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Original Research

The Comparison of the Break Pattern of the Femoral Neck in both Normal and Abnormal Angles (Coxavara, Coxavalga) in Active and Non-Active Postmenopausal Women using Finite Element Method

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ABSTRACT

Fracture of femur is considered as one of the most significant causes of disability and death, especially among the elderly people. Therefore, there is a global effort towards non-invasive assessment of the femoral fractures. The purpose of the present research was to compare the femoral neck fracture pattern in both normal and abnormal angles in active and non - active postmenopausal women.

In this way, 20 postmenopausal women (54.2±2.5 years) were selected as active and non-active groups among all of the patients that registered in the CT scan department of the city hospital during the past three years. In this way, some parameters such as: the geometric data, density of the bone and also the type of bone based on their angles including Coxavara and Coxavalga of the hip joint were calculated by CT-Scan device.

The experimental and computational analysis of fracture patterns were carried out using Finite element method, whereas the model was simulated by 3D Max software. For statistical analysis after using kolmogorov smirnov tnormalization test, two-way ANOVA and Pearson correlation tests were used. Moreover, the data were analyzed with Abacus and SPSS 19 software and the level of significant set as $p \leq 0.05$.

The results showed that there is no significant difference between the femoral neck fracture pattern in both normal and abnormal angles between two groups ($p \geq 0.05$). Moreover, the geometry and density of the femoral neck did not indicate any significant effect on fracture pattern of the hip joint angles. Therefore, it seems that the geometric data could not consider as the predictor indices during fracture pattern of the femoral neck angle in postmenopausal women.

Keywords: Femoral neck angles, Postmenopausal women, Finite element method, Femoral neck fracture

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INTRODUCTION

Bone can be considerd as the most frequently investigated biological material, therefore the Finite Element Analysis (FEA) as a computational tool most commonly used for the analysis of bone biomechanical function (1). FEA has been used in bone research for more than 30 years and has had a substantial impact on understanding of the complex behavior of bone. Therefore, the FEA is useful for understanding the relationship between bone structure and its mechanical function at specific hierarchical levels. A better understanding of the relationship between structure and mechanical function is expected to be important for the current trends in (bio) materials design, where the structure of biological materials is considered as a possible source of inspiration, as well as for more successful approaches in the prevention and treatment of age- and disease-related fractures (1,2). Some research showed that one of the most common fractures around the pelvic joint is neck fractures, which have very important complications in terms of high cost of treatment, length of hospitalization and other important health problems the elderly people (3, 4). Regardless of age, a displaced femoral neck fracture is a severe injury and will almost always require hospitalization and surgery (5). Patients with these fractures have a high risk of subsequent surgical complications, reduced function, hip pain and reduced health-related quality of life.

This damage in the United States has increased from 250,000 in 1995 to 344,000 in 2005 and is projected to reach about 500,000 in 2040 (6), while in Iran this figure is slightly lower than most industrialized countries (7). Fractures of the neck do not have a good prognosis, and one-third of sufferers people die within a year of the fracture, and only about 30-40% of patients with neck fractures can get the previous mobility. It is also reported that more than 50% of these patients suffer from immobility and permanent disability; therefore they need some care to perform their daily activities. Therefore, these problems can reduce their quality of life and also health status (3, 5).

Based on some research, there are significant parameters that can be affect the fractures around the pelvis joint, such as osteoporosis, sedentary lifestyle, poor eating habits, and abnormal angle of the femoral (6,7). Moreover, the angle of inclination as Coxavara or Coxavalga resulting from the head and the shaft of the femur in the transverse plane can be considered as an important factor. In other mean, Coxavara is a deformity of the hip, whereby the angle between the head and the shaft of the femur is reduced to less than 125 degrees. In opposite at the coxavalga the angle increased more than 125 degrees. Increasing this angle (more than 125 degrees) Coxavalga and decreasing this angle (less than 125 degrees) have been introduced by Coxavara. Whereas, the normal adult has an angle of inclination between 120 and 125 degrees, it usually is closer to 125 in the elderly (7, 8).

