

Radiographic measurement of canine stifle joint angles using four different landmark methods

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Received April 28, 2021

Accepted November 9, 2021

Abstract

This study was conducted to compare angles physically set on the stifle joints of cadaveric limbs of dogs with the results by four different radiographic methods for stifle angle measurement. Thirteen pelvic limbs from various large breeds and skeletally-mature dogs were used. The stifles were fixed at four angles: 125°, 130°, 135° and 140°. Altogether 52 radiographs were done. Each stifle angle set on the cadaver limbs was radiographically measured using four sets of landmarks (the goniometric, long axis, eminence and kinematic methods). We found similarity between angles physically set on cadaver limbs and radiographically measured using the long axis method ($P > 0.05$). The goniometric method showed similarity in group of limbs with the stifle fixed at 140° ($P > 0.05$), and other measurements differed significantly ($P < 0.05$). Eminence and kinematic method measurements were different compared to the angle of fixation of the stifle on the cadaver ($P < 0.05$) but similar compared to each other ($P > 0.05$). The method of stifle joint angle measurement should be considered when comparing similar studies, and also in pre-operative measurements for some tibial osteotomies aimed at stabilizing the joint after cranial cruciate ligament rupture.

Determination of angulation, goniometry, stifle instability, dog

Of all the joints in dogs, the stifle joint is most commonly affected with diseases. Most problems relate to joint instability and osteoarthritis because of degeneration and rupture of the cranial cruciate ligament (CrCL) (Vasseur 2003). A large number of different surgical procedures have been described for the treatment of stifle instability in dogs, and decision-making regarding surgical treatment for CrCL remains controversial. Currently the most commonly used are tibial osteotomies (TO). Nisell, who described the resultant joint force as approximately parallel to the patellar ligament, based the advancement of tibial tuberosity on mechanical model analysis of the human knee (Nisell et al. 1986). Based on these data, Montavon and Tepic proposed that a similar situation exists in dogs, and tibial tuberosity advancement (TTA) would similarly neutralize cranial tibiofemoral shear force in CrCL-deficient stifle joints in dogs (Montavon et al. 2002; Tepic et al. 2002; Tepic and Montavon 2004). Based on experimental *ex vivo* models, it has been confirmed that if the patellar tendon angle (PTA) is approximately perpendicular, these shear forces are neutralized and the point is referred to as the “crossover point” (Apelt et al. 2007; Miller et al. 2007; Kipfer et al. 2008; Hoffmann et al. 2011).

An idealized mid-stance stifle angle of 135°, necessary for preoperative planning for some tibial osteotomies, has been proposed from kinematic gait studies, with well-defined anatomical landmarks used to determine the stifle angle (Allen et al. 1994; Schaefer et al. 1998; Tepic et al. 2002; Kipfer et al. 2008; Hoffmann et al. 2011). The most commonly used were as follows: the greater trochanter of the femur, the lateral malleolus of the fibula, and a point of rotation between the fibula head and the femur (Allen et al. 1994; Schaefer et al. 1998; Montavon et al. 2002). For the sake of comparison, the

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landmarks used for stifle joint angle measurement in *ex vivo* clinical studies are not described (Apelt et al. 2007; Miller et al. 2007; Kim et al. 2009), and in the clinical case series of TTA, the anatomical landmarks were, the long axes of the femur and tibia, it means that they were different from those described in the kinematic gait studies mentioned above (Hoffman et al. 2006; Lafaver et al. 2007; Stein and Schmoekel 2008; Voss et al. 2008). Consensus is however lacking among authors regarding the optimal landmarks for radiographic determination of the stifle angle. It would be useful to be able to accurately estimate the real stifle angle using radiographically repeatable anatomical landmarks on the pelvic limbs of dogs (Barnes and Owen 2015). Otherwise, there is still a risk of incorrect preoperative measurements for some TO (Bush et al. 2011).

The purpose of our study was to try to define radiographically repeatable anatomical landmarks which would correlate with the goniometric measurement of the stifle angle set physically on cadaver limbs. In connection with this we hypothesized that if we were able to determine the centre of the medial condyle on the radiographs using the Blumensaat's line, then the radiographic measurement might correlate with the angle set on the cadaver limbs according to the goniometer (Barnes and Owen 2015).

