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Hip geometry measures can predict femoral neck and intertrohanteric fractures. Controversies in literature.

Geometrija mjera kuka kod predviđanja prijeloma femoralnog vrata i intertrohanterične frakture: proturječja u literaturi

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Summary

The most commonly used proximal femoral fracture measures for predicting femur neck and intratrochanteric fractures are femoral axis length (FAL), hip axis length (HAL) and the derived Q angle measure (neck-shaft angle). The listed measures only consider the relationship between the diaphysis and the femoral neck but not also between the femoral head and neck. These measures assume the femoral head as an ordinary extension of the neck with an irrelevant position of the head's centre in relation to the neck axis. Anatomical research has shown that the quotient of the superior and inferior offsets (SOS/IOS) in human anatomy is different than 1 and that the gamma and delta angles are not equal.

These controversies, the mismatch of the definition for measures used in anticipating proximal femur fractures with anatomical reality, have not yet been listed in literature

Ključne riječi: Hip, geometry, fracture

Sažetak

Najčešće korištene mjere proksimalne femoralne frakture kod predviđanja prijeloma femoralnog vrata i intertrohanterične frakture su dužina femoralne osi (FAL), dužina osi kuka (HAL), te izvedena mjera Q kuta (kut središnjeg djela duge kosti). Navedene mjere samo uzimaju u obzir odnos između dijafize i femoralnog vrata ali ne između femoralne glave i vrata. Ove mjere uzimaju femoralnu glavu kao običan produžetak vrata s irelevantnim položajem središta glave u odnosu na osi vrata. Anatomsko istraživanje pokazalo je da je kvocijent viših i nižih odmaka (SOS/IOS) u ljudskoj anatomiji drugačiji za 1, te da gama i delta kutovi nisu jednaki. Kontroverzije, neslaganja definicija za mjere korištene kod procjene proksimalne frakture femora s anatomskom stvarnosti još uvijek nisu navedene u literaturi.

Key words: Kuk, geometrija, fraktura

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Introduction

Hip fractures are significant personal, familiar and public health problems disrupting the quality of life of patients and their families, and adding to health care system costs.[1-3] Globally, every year, about 1,700,000 people sustain a hip fracture,[1-3] and it is estimated that their number will rise to 6,500,000 in the next 30 years.[4-7] Furthermore, hip fracture patients take up 25-50% of trauma surgery beds,[1,5,6] and it is estimated that the annual cost of treatment of 340,000 hip fractures, occurring in the USA alone, ranges from 10 to 14 billion dollars.[4-7] About 50% of hip fracture patients do not regain anything resembling movement ability and general physical activity levels (i. e. ADL-Katz scale degree) they enjoyed prior to the injury.[1-4] Hip fracture mortality rate ranges from 20 to 36% in the first year after the sustained injury.[2-4] About 95%

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of the hip fractures are a consequence of falls, and about 25-30% of people above 65 years of age fall at least once a year, and the fractures occur in about one fall in five.[5] All of the above establishes sound reasons for preventive diagnosing of people at risk of hip fractures. Interest in hip geometry arose in the mid-19th century, primarily in response to orthopaedic and forensic research, and the term itself first appeared in the works of Cooper.[8] In 1975, Phillips et al.[9] published the first paper where hip geometry also addresses identification of individuals exposed to hip fracture risk based on anteroposterior hip projection radiogram. A hip may be viewed, in engineering terms, as a structure whose strength is defined by material quality, geometry of the structure and degree of loading.[10-15] Research performed in the past indicates that hip geometry is a fracture prediction variable independent of bone mineral density (BMD), as pointed out by a series of papers.[16-26] Hip geometry is far more resistant to the effects of medication, metabolic diseases, bodily inactivity and diet in an adult age than BDM. Therefore, hip geometry is more reliable for the forecast of hip fractures as an independent variable, than the patient's age and BDM.[10-29]

