولكن لم يتم الإبلاغ عن تأثير زاوية MCPJ على مقاييس التصوير الشعاعي هذه. هدفت هذه التجربة إلى دراسة تأثير زاوية MCPJ على 27 معلمة (12 زاوية و15 نسبة) لـ MCPJ وأيضاً تحديد المدى المقبول الذي حدث عنده الحد الأدنى من التغييرات في تلك المعلمات. تم جمع ستة أطراف أمامية من ستة خيول مختلفة مع عدم وجود تشوهات MCPJ أو أمراض مرئية. تم وضع كل MCPJ عموديًا وتصويرًا إشعاعيًا رقميًا ظهرانيًا عند سبع زوايا MCPJ مختلفة ضمن النطاق الطبيعي وبفواصل زمنية قدرها 5.5 درجة. تم تحقيق زوايا MCPJ من خلال تطبيق أحمال مختلفة باستخدام خلية تحميل. تم قياس جميع المعلمات على الصور الشعاعية الـ 42 باستخدام برنامج EponaTech Metron. تم تقدير الاختلافات لكل تغيير قدره 5.5 درجة في زاوية MCPJ لجميع المعلمات. كانت معلمات النسبة بشكل عام أقل تأثراً من المعلمات الزاوية. كان مقدار التغيير صغيرًا في غالبية المعلمات الزاوية وصغيرًا جدًا في جميع معلمات النسبة. تعتبر زوايا MCPJ التي تتراوح بين 146 درجة و157 درجة نطاقات مقبولة لجميع هذه المعلمات.

الكلمات المفتاحية: الخيول، المفصل السنعي السلامي، القياس الشكلي، الدوران، صور الأشعة السينية.

INTRODUCTION

Radiography is an important technique in the diagnosis of musculoskeletal injuries. However, in terms of the morphometrical studies, the details of the bony feature might easily be altered due to the high sensitivity of the x-ray to any movement of the radiographic tools while the radiographs are being taken .Thus, in radiographic studies, a number of factors have been investigated for improving the accuracy of measurements, such as projection errors (Curry et al., 1990; Han et al., 1994; Lavin, 2007; Oheida et al., 2016; Walter & Davies, 2001), landmark identification (Chen et al., 2004; Nagasaka, 2003) and contrast of radiographs (Chen et al., 2000; Major et al., 1994).

Unlike most of the joints in the equine body, the angle of the metacarpophalangeal joint (MCPJ) was considered an additional factor that can affect its morphometrical measurements. MCPJ is a hinge joint that is able to flex and extend on its horizontal axis (Dyce et al., 2002; Sisson & Grossman, 1975). The joint angle varies in normal horses, with a reported range of its dorsal extension between 135° and 168° (Holmstrom et al., 1990; Weller et al., 2006). This range was reported to be affected by a number of factors, such as the hoof angle (Bushe et al., 1988; Rooney, 1984) and the uneven distribution of the body weight on the limbs (Denoix et al., 1996). Although the effect of joint angles on radiographic measurements was evaluated and considered as a source of measurement errors in different fields (Lonner et al., 1996; Meijer et al., 2016; Sun et al., 2021), the influence of the MCPJ angle on its radiographic measurements was not investigated. This means that unless the possible effects of such variations in angle were precisely evaluated and understood, MCPJ measurements may have only limited application in the veterinary field.

In dorsopalmar radiographs, the radiographic measurements could be affected by moving the object around its vertical and horizontal axes (Major et al., 1996) but not around its sagittal axis (Ahlqvist et al., (1983; Yoon et al., 2002). The effect of rotation of the MCPJ around its vertical axis on the radiographic parameters has been evaluated in a recent study (Alrtib et al., 2023), but there is no information about the effect of the rotated joint around the horizontal axis. When the joint was loaded, the joint angle changed due to its dorsal extension, which occurred by moving the bones around the horizontal axis of the joint. Accordingly, any changes in radiographic measurements of MCPJ should be interpreted based on the concept of the association between landmarks of the parameters and the rotation around the horizontal axis.

The hypothesis of this study was that changes in the MCPJ angle of horses would affect its radiographic parameters. If so, then was there a limited range of joint angles at which the measurements presented the lowest level of alterations. Therefore, the current study was first aimed at identifying the potential effect of the MCPJ angle on its measurements using dorsopalmar (DP) radiographs. Secondly, to determine an acceptable range of the joint angle at which a minimal amount of change occurred on the parameters.