Our second aim was to compare the angles set physically on cadaver limbs with the angles measured using different radiographic methods (RM), and we assumed that the angles set on the cadavers would differ from those measured by means of RM, except the first one as mentioned above.

Finally, we wanted to compare individual RM with each other, and we hypothesized that the use of different landmark methods would result in different stifle angles being measured.

Materials and Methods

We used thirteen pelvic limbs from various skeletally-mature dogs weighing in excess of 25 kg, euthanized for reasons unrelated to this study. Prior to measurement the stifle joints were radiographically evaluated for any signs of degenerative diseases, and affected ones were excluded. Each limb was harvested by disarticulation of the coxofemoral joint.

The limbs were placed in the medio-lateral view, such that the head of the femur, the stifle and the tibiotarsal joint were all positioned on the cassette. Using a standard transparent plastic goniometer, with one arm directed towards the longitudinal axis of the femur and the second arm centred over the medial malleolus of the tibia, the stifle joint angle was measured approximately at the point of the centre of the medial femoral condyle. We used the centre of the proximal and middle part of the diaphysis of the femurs because the limbs were positioned on the lateral side on the table, so we could not use the line connecting with the great trochanter as it was used by Jaegger et al. (2002). We linked these two points with the centre of the medial condyle of the femur. The stifles were physically positioned at four angles: 125°, 130°, 135° and 140°. Each limb was fixed at the desired angle with intramedullary pins drilled into the proximal part of the femur and the distal part of the tibia, and held in a frame for external fixation of bone fractures (Standard fixation, Veterinary instrumentation, UK) at the required angle. The inclusion criterion for the radiographs was superimposition of the femoral condyles within a maximum tolerance of 2.0 mm. The total number of radiographic images recorded in this study was 52.

For radiological determination of the stifle angles, four different methods of landmarking were used and applied to the radiographs (Plate IV, Fig. 1). These were as follows:

The goniometric method (GM)

The long axis of the femur was defined as the line connecting the midpoint of the shaft in the minor trochanter region with the centre of the medial condyle of the femur. The centre of the condyle was defined with the Blumensaat's line, as a tangent drawn along the roof of the intercondylar notch and separating the articular surfaces of the condyles (Blumensaat 1938; Barnes and Owen 2015). The axis of the tibia was defined as a line connecting the midpoint of the most distal part of the tibia just above the tibiotarsal joint and the centre of the medial condyle of the femur.

The long axis method (LAM)

The long axes of the femur and tibia were defined based on the lines between the two shaft midpoints in the proximal and middle parts of the femoral length, and the two shaft midpoints in the distal and middle parts of the tibia.

The eminence method (EM)

This was defined as the angle between the greater trochanter of the femur, the midpoint of the tibial intercondylar eminence and the midpoint of the most distal part of the tibia just above the tibiotarsal joint.

The kinematic method (KM)

This measured the angle between the greater trochanter of the femur, the midpoint of the distance between the distal sesamoid bone m. gastrocnemii and the fibular head just caudal from the femoral condyles, and the midpoint of the most distal part of the tibia just above the tibiotarsal joint (Bush et al 2011).

All radiographic measurements were repeated two times with a three-month interval, by the same observer, who was appropriately trained and familiar with the stifle anatomy. For each of the two assessments, radiographs were presented in a random order to help ensure on the second occasion that the observer was unaware of their initial angle.

Statistical analysis

Measured values were expressed as means \pm standard deviations. One-way analysis of variance (ANOVA) was performed to compare groups with continuous data which were normally distributed according to the results of the Shapiro-Wilk normality test. Tukey's multiple comparison was used as the *post hoc* test for comparison of individual radiographic methods. For evaluation of differences between the RM and the angles physically set on the cadaver limbs, we used Dunnett's multiple comparisons test as the *post hoc* test. Significance determining the difference between the groups was considered for a *P* value of 0.05.

Intra-observer agreement was evaluated with the two-way random single measures intra-class correlation coefficient for absolute agreement (ICC 2,1) (Shrout and Fleiss 1979). Measurements were grouped by segregating the first and second rounds. The Intra-class correlation coefficient (ICC) ranged from 0 (no agreement) to 1 (perfect agreement). An ICC $<$ 0.5 was considered as indicating poor reliability, values between 0.5 and 0.75 indicated moderate reliability, values between 0.75 and 0.9 indicated good reliability, and values greater than 0.90 indicated excellent reliability (Koo and Li 2016).

