Alexandria Journal of Veterinary Sciences
www.alexjvs.com

AJVS. Vol. 60 (2): 23-33 Jan. 2019

DOI: 10.5455/ajvs.30333

Kinematics Biomechanical Analysis and Three Dimensional Reconstruction Diagnostic Technique of Carpal Joint during gait in One-Humped Camel (*Camelus dromedarius)*

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ABSTRACT

The database of biomechanical variables gained from healthy camels was needed to investigate the main characters of normal gait in one-humped camel and changes of velocity and displacement as well as the anatomical changes of the carpal joint during walking. Nine healthy camels of three different sizes were selected for gait analysis by using Motion track program and four carpal joints cadavers obtained from four healthy dromedary camels of both sex were used for three dimension reconstruction computed tomography (CT). Gait analysis of camel's carpus during walking yielded some data as step length, stride length, stride time, stride frequency, angular change and displacement of the carpal joint. Our results revealed that camels' carpal formed from six carpal bones arranged into two rows, its movement controlled by four dorsal extensor tendons and one palmar flexor tendon so, mainly movement of the joint is extension and flexion and small internal gliding movement. Additionally different sizes of camels had a significant effect on gait parameter as step length, stride length, and stride frequency. Meanwhile, small camels increased their velocity during walking by significant decreased the stride time. Large sized camels showed a significant higher degree of extension of the carpal joint than small camel, especially right carpal joint. Additionally, hyperextension of camel's carpus occasionally occurred. On the other hand, horizontal and vertical displacement of the carpal joint during walking was a significant difference of medium sized camel than small and large camel. The present findings will be a helpful method in lameness diagnosis to recognize between the normal and diseased gait and surviving the inhabitant environment.

Key words:
Carpus, Anatomical variations, Biomechanics, Dromedary camel.

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Article History
Received 01 Dec 2018
Revised 31 Dec 2018
Accepted 20 Jan 2019

1. INTRODUCTION

Camels are an interesting and little studied animals. Furthermore, Camels are not only serve as a source of high quality meat, milk and leather, but also as riding, racing, and pack animals (Khan et al., 2003). Camel is a unique animal in its pacing gait and having a unique leg morphology supposed to be life adaptation for this mode of locomotion (Janis et al, 2002). The uniquely originative wide feet permits him to walk on shifting sand, in the desert, rough rock, and steep inclines. Locomotor apparatus of the camels enables them to travel fast on sandy soil, and be excellent racing animals (Badawy, 2011). The characteristic divergence of the third and fourth digits in dromedary camel was due to a secondarily digitigrade, splayed - toed foot, loss of hooves, addition of a broad foot pad and loss of the interdigital ligaments (Janis et al., 2002 and Masahiko et al., 2002). The first points touch the ground was carpal joint so; spreading of carpal lameness was a common in camels due to increasing the pressure on the dorsal aspect of the joint as camels sit down or standing (Kassab, 2008). Computed tomography is represented as a modern medical diagnostic imaging modality for evaluation of anatomical detailed of joint and its structures (Badawy et al., 2016); musculo-skeletal disorders other than the traditional imaging approaches (Vallance et al., 2012; Raji et al., 2009); general anatomy for carpal affection (Kassab, 2008; Hagag, 2013; Badawy, 2011); carpal sheath contents (Bergman and Saunders, 2011); and also to visualize the complex bony structures of the skull, spine or joints (Raji et al., 2009). Kinematics is the research of changes in the position of certain body segments in space during a specified time (Barrey, 1999). Biomechanical techniques serve as the most important method to diagnosis the locomotor problems in commercial farming system of pig (Pluk et al., 2012) and in discovering of subclinical abnormalities (Maertens et al., 2011). And therefore, progress the breeds selection (Serenius and Stalder, 2006). Many literatures have been studied the anatomical and histological structures of camel bones (Soroori et al., 2007); tendons (Soroori et al., 2011); and digits foot pad (Badawy, 2011) of the forelimb in one-humped camel by means of different methods but the biomechanical study of carpal dromedary camel still lesser and rare. The main goal of the present experiment was to describe databases of biomechanical variables of the normal carpal gait in one-humped camel during stance phase through the use of motion capture technology as well as the normal reconstruction diagnostic technique of carpal joint using three dimension computed tomography.