MATERIALS AND METHODS

Animals

Six (three right and three left) distal forelimbs of six different adult horses were used. Their ages ranged between 7 and 21 years old. The horses had a normal body conformation and were euthanized or died for reasons not associated with the locomotor apparatus. All the forelimbs were collected from the Pathology department, Department of Veterinary BioSciences, The University of Melbourne. The forelimbs were cut at the distal third of the radius.

Preparation of the forelimbs

Each forelimb was set in a load cell in order to get different MCPJ angles. The hoof of the forelimb was rested on the cell base against a V-shaped cut that was made on the Perspex plate to avoid the hoof sliding during loading. The upper part of the limb was fixed into an aluminum cup using fasteners (Figure 1).

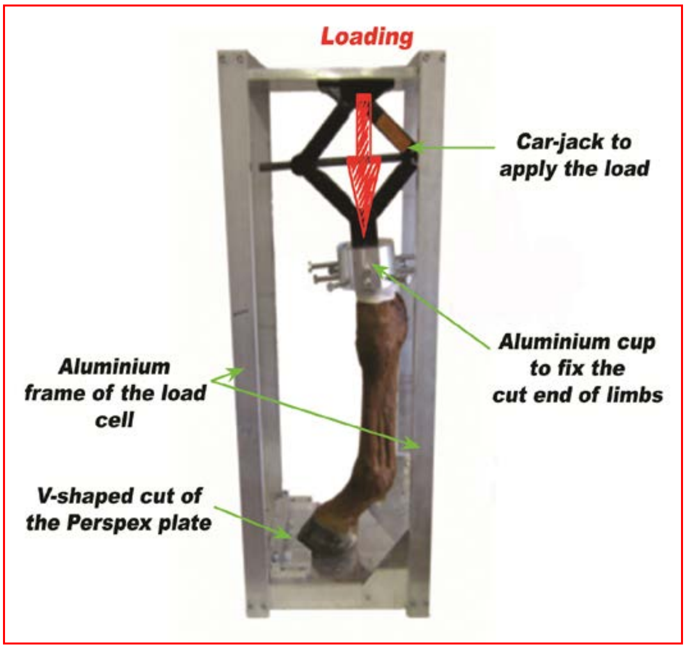

Figure: (1). Installing and loading a horse limb in the load cell.

Limb loading and MCPJ angle

The MCPJ of the installed forelimbs in the load cell were positioned at a normal angle, which ranged between 135° and 168° (Holmstrom et al., 1990; Weller et al., 2006). Each forelimb was loaded seven times to obtain the aimed MCPJ angles within the normal range (Figure 2). The angles were 135°, 140.5°, 146°, 151.5°, 157°, 162.5°, and 168°. A Prestige Medical 8-inch protractor goniometer was used to measure each of the seven MCPJ angles based on Alrtib et al. (2015).

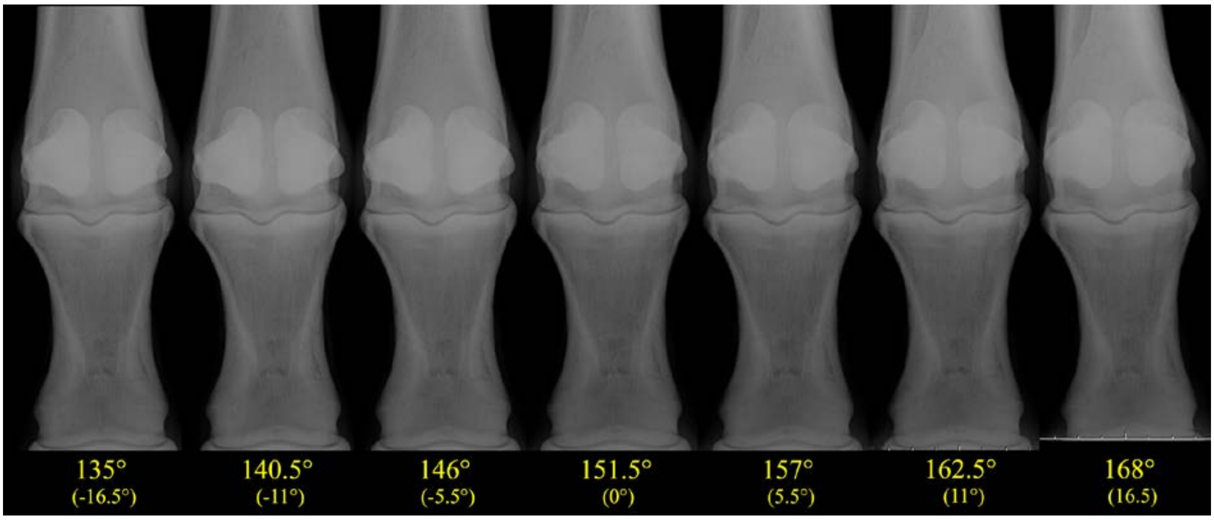

Figure: (2). Dorsopalmar radiographs of an equine metacarpophalangeal joint (MCPJ) during loading the limb. The radiographs showed the resultant changes in MCPJ morphology in seven different joint angles within the normal range.