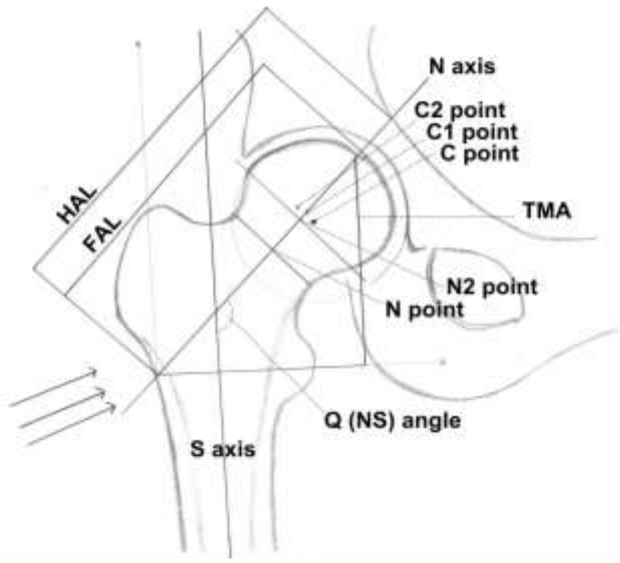
The most common hip geometry measures used in risk estimation for femoral neck fractures

The to-date publications on anticipating femoral neck and intertrochanteric fractures based on hip geometry, usually use femoral axis length (FAL), hip axis length (HAL) and femoral-shaft angle (NSA) (commonly marked as Q angle),[9-27,35-39] (Picture 1).

Faulkner et al[10] published the following results which were analyzed using multiple logistic models, and odds ratios were determined. After age adjustment, each standard deviation decrease in femoral neck bone mineral density, increased hip fracture risk 2.7-fold (95% confidence interval 1.7, 4.3), and each standard deviation increase in HAL nearly doubled the risk of hip fracture (odds ratio = 1.8; 95% CI 1.3, 2.5). The relationship between HAL and fracture risk persisted even after age adjustment, femoral neck density, height, and weight. A longer hip axis length was associated with an increased risk of both femoral neck (OR = 1.9; 95% CI 1.3, 3.0) and trochanteric fractures (1.6; 1.0, 2.4). Almost all publications on hip geometry have a very similar result of increased fracture risk with longer HAL, FAL and a wider NSA. Im and Lim in their study showed results of HAL ($p = 0.046$) and NSA ($p = 0.003$) which were significantly greater in patients with interrochanteric (IT) fracture than in control patients, while neither parameter was significantly greater in patients with femoral neck fractures than control patients.

In patients with IT fractures, the fracture risk increased 1.64-fold ($p = 0.048$) with a 1 SD increase of the HAL, while it increased 2.32-fold ($p = 0.003$) with a 1 SD increase of the NSA.[40]

Ulusoy et al[41] research results showed that HAL, FAL and true moment arm (TMA) were significantly longer in the hip fracture subjects compared to the control group ($p < 0.001$). NSA was wider in the hip fracture group than in the control group ($p < 0.001$).



Picture 1 / *Slika 1.*

HAL (hip axis length) – a part of the Neck axis (N axis) from the trochanter's lateral edge to the acetabulum's inner edge
FAL (femoral axis length) – a part of the N axis from the trochanter's lateral edge to the femur head edge
Q angle – the angle between the N axis and the S axis
N axis – determined are the N and N2 points which are equally distanced from the upper and lower edge of the neck.
Shaft axis (S axis) – also determined by at least 2 points same as the N
C, C1, C2 – possible positions of the femur's head centre in relation to N axis
TMA (true moment arm) = sin (Qangle-90°)x FAL

HAP (dužina osi kuka) – dio N osi trohanterskog lateralnog ruba do unutarnjeg ruba zdjeličnog čaška
FAL (dužina femoralne osi) dio N osi iz trohanterskog lateralnog ruba do glave femura
Q kut – kut između N osi i S osi
N os – određene su točke N i N2 koje su jednako udaljene od gornjeg i donjeg ruba vrata
Os središnjeg djela duge kosti – također određuju dvije posljednje točke kao kod N
C, C1, C2 – moguće pozicije središnje glave femura u odnosu na N osi
TMA (parametar) = sin(Qangle-90°)x FAL

In conclusion, their study showed that the evaluation of TMA in addition to HAL, FAL, NSA, can be used to determine fracture risk independently of BMD. Moreover, based on ROC curve, a TMA length with sensitivity of 44.1%, specificity of 94.4% ($p = 0.006$) is more reliable than the HAL i FAL in detecting people with a hip fracture risk.

However, Center et al.[22] reveal no significant differences of the FAL and HAL lengths in experimental and control groups, while some authors found shorter FAL and HAL in patients who sustained hip fractures, in contrast to other published data.[41,42] Gašpar and Crnković[44] find causes of this contradiction in diverse definitions of control and experimental groups in terms of their age, sex, race, BIM, BDM, radiogram position, differently defined fracture groups (in different combinations of intertrohateric and neck fracture) as well as measurement errors.