2- MATERIAL AND METHODS

2.1. 3D reconstruction CT examination

Four carpal joints cadavers of apparently healthy four one-humped camels *(Camelus dromedarius*), of both sex (3 males and 1 female with average 2.4 ± 0.3 years old) were used in this study. 64 detector row CT scanner (Somatom Sensation, Siemens, Forcheim, Germany), at 130 kVp and 160 mAs. Computed tomographical images were reconstructed in dorsal and sagittal planes via software (Syngo CT 2006G, ICS VB28B, Siemens, Munich, Germany).

2.2. Biomechanical gait analysis

Nine dromedary camels were gained from faculty of veterinary medicine, university of Sadat city. Animal-handling rules were carried out with the regulations of Institutional Animal Care and Use Committee (IACUC) and with the prior approval for using the animals (approval no: VUSC). The present experiment was performed with apparently clinically healthy dromedary camels of three different sizes for gait analysis; small size, medium size and large size as shown in Table (1)

Table (1): Weights, heights, and ages of the three camels of different three sizes used in this study(mean ± SE)

Animals	Weight (kg)	Height (cm)	Age (year)
Small	166.66±16.66	165.00±7.63	3.2
Medium	400.00±100.00	193.00±9.07	4.1
Large	633.33±66.66	216.66±8.64	5.2

Each animal was monitored during walking via video camera (Sony, VHS HI 8 mm) with a fixed carrier for 8 minute. A computer of IBM, 64 Mp and hardware 80 Gp stored the captured videos. Films were processed by using Motion track program (No 665/5 – 2001; 0.50 m × 0.50 m × 0.50 m as measurements unite) for camel gait analysis. Captured motion is one approach of biomechanical gait assessment, gait can be defined as a complex and strictly co-ordinated rhythmic and automatic movement of the limbs and the entire body of the animal resulted in production of progressive movements (Barrey et al., 1999). The motion track program can analyze the normal gait through different frame and process. Each movement of each part of body could be converted to various data. Therefore, some data could be summarized via carpal gait analysis of camel during walking (Table 2).

Table (2): Some biomechanical terms used for carpal gait analysis

1- Step length	The length displacement between two successive placements of two contralateral hooves within a pair, i.e. front and hind (Whittle, 1996).
2- Stride time	The time between two successive hoof placements of the same limb.
3- Stride length	The distance between two successive hoof placements of the same limb.
4- Stride frequency	The number of strides performed per unit of time. The stride frequency is equal to the inverse of stride duration and is usually expressed in stride/s (Barrey, 1999).
5- Velocity	The times when the individual fore limb either right or left contacted and left the ground (Peham et al., 1999)
6- Angular change	Value of flexion and extension degree of carpal joint
7- Horizontal and vertical displacement of the carpal joint from the zero point during walking	

Table (3): Main characters of camel gait during walking (mean ± SE)

Items	Camel			P value
	Small	Medium	Large	
Step length (m)	1.78 ± 0.07^{a}	1.78 ± 0.007^{a}	1.37 ± 0.02^{b}	0.01
Stride time (s)	0.76 ± 0.01^{b}	1.00 ± 0.12^{a}	$0.80\pm.00^{ab}$	0.05
Stride length (m)	1.17 ± 0.02^{a}	1.07 ± 0.12^{a}	0.86 ± 0.00^{b}	0.02
Stride frequency (stride/s)	0.89 ± 0.03^{a}	0.89 ± 0.003^{a}	0.68 ± 0.01^{b}	0.01

2.3. Statistical analysis

All parameters were statistically analyzed via IBM SPSS statistics (version 22). ANOVA test was used for variances between camel sizes.