Some researchers believe that the change at inclination angle could alter the amount and location of forces and pressures on the head and neck of the femur, whereas in people with osteoporosis and during repetitive movements, may cause fractures and other musculoskeletal injuries (9-11).

The unique mechanical properties of bone reflect the need to provide at the same time strength and lightweight design, stiffness and elasticity, the ability to resist deformation and to absorb energy. This is possible because of the complex arrangements in compositional and micro-architectural characteristics of bone as well as continuous adjustments over time in response to dynamic extrinsic and intrinsic factors. Ageing and other factors like estrogen deficiency as during postmenopausal periods can affect these components and eventually result in decreased bone strength and fracture toughness. Osteoporotic fractures, therefore, are the macroscopic result of a sequence of multiple nano- and microstructural events (3, 13, 14).

The Finite Element Method can be considered as one of the most common and useful methods that has been used in medical engineering since 1972. The finite element method is a non-invasive method for designing and analyzing of the bones and joints in the body (15, 16). In this regard, Qian et al. (2009) based on the finite element study examined the relationship between femoral neck structure and fracture. They indicated if the femur - neck angle was less than 125 degrees and the bone density was low, the patient was at a higher risk for femoral neck fracture (11). Therefore, it seems that based on the relationship between femoral neck structure, and also high prevalence of osteoporosis and significant reduction of bone mineral density in Iranian women compared to international standards the identifying of these factors seems to be very important (16). Because these injuries not only increase mortality and reduce life expectancy, rather, it increases the rate of complications such as urinary tract infection, deep vein thrombosis, bed sores, etc. among people with these abnormalities (15-17). On the other hand, middle-aged people are more prone to immobility due to musculoskeletal disorders, which leads to reduction of bone density and, as a result, the geometric deformation of the bone could be happen over time (6). Moreover, with the onset of menopause, the decline rate in bone density of women increases several times, therefore the postmenopausal women are at high risk for osteoporosis and its complications (18, 19). Some studies showed that exercise, along with adequate calcium and vitamin D intake, has a significant effect for increasing bone density (20, 21, 23, 25). In fact, it is one of the most effective, safe and inexpensive ways to prevent or delay osteoporosis. In this way, it is indicated that resistance training not only promotes bone health but also has a direct effect on the overall health of the body by increasing muscle strength, creating balance and coordination in the body. Exercise training has been recommended as a low-cost and safe non-pharmacological intervention strategy for the conservation of musculoskeletal health (22). Although specific mechanisms via which exercise improves bone health are not fully elucidated yet, it is widely accepted that mechanical load induced by exercise training increases the muscle mass, produces mechanical stress in the skeleton, and enhances the osteoblast activity (23, 24). Weight-bearing impact exercise such as hopping and jumping, and/or progressive resistance exercise, alone or in combination can improve the bone health in adults (24). Among them, resistance exercise has been highlighted as the most promising intervention to maintain or increase bone mass and density (18). This is because a variety of muscular loads are applied on the bone during RE, which generate stimuli and promote an osteogenic response of the bone (26, 29).

In this way, Nelson (1994) assessed the effect of high-intensity of stretching exercises on the density of femoral neck and lumbar vertebrae for one year in 40 postmenopausal women. The result indicated that the mineral density of femoral neck and lumbar vertebrae increased by 1%, while the control group showed a decrease in bone density by up to 2.5% (30). Moreover, Exercise training, is important for the maintenance of musculoskeletal health in an aging society. Whereas it exerts a mechanical load on bones consequently leading to increase in the bone strength. Based on the available information, resistance training, either alone or in combination with other interventions, may be the most optimal strategy to improve the muscle and bone mass in postmenopausal women, middle-aged men, or even the older population. Particularly, training seems to be beneficial for the cortical bone. However, several concerns regarding the effects of training on the musculoskeletal system remain to be addressed. On other word, the structure and geometry of the bone can be considered among most important factor of that can be related to level of the bone strength and stiffness against load and resistance to the fracture (26, 29). Therefore, considering the above mentioned, it is necessary to conduct such a study in order to identify some factors that can be effect on fracture of the bones especially the femoral neck fractures. Moreover, due to the geometric deformations of the bone in the elderly due to reduced mineral density, the results of this study can be a good predictor to identify possible injuries and fractures caused by effective engineering deformity of the femoral neck in these people. Therefore, this study was conducted to compare the pattern of femoral neck fracture in both normal and abnormal angles using the finite element method on the population of active and non-active postmenopausal women.