MCPJ radiography

A fixed digital x-ray machine (ToshibaRotanode™, Toshiba- Japan), digital cassettes (Fujifilm, Fuji IP Cassette Type CC), radiographic processor and cassette holder (Fujifilm FCR Capsula XL, CR-IR 356, Fuji Photo Film CO. LTD. Japan) were used. The dorsopalmar view of MCPJ was used. During radiographing the joint in this view, the head of the x-ray machine was faced towards MCPJ where the central beam of radiation was directed onto the dorsal surface of the joint and perpendicular to the long axis of P1. Each joint was radiographed seven times in the positions corresponding to the MCPJ angles listed previously, with an interval of 5.5°. The joint angle of 151.5° was considered as the middle angle or Zero° and hence the radiographs were labelled as 168° (–16°), 162.5° (–11.5°), 157° (–5.5°), 151.5° (Zero°), 146° (+5.5°), 140.5° (+11.5°) and 135° (+16). All the 42 radiographs were sent to a program called Synapse (Synapse Intelligent Connectivity, Version 3.1.1, Fujifilm Medical System, U.S.A. Inc. 419 West Avenue Stamford, CT 06902). The radiographs were then collected after being labeled and recorded with their details..

Radiographic parameters and measurements

27 MCPJ parameters (12 angles and 15 ratios), which were developed by Alrtib et al. (2019), were measured.

They were:

Angular parameters:

Base medial PSB-Proximal P1 angle (B1)
Base lateral PSB-Proximal P1 angle (B2)
Base PSBs angle (B3)
Lowest PSBs-Proximal P1 angle (B4)
Highest PSBs-Proximal P1 angle (B5)
P1 angle (B6)
Trigonum P1 angle (B7)
Medial trigonum-Proximal P1 angle (B8)
Lateral trigonum-Proximal P1 angle (B9)
Medial sagittal ridge Mc3- Proximal P1 angle (B11)
Lateral sagittal ridge Mc3- Proximal P1 angle (B13)
Sagittal ridge angle (B14).

Ratio parameters

Ratio of the lateromedial width of the medial articular cavity to the lateromedial width of the lateral articular cavity of P1 (W2/W3).
Ratio of the lateromedial width of the medial sesamoid bone to the lateromedial width of the lateral sesamoid bone (W4/W5).
Ratio of the lateromedial width of the proximal extremity of P1 to the lateromedial width of the distal extremity of Mc3 (W1/W6).
Ratio of the lateromedial width of the medial sesamoid bone to the palmar lateromedial width of the medial condyle of Mc3 (W4/W7).
Ratio of the lateromedial width of the medial sesamoid bone to the palmar lateromedial width of Mc3 (W4/W7+W8).
Ratio of the lateromedial width of the lateral sesamoid bone to the palmar lateromedial width of the lateral condyle of Mc3 (W5/W8).
Ratio of the lateromedial width of the lateral sesamoid bone to the palmar lateromedial width of the Mc3 (W5/W7+W8).
Ratio of the palmar lateromedial width of the medial condyle to the palmar lateromedial width of the lateral condyle of Mc3 (W7/W8).

Ratio of the lateromedial width of the medial articular cavity of P1 to the palmar lateromedial width of the medial condyle of Mc3 (W2/W7).
Ratio of the lateromedial width of the lateral articular cavity of P1 to the palmar lateromedial width of the lateral condyle of Mc3 (W3/W8).
Ratio of the palmar lateromedial width of the medial condyle to the lateromedial width of the distal extremity of Mc3 (W7/W6).
Ratio of the palmar lateromedial width of the lateral condyle to the lateromedial width of the distal extremity of Mc3 (W8/W6).
Ratio of the proximodistal height of the medial sesamoid bone to the proximodistal height of the lateral sesamoid bone (H1/H2).
Ratio of the proximodistal height of the medial sesamoid bone to the proximodistal height of P1 (H1/H3).
Ratio of the proximodistal height of the lateral sesamoid bone to the proximodistal height of P1 (H2/H3).

