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Accuracy of conventional triplane measures compared to 3-D analysis for assessment of cubitus varus deformities in adults

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Accuracy of conventional triplane measures compared to 3-D analysis for assessment of cubitus varus deformities in adults

Directed by Professor Yun-Rak Choi

The Master's Thesis
submitted to the Department of Medicine,
the Graduate School of Yonsei University
in partial fulfillment of the requirements for the
degree of Master of Medical Science

Gil-Sung Yoon

June 2020

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<ABSTRACT>

Accuracy of Conventional Triplane Measures Compared to 3-D Analysis for Assessment of Cubitus Varus Deformities in Adults

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(Directed by Professor Yun-Rak Choi)

Background: Cubitus varus is a common triplane deformity in adults associated with supracondylar humeral fractures experienced as a child and consists of varus, extension, and internal rotation components. When corrective osteotomy is indicated, these three components should be measured precisely. This study aimed to evaluate the accuracy of radiographic and physical measurements of cubitus varus deformities in adults compared to values measured on three-dimensional (3-D) bone surface models of the adult bilateral humerus.

Methods: 3-D bilateral humerus models were developed using bilateral humerus CT images of 20 adult patients with cubitus varus. The varus, internal rotation, and extension components of the deformity were assessed by superimposing the 3-D bone model onto a mirror-image model of the contralateral normal humerus. Values obtained from the radiographic and physical measurements

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were compared with those from the 3D model. The reliability of each measurement was assessed by calculating correlation coefficients (CCs).

Results: Radiographic measurements of the varus and extension components showed good reliability (CC = 0.796 and 0.791, respectively). Physical measurement of the varus component, however, showed only moderate reliability (CC=0.539), while physical measurement of the extension and internal rotation components exhibited poor reliability (CC =0.164 and 0.466, respectively).

Conclusions: Varus and extension components of cubitus varus in adults can be reliably measured using conventional methods, whereas that internal rotation component cannot. Thus, 3-D methods with which to quantify the rotational component preoperatively might be needed when correction of a rotational deformity is considered.

Keywords: cubitus varus, preoperative evaluation, triplane measurement

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Accuracy of Conventional Triplane Measures Compared to 3-D Analysis for Assessment of Cubitus Varus Deformities in Adults

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I. **INTRODUCTION**

Cubitus varus is a common deformity in adults associated with supracondylar humeral fractures experienced as a child.[1,2,3] Although varus angulation is the most prominent component of this three-dimensional (3-D) deformity,[4] extension and internal rotation of the distal humerus commonly exist.[5,6,7,8] Although an unsightly appearance is often the main complaint of the deformity, long-lasting deformity can cause chronic joint pain, tardy ulnar nerve palsy, and posterolateral rotatory instability, even though these complaints are uncommon because surgical correction is usually performed in childhood.[9,10,11,12] In adulthood, various osteotomy techniques, such as a simple lateral closing wedge,[13] medial opening wedge,[14] step-cut,[15] pentalateral,[7] dome,[16,17,18] and 3-D osteotomy,[5,8,19] have been recommended for correction of cubitus varus deformity.

Using optimal surgical technique, all three components (varus, extension, and internal rotation) of cubitus varus should be addressed to render satisfactory outcomes. A residual rotational deformity after corrective osteotomy not only could cause an unsatisfactory appearance after surgery,[5,7,8,20] but could also be associated with tardy ulnar nerve palsy,[10,11] pathologic elbow motion and muscle activity,[8] and posterior instability of the ipsilateral shoulder.[21] Accordingly, the accuracy of preoperative measures of the deformity can determine the degree of correction and clinical outcomes after surgical correction. Conventionally, the degrees of 3-D correction have been determined by measuring the components by physical and radiographic examinations in comparison to those of the contralateral side.[22,23] Meanwhile, advances in 3-D reconstruction and modeling software have allowed clinicians to accurately generate, process, and analyze 3-D surface models from 2-D medical imaging data. In 2011, Takeyasu et al. analyzed the 3-D patterns of cubitus varus deformities and reported that only radiographic measurements of the varus component and physical measurements of the extension component were reasonably accurate. while radiographic measurements of the extension component and physical measurements of the internal rotation component were relatively inaccurate.[23] However, the authors analyzed data from pediatric patients without skeletal maturity because cubitus varus deformities in adults are uncommon. Nonetheless, the 3-D patterns of cubitus varus deformity in adults could differ from those seen in children: secondary changes, such as osteoarthritis or posterolateral rotatory instability, to long-standing cubitus varus deformity are relatively common in clinical practice.[24,25,26] Therefore, the accuracy of the conventional radiographic and physical methods evaluating the 3-D

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components of cubitus varus is unclear in adults.