MATERIAL AND METHODS

The present study is a quasi-experimental study where the statistical population of this study was all postmenopausal women referred to Imam Reza (AS) Hospital in Birjand with CT-Scan test, from 2015 to 2019. Among all population (200 people) 20 subject were selected based on physician diagnosis and entry and exit conditions. They divided into two groups as active (10 people) and non-active (10 people) groups.

The inclusion criteria included the subjects did not have any history of hormone therapy, calcium and vitamin-D consumption, skeletal abnormalities or lower limb fractures from 5 years before the study until the implementation. Moreover, the criteria for selecting active from non-active people were their regular activity and inactivity during the last 5 years.

In order to conduct the research, first, a summary of the programs for the subjects was explained by the researchers, then a written consent form was obtained from all participants.

Firstly, the CT scan images were collected with a CT scan machine (Multi Detector CT, Activation 16 model, Toshiba manufacturer, installed in 2014) (Figure 1).

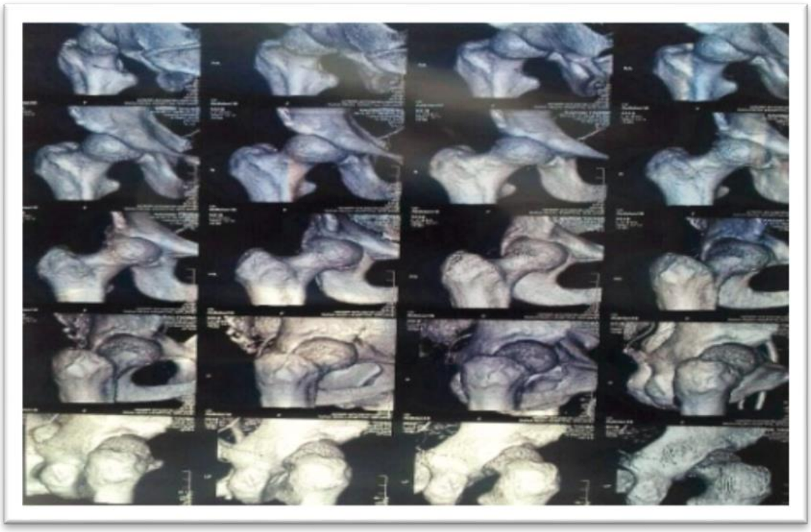

Figure 1. Sample images of CT scan of the femur and pelvis

Then, to obtain the geometric information including: length (mm), diameter (mm), angle (degree) and density (grams per square centimeter), of the femoral neck of the thigh, the CT scan images were corrected and furthers the hard and soft tissue parts were separated.

Every subject were taken 40 CT scans of both pelvis and right leg in the six orientation and 3 planes as posterior, anterior, superior, inferior, medial and external lateral views. After separating these images, in order to build the model, the images were entered into 3D Max software and in 5 steps (model making, binding and creating the model, creating movement and applying forces, determining the required output and results, obtaining the results), The desired bone pattern (Figure 2) was designed (4).

After designing the desired model, this model as a hollow body with elastic modulus properties was entered into Abacus software to analysis the failure pattern and apply load. Therefore, the model was defined as a homogeneous material with a Young's modulus of 14 and a Poisson's ratio of 0.3 (28). Based to this model, when the maximum density of the bone considered 400 gr / cm^3, therefore, the Young's modulus for each group was calculated according to the following formula (8).