Hoof-Metron measurement software (EponaTech LLC, USA) was used to measure the radiographs. In this software, a free Mark-Up utility was used to measure all the parameters. All the 27 parameters were measured on each of the 42 radiographs (7 radiographs from 6 MCPJ). To avoid the risk of errors related to fatigue, no more than eight radiographs were measured in one day. All measurements were taken by the first author.

Acceptable range of joint angle

Identifying the acceptable range of the joint angle was determined based on measuring the amount of change in the parameters between the different MCPJ angles. The joint angle of 151.5° was considered as zero° or the central angle, from which the amount of change in the values of the parameters was calculated in the other six MCPJ angles. The angle of the joint at which the parameters showed a minimum amount of change was identified and considered an acceptable range of MCPJ angle.

Statistical analysis

A mixed model with a fixed effect of MCPJ angle (centered at 151.5° degrees) and a random effect of horse was used to estimate the common slope within horse for each of the measured parameters. The percentage change for a 5.5° increase in the joint angle was calculated as (slope x 5.5/absolute predicted value at zero degrees) x 100. The Stata (v12.0, Stata Corp, College Station, TX) command –(xtmixed-) was used. Statistical significance was set at $P<0.05$. The identification of the acceptable range of the joint angle was determined based on the statistical results. Means of changes, regardless of whether they were increasing or decreasing, in the values of all the parameters were measured per 5.5° of change in MCPJ angle from the Zero° angle (151.5°).

RESULTS

Effect of MCPJ angle changes on parameters

Angular parameters

From the statistical analysis, it can be seen that the effect of the MCPJ angle was significant in B1, B2, B3, B5, B7 and B9 (Table 1).

The increase in the dorsal MCPJ angle led to a gradual increase in the values of B1 and B2 but a gradual decrease in B3. It also led to an overall increase in the values of B5, B6 and B7. The rest of the angular parameters showed fluctuations in their changing values. The greatest change was found in B3 (Figure 3) which changed by 0.72° with every 5.5° change in MCPJ angle. Conversely, B13 had the least amount of change which altered by approximately 0.002° per 5.5° of change.

Table: (1). Comparison between the values of the angular and the ratio parameters measured on the seven MCPJ angles. Six MCPJs from six different horses were used. The percentage change for a 5.5˚ increase in MCPJ angle was calculated as (change per 5.5˚/absolute predicted value at centred zero degrees) x 100.