3- RESULTS

3.1. Three dimension reconstruction computed tomography

The static structures of carpal joint included the bones, joint surfaces congruity, ligaments. The dynamic components include the Arthro-kinematics of the carpal bones and muscle function. Carpal joint was considered as a compound joint; consisted of six carpal bones arranged into two rows. The first proximal one was accessory, ulnar, intermediate, and radial carpal bones while, the second distal row was fused second and third carpal bones, and fourth carpal bones (Fig. 1). Moreover the carpal joint had several articular surfaces; radiocarpal, intercarpal and carpometacarpal joints. Dorsally, the extensor carpi radialis tendon, extensor digitorum communis tendon, and extensor digitorum lateralis tendon were distinctive in 3D

CT (Fig. 2). The palmar surface of the carpal joint contained flexor tendons, and carpal canal (Fig.2)

3.2. Biomechanical gait analysis

Results presented in Table (3) referred to main characters of camel gait during walking as step and stride length, stride time and stride frequency differed from small, medium to large size. Step length, stride length, and stride frequency of small and medium sized camel was significant ($p<0.01$) longer than others of large sized camel. Small sized camels were able to achieve significant increase in speed or velocity than medium sized camels by decreasing the amount of time of foot spends in contact with the ground. As small sized camel take a significant shorter time ($P=0.05$) for taking one stride than medium sized camel with increase the velocity of movement of fore right limb. Velocity of different sized camels of forelimb ranged from 0.22±0.04 to 5.62±0.58 m/sec for small camel, 0.25±0.04 to 6.24±0.83 m/sec for medium camel and 0.23±0.01 to 6.93±0.89 m/sec for large camel as shown in Figure (3). Beside velocity of left forelimb of small camels during walking ranged from 0.32±0.05 to 6.99±1.56 m/sec, medium camels varied from 0.30±0.05 to 7.95±.64 m/sec and large camels extended from 0.21±0.03 to 8.06±1.23 m/sec Figure (4).