All statistical analyses were performed using the IBM SPSS version 27 statistical software.

Results

A total number of 13 stifles were included in this study, and 52 radiographs were evaluated. Results are shown in Table 1 and are presented separately, divided into groups according to the angles set on the cadaver limbs.

Table 1. Mean values, standard deviations and 95% confidence interval of individual radiographic methods shown separately according to angles set on cadaver limbs. Values are expressed in degrees.

C	GM		LAM		EM		KM	
	M \pm SD	95 % CI	M \pm SD	95 % CI	M \pm SD	95% CI	M \pm SD	95% CI
125	132.4 \pm 5.0	130.2–134.6	126.4 \pm 4.5	124.4–128.4	143.3 \pm 4.2	141.5–145.2	146.7 \pm 4.9	144.6–148.9
130	136.9 \pm 4.7	134.8–139.0	127.6 \pm 5.4	127.6–132.5	146.9 \pm 4.6	144.9–148.9	150.3 \pm 4.7	148.2–152.4
135	141.0 \pm 5.2	138.7–143.3	133.3 \pm 6.3	130.5–136.1	150.6 \pm 6.1	147.9–153.3	154.2 \pm 6.6	151.2–157.1
140	144.0 \pm 5.5	141.5–146.4	136.8 \pm 6.5	133.9–139.6	153.4 \pm 5.6	150.9–155.9	157.7 \pm 6.4	154.9–160.5

M - mean value; SD - standard deviation; 95% CI - confidence interval; C - Cadaver; GM- goniometric method; LAM - long axis method; EM - eminence method; KM - kinematic method.

Table 2. Comparison of angles set physically on cadaver limbs with individual radiographic method results. Values are expressed in degrees.

C	RM	Mean difference	P value
125	C vs. GM	7.44	< 0.05
	C vs. LAM	1.40	> 0.05 ^a
	C vs. EM	18.35	< 0.05
	C vs. KM	21.74	< 0.05
130	C vs. GM	6.90	< 0.05
	C vs. LAM	0.04	> 0.05 ^a
	C vs. EM	16.91	< 0.05
	C vs. KM	20.31	< 0.05
135	C vs. GM	6.01	< 0.05
	C vs. LAM	1.67	> 0.05 ^a
	C vs. EM	15.62	< 0.05
	C vs. KM	19.18	< 0.05
140	C vs. GM	3.95	> 0.05 ^a
	C vs. LAM	3.24	> 0.05 ^a
	C vs. EM	13.43	< 0.05
	C vs. KM	17.69	< 0.05

C - angle set on cadaver limb; RM - radiographic method; GM - goniometric method; LAM - long axis method; EM - eminence method; KM - kinematic method; ^a - non-significant difference

Comparisons of angles set on cadaver limbs and individual radiographic measurements are shown in Table 2. We found no significant differences between angles set on the cadaver limbs and angles measured by the LAM in any angle group, with a mean difference of 1.4° ($P = 0.62$) in the 125° group; 0.04° ($P = 0.99$) in the 130° group; 1.67° ($P = 0.69$) in the 135° group, and 3.24° ($P = 0.15$) in the 140° group. Significant differences were found between angles set on the cadaver limbs and angles measured by the GM in three groups, with a mean difference of 7.44° in the 125° group; 6.9° in the 130° group; 6.01° in the 135° group; there was no significant difference in the 140° group with a mean difference of 3.95° ($P = 0.06$). The two other methods (EM and KM) differed significantly from the angles set on the cadaver limbs in all four angle groups ($P < 0.05$).

Significant differences were observed comparing the measured angles between most RM ($P < 0.05$) in each angle group, except between the EM and KM (Table 3, Fig. 2).