Parameter		135° (-16.5°)	140.5° (-11°)	146° (-5.5°)	151.5° (0°)	157° (5.5°)	162.5° (11°)	168° (16.5)	Predicted change per 5.5°	
									Change SE P-value	Percentage
	Mean	16.91	17.18	17.58	17.87	18.21	18.59	18.76	0.32256	
B1	Mean Diff	-0.97	-0.70	-0.30	0.00	0.34	0.72	0.89	0.04252	1.81
	SE Diff	0.34	0.29	0.15	0.00	0.11	0.26	0.25	< 0.001	
	Mean	14.65	15.12	15.69	16.00	16.48	16.79	16.96	0.39577	
B2	Mean Diff	-1.36	-0.88	-0.31	0.00	0.48	0.79	0.96	0.03590	2.47
	SE Diff	0.31	0.19	0.14	0.00	0.16	0.22	0.24	< 0.001	
	Mean	148.45	147.70	146.73	146.13	145.31	144.62	144.27	-0.71833	
B3	Mean Diff	2.32	1.57	0.60	0.00	-0.82	-1.51	-1.85	0.06880	-0.49
	SE Diff	0.53	0.42	0.26	0.00	0.21	0.43	0.43	< 0.001	
	Mean	2.37	2.34	2.67	2.45	2.62	2.27	2.27	-0.01768	
B4	Mean Diff	-0.08	-0.11	0.22	0.00	0.17	-0.18	-0.19	0.03948	-0.72
	SE Diff	0.40	0.37	0.28	0.00	0.17	0.25	0.35	0.65	
	Mean	3.13	3.07	3.01	3.34	3.61	3.75	3.80	0.14131	
B5	Mean Diff	-0.22	-0.27	-0.34	0.00	0.26	0.40	0.45	0.03442	4.23
	SE Diff	0.20	0.17	0.15	0.00	0.12	0.20	0.27	< 0.001	
	Mean	4.17	4.17	4.22	4.25	4.12	4.31	4.44	0.03571	
B6	Mean Diff	-0.08	-0.08	-0.03	0.00	-0.13	0.06	0.19	0.01992	0.84
	SE Diff	0.17	0.18	0.23	0.00	0.15	0.23	0.19	0.073	
	Mean	36.03	36.04	36.19	36.26	36.48	36.26	36.43	0.06899	
B7	Mean Diff	-0.24	-0.23	-0.07	0.00	0.22	-0.01	0.16	0.02638	0.19
	SE Diff	0.22	0.25	0.18	0.00	0.17	0.14	0.24	0.0090	
	Mean	72.25	72.23	72.36	72.14	72.22	72.69	72.37	0.04149	
B8	Mean Diff	0.11	0.09	0.22	0.00	0.08	0.55	0.23	0.03167	0.06
	SE Diff	0.18	0.24	0.20	0.00	0.14	0.21	0.22	0.19	
	Mean	71.73	71.74	71.45	71.60	71.30	71.06	71.20	-0.11048	
B9	Mean Diff	0.13	0.14	-0.14	0.00	-0.30	-0.54	-0.40	0.02998	-0.15
	SE Diff	0.13	0.17	0.15	0.00	0.29	0.11	0.17	< 0.001	
	Mean	38.85	39.19	39.17	39.01	39.12	39.07	38.87	-0.00887	
B11	Mean Diff	-0.16	0.18	0.16	0.00	0.10	0.06	-0.14	0.02194	-0.02
	SE Diff	0.15	0.11	0.05	0.00	0.17	0.10	0.17	0.69	
	Mean	37.60	37.48	37.38	37.71	37.38	37.46	37.60	-0.00179	
B13	Mean Diff	-0.11	-0.23	-0.32	0.00	-0.33	-0.25	-0.11	0.02980	0.00
	SE Diff	0.17	0.30	0.25	0.00	0.16	0.29	0.14	0.95	
	Mean	103.55	103.32	103.44	103.28	103.50	103.47	103.53	0.01065	
B14	Mean Diff	0.27	0.05	0.16	0.00	0.22	0.19	0.25	0.03563	0.01
	SE Diff	0.32	0.28	0.27	0.00	0.19	0.27	0.27	0.77	
	Mean	1.14	1.13	1.13	1.14	1.13	1.12	1.12	-0.00228	
W2/W3	Mean Diff	0.00	-0.01	-0.01	0.00	-0.01	-0.02	-0.01	0.00085	-0.20
	SE Diff	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.0070	
	Mean	0.99	0.99	0.99	0.99	0.99	0.99	0.99	-0.00010	
W4/W5	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00029	-0.01
	SE Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	
	Mean	1.10	1.10	1.10	1.10	1.10	1.10	1.09	-0.00051	
W1/W6	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00018	-0.05
	SE Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0050	
	Mean	0.89	0.90	0.89	0.89	0.90	0.90	0.89	0.00018	
W4/W7	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00039	0.02
	SE Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	
	Mean	0.99	0.99	0.98	0.99	0.99	0.98	0.99	-0.00004	
W5/W8	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00052	0.00
	SE Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	
	Mean	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.00003	
W4/(W7+W8)	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00016	0.01
	SE Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86	
	Mean	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.00007	
W5/(W7+W8)	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00014	0.02
	SE Diff	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.62	

Parameter		135° (-16.5°)	140.5° (-11°)	146° (-5.5°)	151.5° (0°)	157° (5.5°)	162.5° (11°)	168° (16.5)	Predicted change per 5.5° Change SE P-value	Percentage
	Mean	1.10	1.09	1.09	1.10	1.10	1.09	1.09	-0.00044	
W7/W8	Mean Diff	0.00	0.00	-0.01	0.00	0.00	-0.01	0.00	0.00077	-0.04
	SE Diff	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.56	
	Mean	1.02	1.01	1.01	1.01	1.01	1.01	1.01	-0.00015	
W2/W7	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00048	-0.01
	SE Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	
	Mean	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.00147	
W3/W8	Mean Diff	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00049	0.15
	SE Diff	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.0020	
	Mean	0.53	0.52	0.52	0.53	0.52	0.52	0.52	-0.00032	
W7/W6	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00022	-0.06
	SE Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	
	Mean	0.48	0.48	0.48	0.48	0.48	0.48	0.48	-0.00011	
W8/W6	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00020	-0.02
	SE Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	
	Mean	0.97	0.97	0.97	0.98	0.98	0.98	0.97	0.00034	
H1/H2	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00031	0.03
	SE Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	
	Mean	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.00031	
H1/H3	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00017	0.10
	SE Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.064	
	Mean	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.00021	
H2/H3	Mean Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00018	0.06
	SE Diff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	