Yang modulus of X group = neck bone density in X group × 14/400

Yang Module Group A: 12/84

Yang Module Group B: 12/66

The Young's modulus for each group was applied separately to the neck of the bone, and since the fracture pattern in the neck of the femur was assumed, the density of the rest of the bone was assumed to be constant. The bone layer or its thickness was assumed to be 3 mm based on CT scan images (8). Then, according to the both amount, and direction of the force, the desired forces were applied according to Table 1. In this study, the applied force was considered to be 60 kg (4) [approximately the weight of a postmenopausal woman between the ages of 50 and 60 years].

Table 1. Forces applied to the model

Forces (N)	Fx	Fy	Fz
Joint Contact Force (A)	303.45	-2471.44	0
Abductor Force (B)	-789.14	718.65	0
Adductor Force (C)	-126.55	279.77	0

Therefore at the point of contact of the joint (A), the force of abductor muscles (C), and the force of adductor muscles (B) are as follows:

A: $60^1 \times 4.9^2 \times 10^3$= 2490 N

B: 60 × 0.6 ×10= 360 N

C: 60 × 1.97×10 = 1074 N

1Weight, 2force of the selected muscle, 3Newtoun

For analyzing the force the static load was performed, by using the Abacoss software, in this way, 3 surfaces including the head surface of the femur that is in contact with the acetabulum cavity, the surface attachment of the Gleutues Maximus muscle, and the surface of the Posoas muscle were selected and the rest of the femur was considered fixed, and the load was applied to these surfaces with a certain ratio of weight and angle that already explained. (Figure 2).

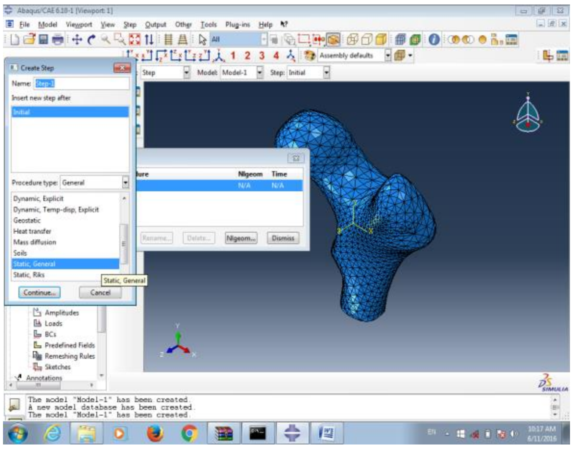

Figure 2. The first stage of applying static load

Finally when the model was properly constructed, the forces and torques also were applied to determine the expected outputs. These information were included the area of onset of load and the maximum tension applied to the femoral neck relative to the forces exerted by the abductor and adductor muscles and also the joint contact force (Figure 3).