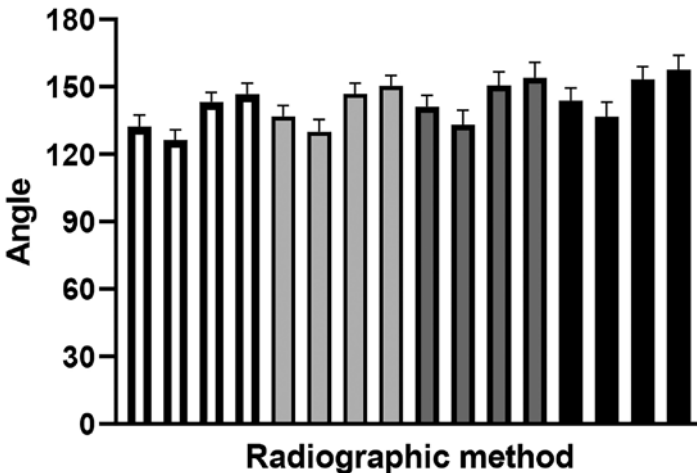


Fig. 2. Mean values and standard deviations of radiographic methods.

Different colours represent individual angles set on cadaver limbs: white - 125°, light grey - 130°, dark grey - 135°, black - 140°. Columns from left to right represent radiographic methods: 1) goniometric method, 2) long axis method, 3) eminence method, 4) kinematic method.

Table 3. Comparison of individual radiographic methods in each group of measurements based on different angles fixed on cadaver limbs. Values are expressed in degrees.

C	Rm	Mean difference	P value
125	GM vs. LAM	6.03	< 0.05
	GM vs. EM	10.91	< 0.05
	GM vs. KM	14.30	< 0.05
	LAM vs. EM	16.94	< 0.05
	LAM vs. KM	20.33	< 0.05
	EM vs. KM	3.38	> 0.05 ^a
130	GM vs. LAM	6.85	< 0.05
	GM vs. EM	10.00	< 0.05
	GM vs. KM	13.40	< 0.05
	LAM vs. EM	16.86	< 0.05
	LAM vs. KM	20.26	< 0.05
	EM vs. KM	3.40	> 0.05 ^a
135	GM vs. LAM	7.68	< 0.05
	GM vs. EM	9.61	< 0.05
	GM vs. KM	13.17	< 0.05
	LAM vs. EM	17.29	< 0.05
	LAM vs. KM	20.85	< 0.05
	EM vs. KM	3.55	> 0.05 ^a
140	GM vs. LAM	7.19	< 0.05
	GM vs. EM	9.47	< 0.05
	GM vs. KM	13.73	< 0.05
	LAM vs. EM	16.67	< 0.05
	LAM vs. KM	20.93	< 0.05
	EM vs. KM	4.25	> 0.05 ^a

C - angle set on cadaver limb; RM - radiographic method; GM - goniometric method; LAM - long axis method; EM - eminence method; KM - kinematic method; ^a - non-significant difference

was 0.06, which was almost a significant difference. Another *ex vivo* study in which the authors evaluated the reliability of goniometry by comparing goniometric measurements with radiographic measurements found no significant differences between goniometric and radiographic measurements (Jaegger et al. 2002). In the study, the authors did not define the exact point of the condyle at which they made their radiographic measurements, and they used the greater trochanter for the femoral axis, which was not what we did. In addition, the radiographic measurements were done by one observer only once. To our knowledge, only one study has used the Blumensaat's line to measure stifle angles in dogs. The authors have reported that the Blumensaat's line provided a useful consistent radiological landmark on the distal femur for the assessment of stifle joint angulation (Barnes and Owen 2015). Our intra-observer measurements (ICC Gm- 0.97) confirmed that the Blumensaat's line is a replicable and constant feature for radiographic measurements. The angles set on the cadaver limbs using a goniometer differed significantly from the radiographic measurements using the GM. One of the possible reasons for this difference is that we measured the angles on the cadaver limbs still bearing the soft tissues, which may have led to slightly inaccurate locating of the centre of the medial epicondyle. The lastly mentioned study was conducted on client-owned dogs, and the authors did not use a goniometer but a neutral stifle angle

The mean difference between measurements by the EM and KM in the 125° group was 3.38° ($P=0.08$); in the 130° group it was 3.40° ($P=0.1$); in the 135° group it was 3.55° ($P=0.22$) and in the 140° group it was 4.25° ($P=0.09$).

For intra-observer measurements we used all values from each method, without respect to the groups according to which the measurements were previously performed. We compared all values obtained from each radiographic method, measured twice at a three-month interval. The ICC was excellent for each radiographic method: 0.97 for GM; 0.94 for LAM; 0.96 for EM and 0.95 for KM.