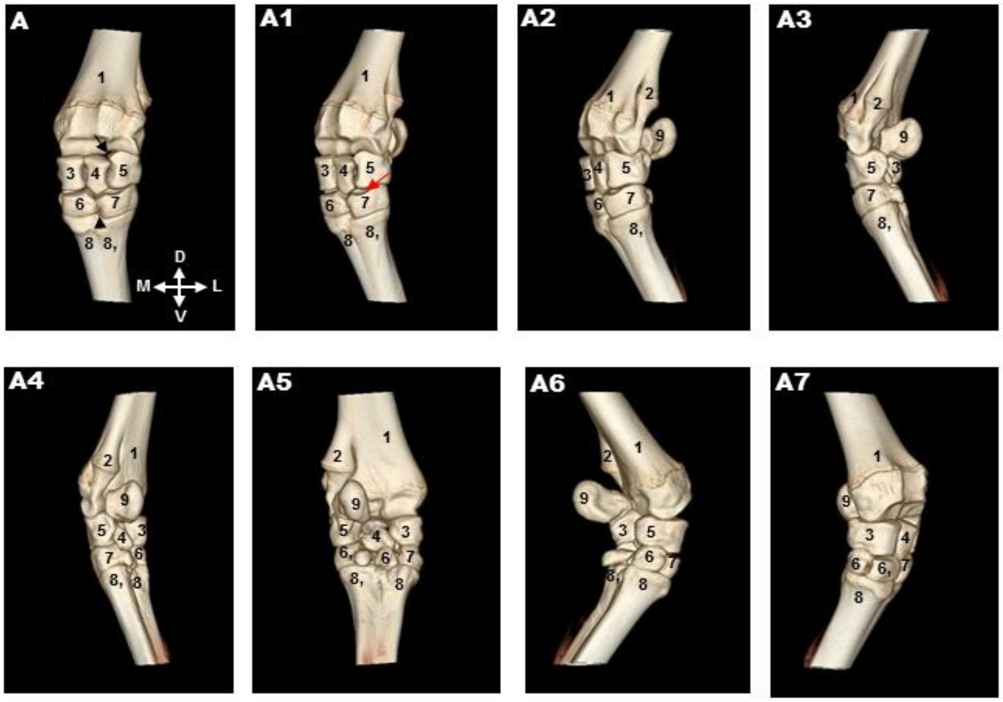

Figure (1): 3D CT images of carpal region in young (2.4 years old) dromedary camel showing; A-A7: Images rotation toward the left side. A: Dorsal view. Black arrow; Radiocarpal joint, yellow arrow; Intercarpal joint, arrow head; Carpometacarpal joint **1:** Distal extremity of radius, **2:** Ulna **3:** Radial carpal bone **4:** Intermediate carpal bone , **5:** Ulnar carpal bone , **6:** Fused second and third carpal bone ,**6,:** Second carpal bone**7:** Fourth carpal bone **8:** Fourth metacarpal bone **8,:**Third metacarpal bone **9:**Accessory carpal bone

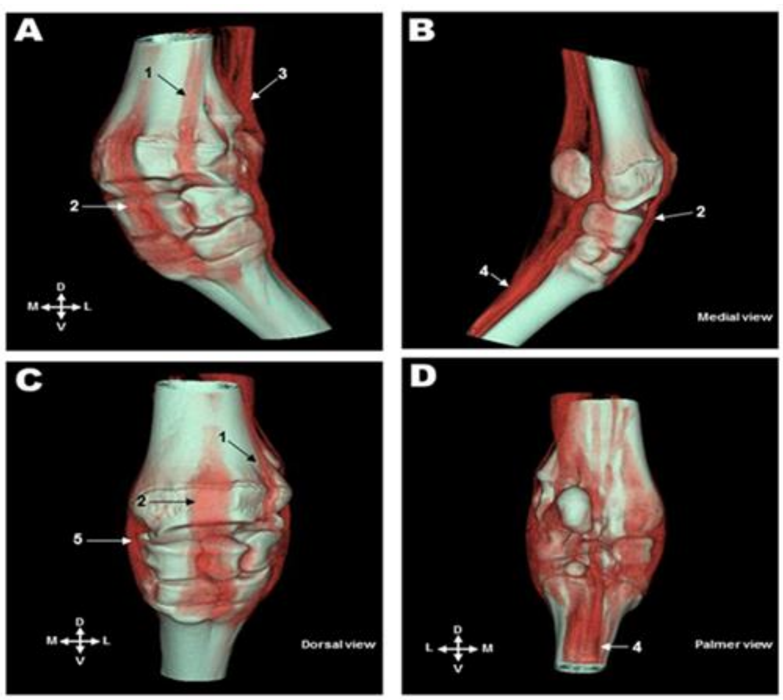

Figure (2): 3D CT images of carpal region in young (2.4 years old) dromedary camel showing different tendons; 1: Extensor digitorum lateralis tendon, **2:** Extensor digitorum communis tendon, **3:** Extensor carpi ulnaris tendon, **4:** Flexor tendons, **5:** Extensor carpi radialis tend

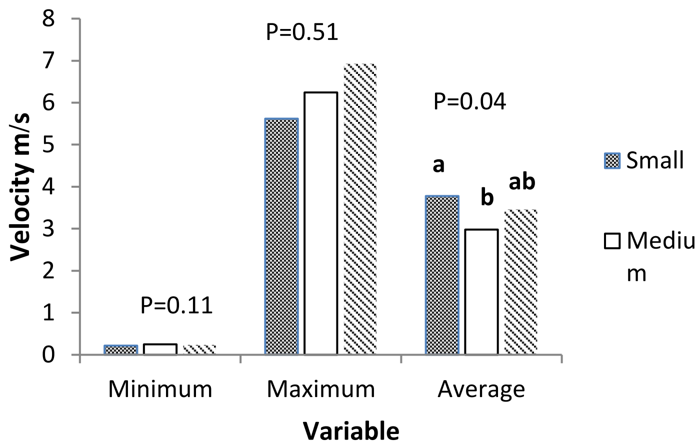

Figure (3): Velocity of right forelimb of different sized camels m/s (mean ± SE)