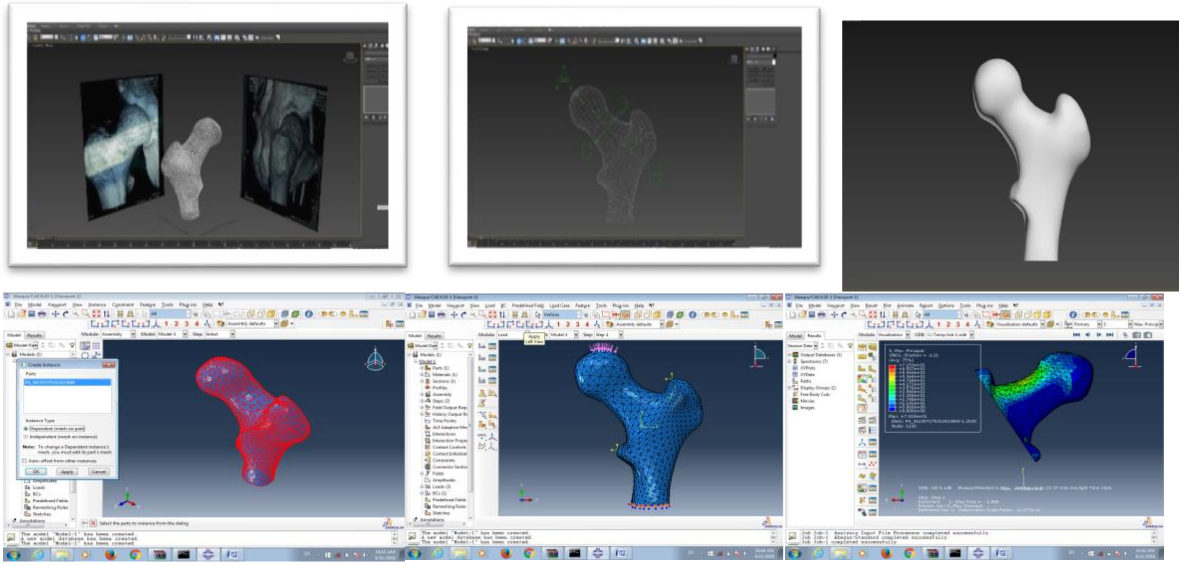

Figure 3. Sample images of bone design steps in 3D Max and Abacus software

It should be noted, because the maximum load were applied at the point of contact of the femoral head with the acetabular cavity, therefore, in this study, the force was analyzed and applied during the foot of the ground (4).

For statistical analysis, the data were analyzed by Shapiro-Wilk normality test, Two-way Anova (3*2) and Pearson correlation coefficient using SPSS 19 software at the level P≤0.05.

RESULTS

The mean, standard deviation, of the all subjects were indicated in Table 2.

Table 2. Basic information of the study population

Variables	Total Group	Non-active group	Active group
Number	20	10	10
Age (year)	54.21±2.5	53.62±3.2	52.81±2.9
Femoral Neck Angle (D)	126.02±5.1	122.23±6.1	124.42±4.3
Length of Femoral Neck (mm)	87.90±2.3	88.42±2.9	88.26±3.3
Width of Femoral Neck (mm)	27.06±1.5	26.96±1.8	27.16±3.0
Femoral Neck D (g/cm^3)	364.4±6.3	361.29±7.3	367.01±4.9

In addition, Two-way Anova (3*2) results were reported in comparison with the femoral neck fracture pattern in the three conditions examined.
Moreover, the level of tension on the femoral neck (femoral neck fracture pattern) were indicated for three groups in Table 3.

Table 3. Comparison the femoral neck fracture pattern of the three conditions (post-hoc Tukey)

Femoral Neck Type	Non-active People/Tension (MegaPascal)	Active People/Tension (MegaPascal)	Pvalue
Normal	4.63±1.23	4.38±0.96	0.86
Coxa-Vara	7.69±1.68	7.27±1.53	0.75
Coxa-Valga	4.16±0.87	4.09±0.80	0.64

Table3 indicated although the tension exerted on the femoral neck was higher in the Coxa-Vara group as compare to the other group, but it was not significant. Therefore, it can be stated that the level of tension that can be cause fracture in the femoral neck were the same for all groups in postmenopausal women ($P \geq 0.05$). In other words, considering that in both models the same force is applied for every angles during foot off the ground in postmenopausal women regardless of the level of their activity. Therefore, it can be concluded that there is no significant difference between the pattern of fracture of the femoral neck at normal angles in active and non-active postmenopausal women ($P \geq 0.05$).

In addition the result of correlation between geometric indices (length, diameter, angle, and femoral neck density) with the femoral neck fracture pattern were depicted in Table 4.