Discussion

Firstly we hypothesized that if it were possible to determine the centre of the medial condyle on the radiographs using the Blumensaat's line, then the radiographic goniometric measurements would correlate with the angles set on the cadaver limbs according to the goniometer. We found significant differences between the angles set on the cadaver limbs and radiographic goniometric measurements in all groups except the 140° group, where the P value

(nSA) for radiographic positioning, which was physiological for each particular dog. In addition, they used the mechanical axis of the femur rather than the mid-shaft line as we did, so the results cannot be compared.

We did not find significant differences between the angles set on cadaver limbs and the LAM in any group. Significant differences were found between angles set on cadaver limbs and angles measured by the GM in three groups but was no significant difference was found in the 140° group, while the other methods differed significantly in all groups. By comparing individual RM, we found significant differences between all of them, except between the EM and KM. This finding almost completely supports the hypothesis that using different radiographic landmark methods would result in different stifle angles, which may subsequently affect the calculated advancements of some tibial osteotomies. According to the findings of another study, the use of different anatomical landmark methods for stifle angle determination can also result in different angles, and finally influence the value of the required advancement of tuberositas tibiae in the TTA procedure. The study did not identify the clinically relevant TTA required to achieve a PTA of 90° using the EM and KM methods, only greater advancement with the LAM (Bush et al. 2011). Our results are similar, with large discrepancies found between the LAM vs. EM and KM but no significant difference between the EM and KM.

There are many considerations regarding the pre-planning of TTA, but the aim of each plan is to achieve a perpendicular post-operative PTA (Kapler et al. 2015). Some of these methods require the joint to be set close to full extension, at approximately 135°, which is the average midstance stifle angle at the walk and trot, as determined in kinematic gait studies with well-defined landmarks (Allen et al. 1994; Schaefer et al. 1998; Tepic et al. 2002; Kipfer et al. 2008; Hoffmann et al. 2011). In contrast, the landmarks used for measuring stifle angle in *ex vivo* clinical studies reporting the TTA surgical procedure are not described (Apelt et al. 2007; Miller et al. 2007; Kim et al. 2009). Consequently, during TTA planning, if the stifle is positioned at 135° using inappropriate landmarks, the resultant stifle angle may actually be more flexed or extended than the required 135° angle determined in kinematic studies. This situation can affect the PTA, because stifle joint flexion is a major contributor to the PTA, with a linear decrease in the PTA with increasing flexion (Dennler et al. 2006). The landmarks for angle measurement, if they are described, vary among the studies (Jaegger et al. 2002; Dennler et al. 2006; Lafaver e al. 2007; Voss et al. 2008; Hoffmann et al. 2011; Millet et al. 2013; Cadmus et al. 2014). If the stifle is not at a true 135° angle because of a discrepancy between the methods of angle measurement, or the midstance angle of 135° cannot be applied to all dogs, then radiographs from standing dogs should be made to determine the real neutral angle of the joint. Pre-operative measuring using inappropriate radiographs may result in under- or over-advancement of the tibial tuberosity. Residual cranial tibial translation is a potentially clinically important post-operative finding after TTA. The high number of meniscal tears associated with TTA in the initial phase of clinical introduction may be due, at least in part, to residual cranial translation. Numerous theories have been proposed for under-advancement during TTA (Meeson et al. 2018). A recent study reported that the selection of a larger cage size during TTA may be advantageous to compensate for under-advancement and to minimize the risk of residual cranial tibial translation (Jin et al. 2018). In light of another recent study which showed that 70% of TTA dogs had persistent post-operative femorotibial subluxation on weight-bearing radiographs, any combination of methods that would lead planners to select a larger advancement cage size may be warranted (Skinner et al. 2013). One of the possible reasons for the results of these studies is an inaccurate pre-operative assessment due to incorrectly measured angles in the stifles, as the procedure for measuring the joint angle is not precisely defined and the available methods provide different results.

A single observer was responsible for all measurements in this study, but for that reason they were done twice. Determination of the Blumensaat's line is subjective, although it is a distinct landmark and there should not be a wide inter-observer variation in its assessment. The limbs of large dogs of various breeds were used in this study, whereas there may be differences between the angles in the stifle joint of small breeds due to differences in their bone formation.