All these studies, as most of the listed publications, use the measures definitions HAL, FAL, NSA, and others which were most vividly described according to Michelotti and Clark[24] In short, the HAL, FAL, OFF (distance of head centre from shaft axis), NL (distance from shaft axis to the head centre measured along the central axis of femoral neck), clearly present the femur's neck centre as the key part of the N axis (neck axis).

Picture 1 shows the construction of the N and S axis and the size of currently known measures HAL, FAL and Q (NS) angle and TAM and the possible location of the femur's head centre (C) in relation to the N axis (C- the anatomical centre of the head in this case; C2- the possible anatomical position of the head's centre also above the N axis; C1- in previous studies on hip geometry including an unanatomical position of the head's centre on the N axis). An axis is a direction determined by at least two points which are equally distant from the edges of the neck and diaphysis.

The N point, is equidistant from the upper and lower edges of the femoral neck radiogram shadow in the anteroposterior position projection at the narrowest portion of the femoral neck.[45,46]

The N axis (neck axis) runs through the N point and another point (N2 point) equidistant from the upper and lower edges of the femoral neck, corresponding in definition to the S axis (diaphyseal shaft). The N axis and the S axis form the colodiaphyseal or neck-shaft angle, also frequently designated as the Q angle. It is measured, using a goniometre, in degrees equal to 1/360 of a full circle.

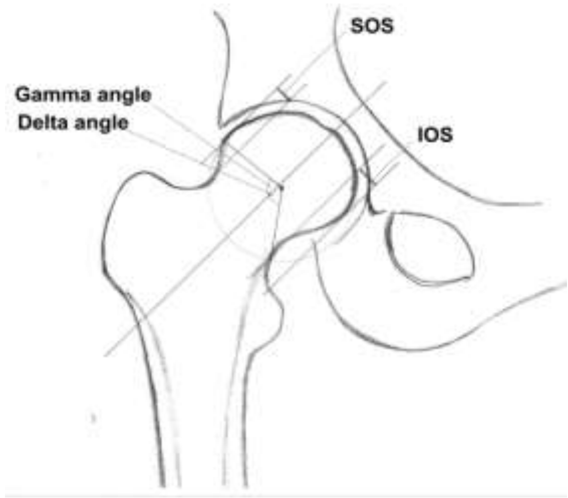
HAL (hip axis length) is a line between the lateral section of the greater trochanter base and the internal edge of the pelvic ring. FAL (femoral axis length) is shorter than the HAL by width of the acetabulum and the joint ring at the N axis location. The measurements are expressed in millimetres.

Ulusoy[41] introduced a new measurement – the true moment arm (TMA). The authors specify that the load generated by ground impact in sideways falls is distributed along two vectors, one parallel and the other perpendicular to the diaphyseal shaft – the S axis (Picture 1 – bolded arrows, hip impacting the ground). This perpendicular load leads to the neck fracture, and its size depends on the angle between the neck axis and the femoral diaphyseal shaft (indicated as the Q-angle, Picture 1) and the FAL, as described by the following equation: $TMA= \sin(Qangle-90°)xFAL$. The TMA is a more specific and more sensitive hip geometry measurement used in fracture prediction than the HAL, FAL and Q-angle. The authors propose that the acetabular bone and joint fracture width, in a biomechanical sense, are not significant to femoral neck fracturing, and that the femoral head medial border, representing a support, plays a role in neck fracturing.[41] As the TMA increases, i.e. as the Q-angle and the FAL increase, the load required to fracture a hip decreases.

Faulkner et al.[10] promoted the moment arm (MA), likewise perpendicular to the load vector leading to the femoral neck fractures. However, the paper applies the HAL instead of the FAL in the equation, thereby limiting the effectiveness of the MA after proving that the HAL is positively correlated with the neck width. An increased neck width compensates better[10] for the effects of the moment arm (MA).

Are the listed hip geometry measures for anticipating femoral neck fractures compatible with anatomical facts?

Picture 2 shows the construction of SOS and IOS, their anatomical relation and anatomical relation of gamma and delta angles in normal human population.[46] The length of FAL and HAL and NS angles, which describes the relation between the S and N axis, do not consider the anatomical relation of the head and neck but only the relation of the femoral neck and diaphysis. The position of the femoral head's centre to the N axis is irrelevant for the listed measures. Moreover, these measures assume that the position of the femoral neck's head is possible on the N axis. The head to neck relationship is defined by translation, rotation and concavity of the junction.[46-48] The head and neck translation is defined by the quotient of superior and inferior offsets (SOS/IOS) in the hip radiograms at the anteroposterior projection.