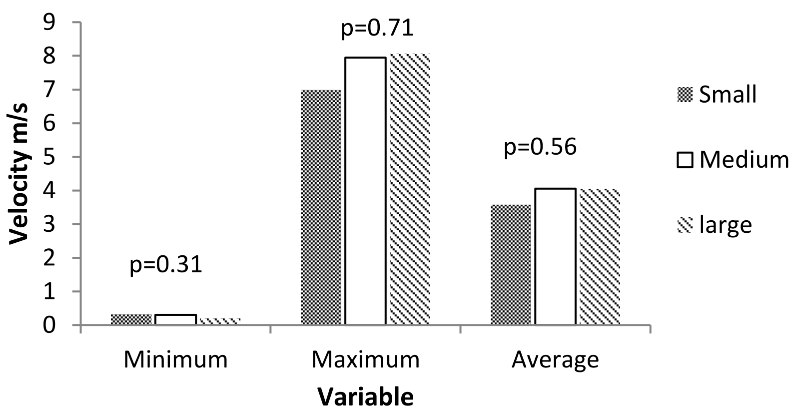

Figure (4): Velocity of left forelimb of different sized camels m/s (mean±SE)

During normal gait of camels (walking) the degree of angular change of carpal joint significantly differed between different sized camels as illustrated in Figure (5) and (6). Large sized camels showed significant higher degree of extension of carpal joint ($P<0.05$) than small camel especially right carpal joint. However value of extension of carpal joint of small and medium camel not significantly differed. Additionally, hyperextension of camel carpel joint either right or left occurred amazingly over 180°. As average of angular change of right carpal joint of small sized camels when compared with medium and large sized ones (155.95, 167.11and 171.49°) respectively. Whenever, the minimum value of right carpal joint angle (108.34, 106.40, and 112.24°) while the greatest value of hyperextension in right carpal joint reached 193.07°, 199.43°, and 198.40° for each small, medium and large camel respectively (figure 5). As well as, in left carpal joint reached 190.69°, 197.22°, and 197.95° for small, medium and large camel respectively. Moreover, angular change degree of left carpal joint for small, medium and large camels equal (165.37, 168.72 and 168.52 °) respectively. As the least value of angular change in left carpal (105.13, 95.01 and 103.47°) and the maximum extension degree (190.69, 197.22, and 197.95°) for small, medium and large camel respectively (figure 6). The data represented in Figure (7,8,9) indicated that wave changing of carpal angle either right or left and illustrate hyperextension degree of joint angle (over 180°) during gait

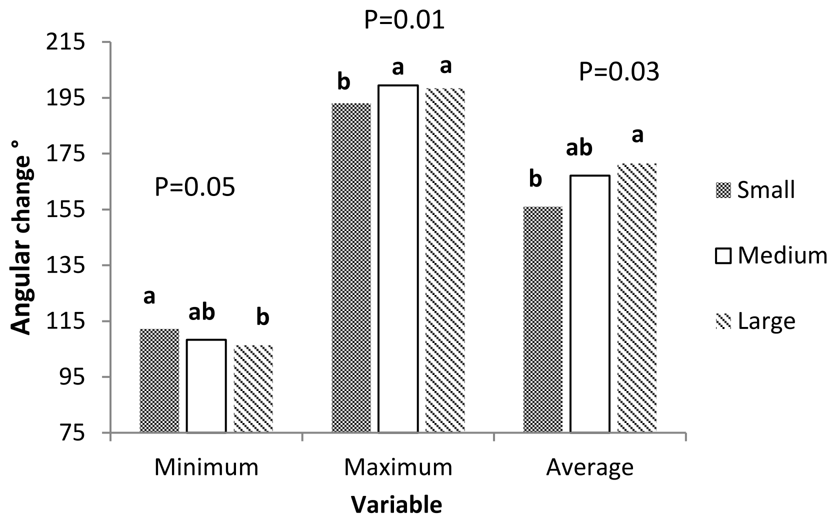

Figure (5): Angular change of right carpal joint of different sized camel (°) (mean ± SE)