In conclusion, we found large discrepancies between the angles set physically on the cadaver limbs and the radiographic measurements, except for the LAM, and also between individual RM, except EM and KM. These results suggest that using different radiographic landmark methods results in different stifle angles, which may have a negative impact on further measurements. The specific stifle angle measurement method should be considered when comparing similar studies, and also in pre-operative measurements for some tibial osteotomies aimed at stabilizing the joint.

Acknowledgement

This study was supported by the Ministry for Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Sciences through VEGA project no. 1/0561/19.

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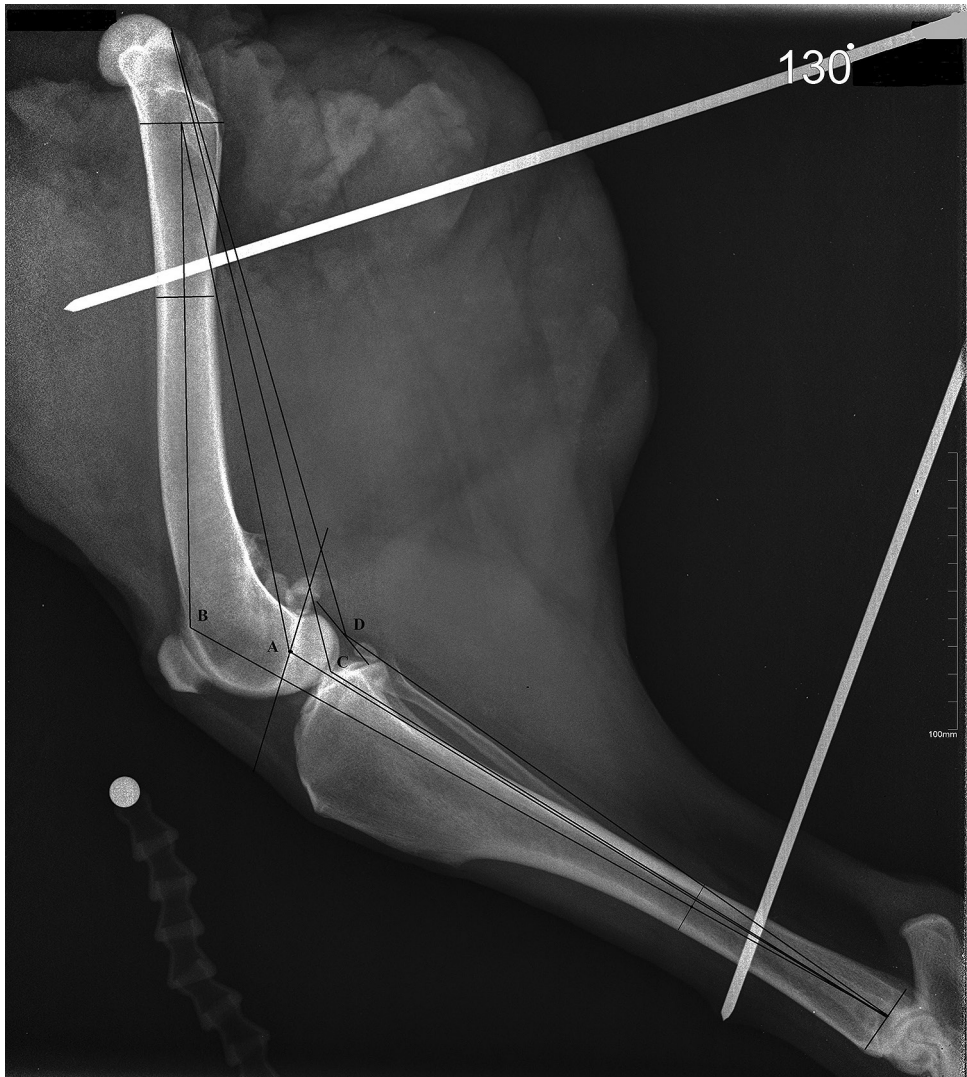


Fig. 1. Radiographic representation of landmarks used to determine the stifle angle. The stifle joint is fixed at 130°. A - goniometric method, B - long axis method, C - eminence method, D - kinematic method