Picture 2 / *Slika 2.*

In normal human anatomy SOS/IOS are not equal to 1 and the gamma and delta angle are not the same. The previously used measures for hip geometry (HAL, FAL, Q angle), however, have allowed such possibility.

U normalnoj ljudskoj anatomiji SOS/IOS nisu jednaki te gama i delta kutovi nisu jednaki. Ali ranije korištene mjere za geometriju kuka (HAL, FAL, Q kut) dozvolile su navedene mogućnosti.

The upper bone segment is the vertical separation of two lines parallel to the N axis, one tangent to the concave curvature of the femoral neck, and the other tangent to the concave curvature of the femoral head. The lower bone segment (IOS) is defined in the same way. In normal human anatomy, SOS/IOS does not equal to 1.[46] FAL and HAL assume that the femoral head's centre is on the N axis, and that the SOS/IOS is possible and equal to 1. The rotational relation of the head and neck is defined by an angle which consists of the N axis and the epiphiseal scar which is though sometimes hard to spot on the radiogram,[46-48] so that we won't consider this any further because of the listed variability.

Notzli et al.[48] define the head and neck junction concavity through the gamma and delta angles. The gamma angle is defined by the N axis and an axis running through the C point, and the first point on the cortical upper surface of the head and neck junction departing from a perfect circle representing an ideal femoral head curvature.[46] The delta angle is defined similarly, using the junction of the C point and a corresponding point on the lower neck corticalis.[46]

In normal human anatomy, the gamma and delta angles vary,[46] while the FAL and HAL assume that the two angles match (Picture 2).

The research results of Toogood et al[46] show, amongst other, the following: mean, including male and female, SOS/IOS is 0.90, standard deviation (SD) 0.39, range (R) 0.16-2.66, for male 0.84, SD 0.37 ($p < 0.01$), female 0.97, SD 0.39 ($p > 0.01$). Gamma angle- in the male and female group mean 53.46°, SD 12.56°, R 31.21°- 111.50° and delta angle together in the male and female group mean 42.95°, SD 4.86°, R 26.83°- 60.80°. The correlation between SOS/IOS and gamma angle is -0.5 Pearson`s coefficient, and the correlation between SOS/IOS and delta angle is 0.73 Pearson`s coefficient. The author himself concludes "Although the femoral head often is described as centred on the neck, our data suggests that its true position is more often slightly anterior and inferior".[46]

From all limitations researches have in anticipated the risk of intertrohaterial and neck fractures based on geometry. Also sure is the fact that the distances were measured on the anterior-posterior radiogram. This way of imaging describes the three-dimensional structures of the proximal femur as two-dimensional.

On the basis of the above facts, we conclude that the femoral head relative to the neck of the femur is positioned slightly inferior, not being centred as we have seen from the quotient of the superior and inferior offsets (SOS/IOS), which in human anatomy is different than 1. By working on the skeleton of the proximal femur, anatomists conclude from the quotient of anterior and posterior offset (AOS/POS) that the femoral head is positioned anterior in relation to the femoral neck.

Conclusion

Most of the to-date publications on anticipating femoral neck fractures from hip geometry measures have shown that the hip axis length (HAL) and femoral axis length (FAL) as the Q (neck-shaft) angle are acceptably specific and sensitive in patients at highest risk. TMA has shown to be an even more specific and sensitive measure for hip geometry than the previously listed ones. All four measures HAL, FAL, Q angle and TMA are not synced with anatomical facts on relationships between the femoral neck and head.

The head is not an ordinary extension of the neck without any biomechanical role in the creation of femoral neck fractures.

HAL, or the shortened variant FAL, allows the possibility for the head's centre to be on the neck's axis (N axis) and the possibility for the gamma and delta angles to be equal, which they are not as anatomical studies have shown. But the cognition remains that the listed hip geometry measures with the NS angle and TMA can diagnose risky individuals for hip neck fractures before the fracture occurs with sufficient specific quality and sensitivity and can use appropriate measures to prevent femoral neck fractures.

We suggest, for future research, the development of hip geometry measures which will include the head and neck relationship, so we could bring the measures closer to anatomical reality. Also, the development of diagnostic protocols for patients with a risk of femoral neck fractures based on hip geometry should be done.

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