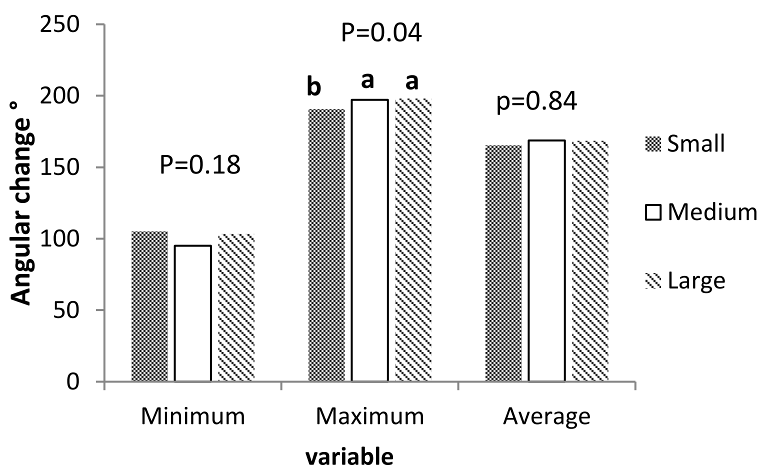

Figure (6): Angular change of left carpal joint of different sized camel (°) (mean ± SE)

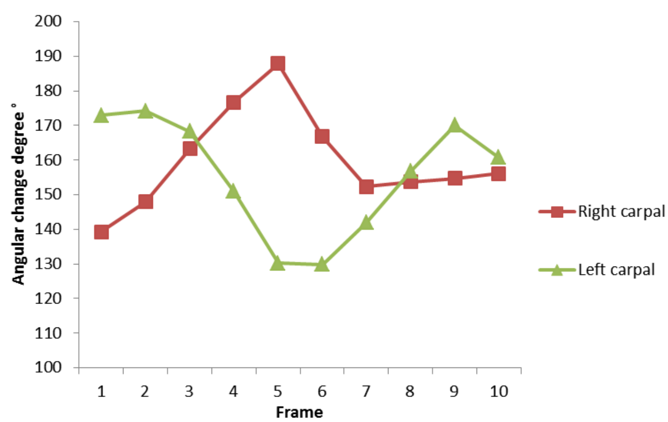

Figure (7): Wave changing of angle in carpal joint (left and right) of the Small Camel

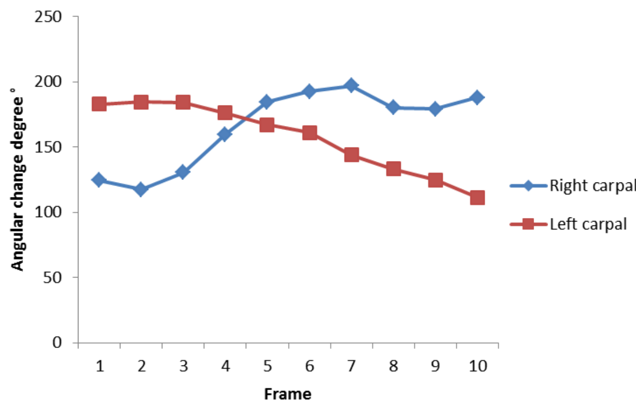

Figure (8): Wave changing of angle in carpal joint (left and right) of the medium camel

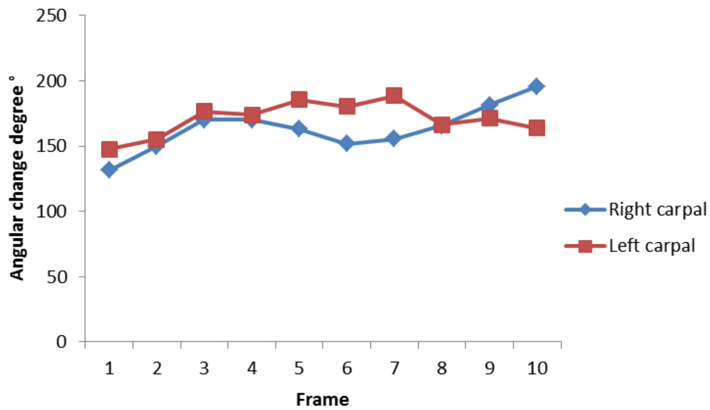

Figure (9): Wave changing of angle in carpal joint (left and right) of the large Camel