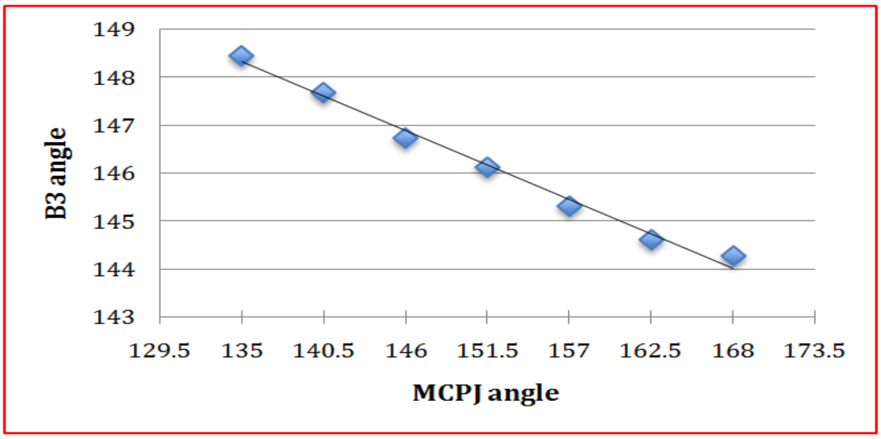

Figure: (3). Effect of changing the metacarpophalangeal jointangle on B3 parameter in 6 joints.

The minimum change was found in W4/(W7+W8) with 0.00003 units of change (Figure 4), whereas the W2/W3 ratio demonstrated the greatest amount of change with an average of 0.0023 units per 5.5° of the joint angle change.

Ratio parameters

The change in MCPJ angle had generally less effect on the ratios than on the angular parameters. The majority of the ratio parameters showed no significant effect per 5.5° change across the whole range of angles that were measured. Only three ratios were changed significantly (p values ≤ 0.01) per 5.5°change in MCPJ angle. They were W2/W3, W1/W6 and W3/W8. In all the ratio parameters, changing the joint angle by 5.5° resulted in very small changes.

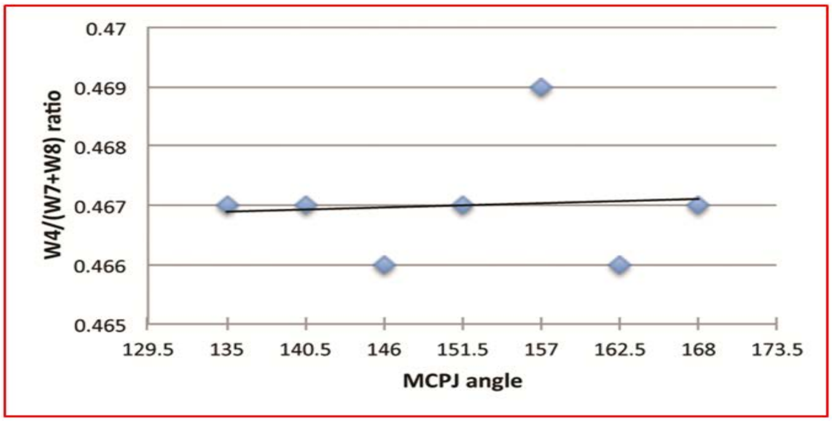

Figure: (4). Effect of changing the metacarpophalangeal joint angle on W4/(W7+W8) parameter in 6 joints.

Acceptable range of MCPJ angle

The amount of change of all the parameters per 5.5° change in MCPJ angle from the centred angle is summarised in Table 2.

The changes in the joint angle by + or −5.5° demonstrated the minimal amount of change in all the parameters. The angular parameters presented an approximate change of less than 0.5° the joint angles of ±5.5° (146°- 157°) except in B3 which changed by 0.72°. At the joint angles of ±11° and ±16.5°, the amount of change in all the angular parameters was less than 1° except in B2 and B3, which showed greater alteration. In the ratio parameters, the amount of change was very small at all the joint angles that were located within this normal range. The amount of change in the ratios at ±5.5° of the joint angle was less than 0.0023 units while at ±11° and ±16.5° changes were less than 0.005 and 0.007 units, respectively.