Table 4. Correlation coefficient between geometric indices (length, diameter and angle) and femoral neck fracture pattern

Variables	Mean ± SD	R-value of and femoral neck fracture pattern
Femoral Neck Angle (D)	126.02±5.10	0.06
Length of Femoral Neck (mm)	87.90±2.32	0.12
Width of Femoral Neck (mm)	27.06±1.5	0.38
Femoral Neck Density (g/cm3)	364.40±6.30	0.43

Table 4 shows that there was no significant correlation between femoral neck length ($r = 0.12$), femoral neck width ($r = 0.38$), femoral neck angle ($r = -0.06$) and femoral neck density ($r = - 0.43$) with femoral neck fracture pattern in postmenopausal women.

DISCUSSION

The aim of this study was to compare the pattern of femoral neck fracture in both normal and abnormal angles between active and non-active postmenopausal women using the finite element method. The results showed no significant difference between the fracture pattern of the femoral neck in both normal and abnormal angles (coxavara, coxavalga). Therefore, it can be concluded that the tension was applied on model B (women non-active postmenopausal women) is higher than model A (active postmenopausal women) but is not significant. The reason for this small difference between the two normal angles and coxavalga, can be due to more load is applied on the femoral head as compare to femoral neck in Coxavara angle (27).

As the same, the femoral neck fracture also were studied by, Qian and et al (2009), they indicated significant relationship between femoral neck angle, bone density and femoral neck pattern when the lower femoral neck and bone density can be cause femoral fracture (11). Therefore, the result of this study although wasn't significant, but was in consistent with the study of Qian et al. (2009) that they indicate in the significant increase of the tension on the femoral neck of the Coxavara angle (11).

Moreover, Lolaskon (2015) evaluated the effect of proximal geometry of the femur on pelvic fractures of the females; they indicated that all geometric parameter except the length of the pelvic axis can be considered as important factors on the history of fracture (12). In this way, in the present study, the non-active postmenopausal women, indicated lower femoral neck density (367 2 220 g / cm2) and a longer pelvic axis length than the active postmenopausal women (87.90±2.32 mm) but it was not significant ($p \geq 0.05$).

Based on the result of some researchers, the pelvic structural are useful in determining the risk of pelvic fractures in women during the postmenopausal periods, when the spatial distribution of bone mass are strongly correlated with bone strength. Therefore, the bone geometry can be considered as important factors for preventing of bone fractures. In addition, previous results confirmed that bone proximal femoral strength was lower in the women with pelvic fractures as compared to controls groups (6, 7, 27).

Moreover, the result of this study showed that there was no significant correlation between femoral neck length (r = 0.12), femoral neck width (r = 0.38), femoral neck angle (r = --0.06) and femoral neck density (r = - 0.43) with femoral neck fracture pattern in postmenopausal women. Consistent with these results, Quinn et al. (2009) reported in a study: The length of the pelvic axis was similar in both the control and femoral fracture groups, and there was no evidence of an association between longer femoral axis length and femoral neck fractures (12).

Also, Seeman et al. (2011) did not find any difference in femoral neck angle between women involve pelvic fractures and women without pelvic fractures (22). In addition, Li (2012) concluded in another study that women with pelvic fractures had lower pelvic stiffness, cervical bone density indices and also longer pelvic axis lengths than the control group, but no significant difference was found between these groups on width of the femoral neck (27).

Based on the results of this study, the comparison between tensions applied on theses 3 angles, indicating of the more tension on the Coxavara angle than two other (Coxavalga and Normal) angles that seems that the angle has a great effect on the level of stress on the femur neck.

Moreover, because the load applied to each model was performed at the same angle, direction and value, it is possible that this small difference in stress between the two groups of active and non-active postmenopausal women could be attributed to geometric indices as the length, width, and density.

Therefore, geometric indices of the femoral neck (such as the length of the femoral neck and the angle of a femoral neck angle) accompany with bone mineral density can play an important role in determining the risk of fracture and stiffness for the femur (29-31).

Although, geometric indices of the femoral neck (such as the length and the angle of a femoral neck) and bone mineral density can play an important role in determining the risk of fracture and stiffness of the femur, however, based on the findings of our study, it seems that geometric factors of femoral neck do not play an effective role in the pattern of femoral fracture in postmenopausal women, which can be further influenced by genetic and racial factors.