Different size of camels had a significant effect on horizontal and vertical displacement of carpal joint either right or left during walking as shown in Table (4). Horizontal and vertical displacement range of medium sized right carpal was significant ($p<0.05$) longer than displacement of small and large carpal camels. Beside, medium and large camels show higher horizontal displacement range significantly of left carpal joint movement than small camels ($p=0.001$). Vertical range of left carpal of medium sized camel higher than vertical displacement of small camels ($p=0.00$)

Table (4): The displacement of the carpal joint of camel during normal gait (m) (mean ± SE)

Items	**Right carpal joint**			**P value**
	Camel			
	Small	**Medium**	**Large**	
X range	1.36±0.31[b]	2.19±0.23[a]	1.76±0.019[b]	0.04
Y range	0.15±0.001[b]	0.27±0.002[a]	0.16±0.008[b]	0.001
	Left carpal joint			
X range	0.84±0.23[b]	1.97±0.12[a]	1.78±0.14[a]	0.001
Y range	0.09±0.007[b]	0.62±0.17[a]	0.17±0.01[b]	0.002

X and Y means horizontal and vertical distance of carpal joint motion respectively

4- DISCUSSION

4.1. Three dimension reconstruction computed tomography

The camel's carpus is anatomically similar to other domestic animals (Kassab, 2008), 3D reconstruction CT technique findings were confirmed the previous gross anatomical description of the joint capsule. Carpal joint of camel is a complex joint which constructs of three joints, radiocarpal, intercarpal, and carpometacarpal joints, (Budras et al., 2012). Joint capsules, the proximal and middle sacs of joint capsules are capacious and each one has a dorsal recess. The intercarpal and carpometacarpal joints connected each other, while the radiocarpal joint has a separate sac (Kassab, 2008; Al-sobayil et al., 2015). Camel carpus moves for extension and flexion (Smuts and Bezuidenhout, 1987; Kassab, 2008). Extension of carpus during stance phase permits the forelimb to act as a solid support while flexes in swing phase to elevate the foot away from the ground (Rooney et al., 1991). In kneeling position, camel carpus flexes, hyperextension of camel carpus was amazing. The knowledge of normal structure of the carpal region in camel by means 3D CT and biomechanics is essential for examination of its normal compositions, which aid prevention of the joint disease as fractures. It was a difficult radiography to accurate examine the carpal joint due to the overcrowded of bones. Thus, CT used for diagnosing the location of fracture as well as configuration (Bergman and Saunders, 2011). Many factors affecting the mobility and fitness of the carpal joint, the muscles and tendons were the most important factors in fixation of the joints. Biomechanical methodss yield knowledge on development and environmental adaptation of species. (Cake et al., 2013). The gait of dairy cows, sheep and pigs was investigated biomechanically (Thorup et al., 2007; Liu et al., 2009). Biomechanical approaches in dairy cows developed some advances techniques in diagnosis of lameness and give the periority for monitoring the mobility scores (Maertens et al., 2011). The first biomechanical research into pigs lameness begun with (Gregoire et al., 2013). The most benefits of biomechanical analysis was reliable and accurate gait assessment (Barrey, 1999). 3D reconstructions CT represent the most useful method for the biomechanics principals in the horse and give the possibility for the application in different species (Barrey, 1999).