Table: (2). Means of changes per 5.5° change in MCPJ angle from the centred angle (151.5°), regardless increasing or decreasing the values, in each change in MCPJ angle for all the angular and ratio parameters.

Parameter category	Parameters	0 (151.5°)	±5.5° (146° - 157°)	±11° (140.5° - 162.5°)	±16.5° (135° - 168°)
Angular parameters	B1	0	0.32256	0.64512	0.96768
	B2	0	0.39577	0.79155	1.18732
	B3	0	0.71833	1.43667	2.15500
	B4	0	0.01768	0.03536	0.05304
	B5	0	0.14131	0.28262	0.42393
	B6	0	0.03571	0.07143	0.10714
	B7	0	0.06899	0.13798	0.20697
	B8	0	0.04149	0.08298	0.12447
	B9	0	0.11048	0.22095	0.33143
	B11	0	0.00887	0.01774	0.02661
	B13	0	0.00179	0.00357	0.00536
	B14	0	0.01066	0.02131	0.03196
Ratio parameters	W2/W3	0	0.00228	0.00457	0.00685
	W4/W5	0	0.00010	0.00019	0.00029
	W1/W6	0	0.00051	0.00102	0.00153
	W4/W7	0	0.00018	0.00037	0.00055
	W5/W8	0	0.00004	0.00007	0.00011
	W4/(W7+W8)	0	0.00003	0.00006	0.00008
	W5/(W7+W8)	0	0.00007	0.00014	0.00022
	W7/W8	0	0.00044	0.00089	0.00133
	W2/W7	0	0.00015	0.00030	0.00045
	W3/W8	0	0.00147	0.00294	0.00442
	W7/W6	0	0.00032	0.00064	0.00095
	W8/W6	0	0.00011	0.00022	0.00034
	H1/H2	0	0.00034	0.00067	0.00101
	H1/H3	0	0.00031	0.00063	0.00094
	H2/H3	0	0.00022	0.00043	0.00064

DISCUSSION

The effect of changing MCPJ angles on landmarks and consequently on the values of their radiographic parameters was evaluated in this study, which found that changing MCPJ angles resulted in both significant and insignificant alterations in the measurements of most of the parameters. The majority of the significant changes occurred in the angular parameters, especially B1, B2 and B3, while the ratio parameters were generally less affected.

During extension or flexion of the MCPJ, its angle was mainly changed by moving or rotating the proximal P1 and the dorsal PSBs around the distal condyles of Mc3. This movement meant that the bones rotated around the centre of the joint motion transversely. Hence, analysing the changes in values of the parameters was based on the relationship between the landmarks and the horizontal axis of the joint on DP radiographs.

In the angular parameters, B1 and B2 angles showed a steady increase in their values when MCPJ angle was increased. This result might be associated with the tension that would have been applied through the suspensory (interosseous medius muscle) ligament and the distal sesamoidean ligaments during joint movement. The suspensory ligament originates from the distal carpal row and the adjacent area of the proximal Mc3 and runs distally on the palmar surface of the metacarpus. At the distal third or fourth of Mc3, it divides into two parts, which then insert on the abaxial surfaces of the PSBs (Dyce et al., 2002). The distal sesamoidean ligaments are three ligaments (straight, oblique and cruciate) originating from the base of the PSBs. The straight ligament inserts on the middle phalanx (P2), while the other two ligaments insert on the palmar surface of P1 (Dyce et al., 2002; Sisson & Grossman, 1975). The distal sesamoidean ligaments act against the pulling of the suspensory ligament (Pasquini & Spurgeon, 1989). So, when the loading decreased on MCPJ and its angle changed towards 168°, the tension on the ligaments would have started to be relieved, resulting in a gradual alteration in the level of the basilar borders of the PSBs. This probably occurred due to the pulling of the abaxial end (distal end of the abaxial surface) of the PSBs proximally by the suspensory ligament. While, when the loading increased and the MCPJ angle became smaller, the tension would be increased on the ligaments at which time the distal sesamoidean ligaments would have prevented the abaxial edges of the PSBs from being pulled proximally by the action of the suspensory ligament. Therefore, shifting the abaxial edges proximally and distally seemed to cause an increase and decrease in the values of the two parameters, respectively. B3, which was the most affected parameter, showed a steady and significant alteration during changes in the joint angle. However, contrary to B1 and B2, the value of B3 was increased when the MCPJ angle was decreased and vice versa. The parameter was established as an angle formed between the basilar surfaces of the medial and lateral PSBs (Alrtib et al., 2019). Hence, it can be suggested that when the joint angle increased by reducing the load, the abaxial ends of the two PSBs were pulled proximally by the suspensory ligament, leading to a decrease in the angle of the parameter.