Moreover, Pearson correlation test showed that there was no significant relationship between geometric indices and bone mineral density indices in different areas. In summary, the present study showed that the geometric indices of the femoral neck cannot play an effective role in the type of femoral fracture, although active women had more appropriate geometric features, although it was not statistically significant. Therefore, according to the finding of this research, it can be suggested that this small difference in stress in the two groups of active and non-active postmenopausal women at any angle can be related to the geometric indices of length, width and density. In addition, the level of activity in postmenopausal women had no diagnostic effect in predicting the pattern of femoral neck fracture, but the general conclusion about it is still a controversial issue and requires further research.

CONCLUSION

Geometric factors of the femoral neck didn't play any effective role in the pattern of femoral fracture in postmenopausal women, although quantitatively it can be considered as an important factor in increasing bone properties to prevent injury.

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مقایسه الگوی شکست گردن استخوان ران در دو زاویه طبیعی و غیرطبیعی به روش المان محدود دربین زنان یائسه فعال و غیرفعال

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فرایند افزایش سن باکاهش عملکردسیستمهای مختلف بدن از جمله تغییرات آناتومیکی و فیزیولوژیکی درسیستم حرکتی بویژه سیستم اسکلتی و عضلانی، یکی از عوامل موثر در ایجاد آسیب های اندام تحتانی به ویژه آسیب های ناحیه لگن محسوب می شود. لذا، شناسایی عوامل موثر بر کاهش این آسیب دیده گی ها موثر و ضروری است. هدف از پژوهش حاضر، مقایسه‌ی الگوی شکست گردن استخوان ران در دو زاویه طبیعی و غیرطبیعی (کوکساوارا، کوکساوالگا) دربین زنان یائسه فعال و غیرفعال بود. **روش کار:** در این مطالعه علی- مقایسه ای تعداد بیست زن یائسه با میانگین سنی (**۲,۵±۵۵ سال**) که در سه سال اخیر به بخش سی‌تی‌اسکن بیمارستان امام رضا (ع) بیرجند مراجعه داشته‌اند به صورت هدفمند به دو گروه ده نفره فعال و غیر فعال تقسیم شدند. به منظور بررسی میزان تنش و الگوی شکست گردن استخوان ران در مرحله جدا شدن پنجه پا از زمین، پس از جمع آوری تصاویر سی تی اسکن مدل مورد نظر توسط نرم افزار تری دی مکس شبیه سازی شد. و با نرم افزار های آباکوس و SPSS۱۹ داده های مورد نظر تجزیه و تحلیل شدند. **نتایج:** یافته ها نشان داد که تفاوت معناداری بین الگوی شکست گردن استخوان ران در دو زاویه طبیعی و غیرطبیعی (کوکساوارا، کوکساوالگا) در زنان یائسه فعال و غیرفعال وجود نداشته (P≥ ۰/۰۵)، و تنش اعمال شده در هر دو مدل فعال و غیرفعال نیروی تقریبا یکسان و در زوایای مشخص در مرحله‌ی جدا شدن پنجه پا از زمین وارد شده است، (مقدار نیروی وارده در وضعیت طبیعی، **کوکساوارا و کوکساوالگا به ترتیب ۰/۹٦±٤/۳۸، ۱/۵۳±۷/۲۷** و **۰/۸۰±٤/۰۹** مگا پاسکال می باشد). **بحث و نتیجه گیری:** براساس نتایج به نظر می رسد که وضعیت غیرطبیعی آناتومی ران باعث مشکلات زیاد مفصلی و شکستگی می‌شود که احتمال شکستگی در افراد دارای زاویه کوکساوارا و احتمال ساییدگی سر استخوان ران در افراد دارای زاویه کوکساوالگا بیشتر باشد.

واژه های کلیدی: زوایای گردن استخوان ران، زنان یائسه، روش المان محدود، شکستگی گردن استخوان ران