4.2. Biomechanical gait analysis

It was anticipated that, camel's carpus play a pivotal role in surviving in the arid and semiarid region. The biomechanical gait survey of camel carpal is rare and represents a fruitful area of upcoming research. Camel gait represented as a complex and hard automatic movement of limbs. Thus entire body produce a progressive movements (Barrey, 1999). Motion track software program 2001 was a useful as well as an accurate and reliable tool to parameterize the kinematic data captured from nine camels of three different sizes during normal gait. The present study documented that step length, stride length, and stride frequency of small and medium sized camels were significantly differed than large sized camel. These findings were attributed to gait parameters are influenced by differences between camel's sizes. These results were supported by (Hof, 2001) who documented that, gait variables are affected by animal size and it had been recommended to adjust the size during comparisons between individuals. In contrast, velocity of forelimb of small camels was significantly higher than velocity of medium camels of the same limb. These findings suggested that, small sized camels increased their velocity during walking gait by increase step length, stride length, stride frequency, and decreased stride time (stride duration) as mentioned previously in our results. These results were agreement with Pfau et al., (2010) who studied gait parameters in the alpaca indicated that stride time was decreased and stride length and stride frequency were increased with speed increasing for symmetrical gaits. Clayton, (1995) reported that improvement of dressage horses velocity was achieved by a large increase in stride length and a smaller decrease in stride duration. Besides, the walking velocity increased mainly as a result of a decrease in stride duration, and assisted by a smaller increase in stride length (Rooney et al., 1991). Therefore, Changes in walk velocity were the result of adjustments in between stride length and stride duration (Khumsap et al., 2002). It is

common to many animals to increase stride length rather than stride frequency (Heglund and Taylor, 1988).
The camels of different sizes in this study showed different degree of extension of carpal joint during gait. Carpal extension in one-humped camel was amazing and unique for that animal. Large sized camels showed significant higher degree of extension of carpal joint than small one especially right carpal joint. Additionally, hyperextension over 180° occurred in some situation either in the right or left limb. This may be attributed to the histological and anatomical structures of carpal joint which permit the articular surfaces and joint ligament to extend over 180°. Awareness of that unique features in dromedary camel gives the veterinarian fruitful information during handling of one-humped camel. Meanwhile, allow the carpus to extend freely during stance, and permits the forelimb to aid propelling the body mass forward. Clayton et al., (2004) suggested that carpus flexion and extension degree of trotting horse differed for the reason of laxity in the carpal ligaments of the flexed joint allowing a widening and forward sliding of the articular surface of the metacarpus relative to the radius. On the other hand horizontal and vertical displacement of carpal joint either right or left during gait were significant different of medium sized camels than small and large camel. This means that large sized camels in our study characterized by high flexion degree of carpus with minimum displacement. These differences of carpal displacement might regard to changes that occur to the soft tissues of carpus during movement. Therefore, the carpus undergoes extension and internal rotation, combined with a little displacement. Carpal movements either flexion or extension, might be affected by laxity of the stabilizing soft tissues, which could contribute to differences between individuals in displacement (Clayton et al., 2004). Faria et al., (2014) reported, carpal joint of older sheep significantly more than young one, but angular displacement of carpal joint was vice versa. This may regard to the former's higher flexibility. High loading rate and absolute loading to the structures of the carpus leading to these changes in movement and displacement have been suggested as factors leading to joint injury. Besides, Overextension has been considered to be an important component in carpal joint injury (Johnston et al., 1997). The forces associated with carpal loading during stance could play a role in the etiology of carpal fractures and development of carpal injuries (Clayton et al., 2004).

5- CONCLUSIONS

It was concluded that large sized camels showed significant higher degree of extension of carpal joint than small camels especially right carpal joint during normal gait with hyperextension occasionally occur. Additionally, velocity of small camels was significantly higher than velocity of medium sized camel of the same limb. This is may be attributed to anatomical and histological structure of carpal joint as articular surfaces with ligaments and tendons fixation. Meanwhile, we recommended the veterinarian to decrease the high loads to the dromedary camels and handle the dromedary camel from left side to avoid overextension and risk of carpal joint injuries. The present findings will be a helpful method in lameness diagnosis to recognize between the normal and diseased gait and surviving the inhabitant environment.

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