In comparison to the angular parameters, the ratio parameters were generally less affected by changing the joint angle. Six of the fifteen ratio parameters did not change at any of the joint angles. This was in addition to two more ratios that had a very small change in only one joint angle, W1/W6 at 168° and W2/W7 at 135°. The result was not unexpected, based on two possible reasons. Firstly, the size of the ratios was relatively small, and thus any change in their values would be very small or even effectively zero. The value of W4/(W7+W8), for instance, stayed at 0.47 units in each of the joint angles, although it did change by 0.00003 unist per 5.5°. Such a tiny amount of change which was the smallest change in the study, was too small to show up in the presented values. Secondly, since the majority of the linear landmarks were measured lateromedially (horizontally), changing the joint angle due to moving the bones around the joint's horizontal axis would have little influence on the ratios. This was in agreement with many morphometrical studies that reported that horizontally measured parameters would not be affected during the rotation of the object around its horizontal axis (Ahlqvist et al., 1986; Malkoc et al., 2005; Oheida et al., 2017).

There were twelve (6 angular and 6 ratio) parameters that showed irregular patterns of changes in their values with the different MCPJ angles. The fluctuating pattern would presumably be an indication of landmark identification errors. This type of error was correlated to a number of factors such as the nature of the landmark anatomical details (Gravely & Benzies, 1974), inter-landmark distance (Chen et al., 2004), investigator experience (Major et al., 1994) and radiographic technique (Turner & Weerakone, 2001). The likely source of errors in the current study seemed to be associated with the nature of the landmarks and the inter-landmark distance. The features of interest in B11, B13 and B14, for example, were the sagittal ridge of Mc3 and proximal P1. This ridge had small medial and lateral sides that were located adjacent to each other. If a little mistake occurred while locating such small and closely positioned landmarks, inconsistencies would easily occur in their measurements. Furthermore, in both W4/W7 and W5/W8 ratios, the landmarks were on the PSBs, which were located palmar to the condyles of Mc3. Radiographically, there was a superimposition between the PSBs and Mc3 that probably caused some difficulties in locating the landmarks on the radiographs, leading to inconsistency in the measurements. Despite the possible errors in the measurements of these parameters, their amounts of change were very small and reasonably applicable for diagnostic and morphometrical purposes. However, if such measurements are required for the clinical interference, more caution should be taken.

The second aim of the study was to identify the range of MCPJ angles at which the parameters expressed a minimal amount of change. According to cephalometric studies (Gregston et al., 2004; Kumar et al., 2008), measurement differences of 2° in angular parameters and 2 mm in linear parameters were considered to be a potential threshold for clinically meaningful differences. In addition, in an equine carpal study, it was found that the carpal rotation around its horizontal axis would result in a changing mean of less than 1° in the angular parameters per 5° of rotation, and thus ±5° was considered an acceptable range of rotation (Oheida et al., 2017). The current findings showed that changes in MCPJ angle by ±5.5° from 151.5° (146° and 157°) resulted in the minimum amount of changes in all the parameters. At these joint angles, the changes in angular measurements ranged between 0.0018° and 0.72°, whereas in the ratio parameters, the range was between 0.00003 and 0.0023 units. Hence, MCPJ angles that ranged between 146° and 157° can be assumed to be within an acceptable range of the joint angle. However, depending on the total changes that are shown in Table 2, this acceptable range could be widened to include not only the angles between 140.5° and 162.5° (±11°) but also the angles between 135°- 168° (±16.5°), but with considering the possible larger changes in B2 and B3. Using the acceptable range of MCPJ angle would be applicable as long as the joint was not rotated around its vertical axis, which was reported to have a potential effect on the measurements (Alrtib et al., 2023). If so, then more investigations should be performed to include the effect of the joint angle and the vertical axis on MCPJ parameters.

CONCLUSION

In conclusion, changing the MCPJ angle affected the radiographic measurements in most of the parameters. The angular parameters showed more significant changes than the ratio parameters. Larger changes were found in the significantly influenced parameters. The irregular pattern of changes in some parameters seemed to be related to a number of factors, such as the nature of the landmarks and the superimposition of bones. The range of 146° to 157° of MCPJ angle could be considered an acceptable range for reliable and representative measurement of the parameters included in this study.

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As the experimental work conducted in cadavers, no ethical approved was required.

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