We hypothesized that true 3-D humerus models of adult cubitus varus deformities can be obtained using customized software from high-resolution computed tomography (CT) data. Herein, the three components (varus, extension, and internal rotation) of cubitus varus were measured by comparison with mirrored contralateral normal 3-D humerus models. The purpose of this study was to evaluate the accuracy of conventional radiographic and physical measurements of the components in comparison with those measured on 3-D humerus models.

II. MATERIALS AND METHODS

1. Participants

Between January 2010 and May 2013, 15 male and 5 female patients with unilateral cubitus varus deformities caused by malunion after distal humeral supracondylar fracture when they were children were enrolled in this study. The mean age was 35.4 years (range, 20–49 years), and the mean interval between original injury and image acquisition was 28.3 years (range, 16–44 years). The mean age at the time of injury was 7.1 years (range, 4-12 years). Original fractures were treated conservatively in all patients except two, who underwent percutaneous pinning. One of the patients had posterolateral rotatory instability, and three patients had tardy ulnar nerve palsy.

2. Three-Dimensional evaluation of cubitus varus

CT images of the affected and contralateral normal elbow (including the upper arm and forearm) with a 1.0-mm slice thickness were obtained with a high-resolution CT scanner (SOMATOM sensation; SIMENS, Germany). Digital imaging and communications in medicine (DICOM) data were imported to customized software (Mimics 14.01 software, Materioalise, Leuven, Belgium), and 3D models of the affected and contralateral normal humeri were constructed.(Fig. 1A).

To evaluate humerus deformity in three dimensions, the affected humerus was compared with the mirror image of the contralateral normal humerus. In the distal humerus, the centers of the capitellum and trochlea were obtained with the use of a circle-fit algorithm at the lateral surface of the capitellum and the narrowest part of the trochlear groove, and the center (flexion-extension) axis was created as a line through the geometric centers of the trochlea and capitellum (Fig. 1B).[22] Then, the distal part of the model of the affected humerus was superimposed onto the corresponding part of the mirror image of the normal humerus to measure the degrees of varus and extension components of the deformity by point and surface registration using the medial and lateral epicondyles, the distal articular surface, and the flexion-extension axis as references (Fig. 1C).

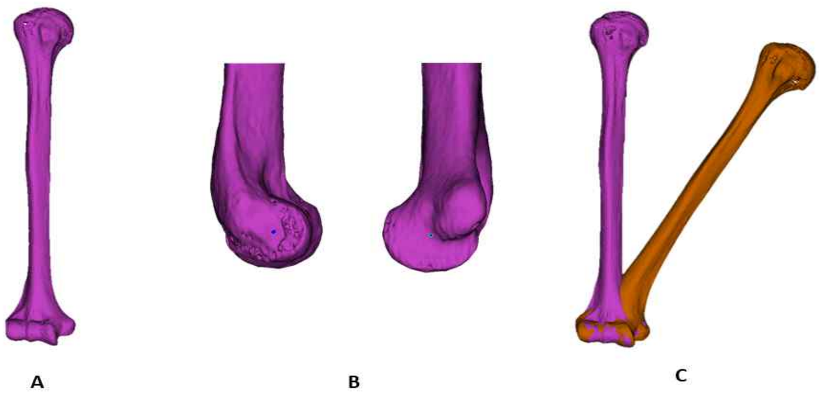

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Fig. 1. Using customized software (Mimics 14.01 software, Materioalise, Leuven, Belgium), 3-D models of the affected and contralateral normal humeri were constructed (A). On the affected humerus and the mirror image of the contralateral normal humerus, the centers of the capitellum and trochlea were obtained with the use of a circle-fit algorithm at the lateral surface of the capitellum, and the center (flexion-extension) axis was created as a line through the geometric centers of the trochlea and capitellum (B). Then, the distal part of the model of the affected humerus was superimposed onto the corresponding part of the mirror image of the normal humerus to measure the degrees of varus and extension components of the deformity by point and surface registration using the medial and lateral epicondyles, the distal articular surface, and the flexion-extension axis as references (C).

We quantified the varus component of the deformity by measuring the angle between the longitudinal axes of the affected and normal humeri on the true anterioposterior view (Fig. 2A). The extension component was quantified using the same method on the true lateral view (Fig. 2B). The degree of internal rotation deformity was measured by comparing the retroversion angle of the affected humerus and that of the mirror image of the contralateral normal humerus. The retroversion angle was measured as the angle subtended by the flexion-extension axis of the distal humerus and the humeral head axis, which is the line between two points at 90° to the anterior and the posterior articular margins (Fig. 2C).[27] To establish the interobserver reliability for these measurements, two experienced hand surgeons (IHK and YRC) evaluated all 3-D images, and the mean value of each measurement was used in this study.

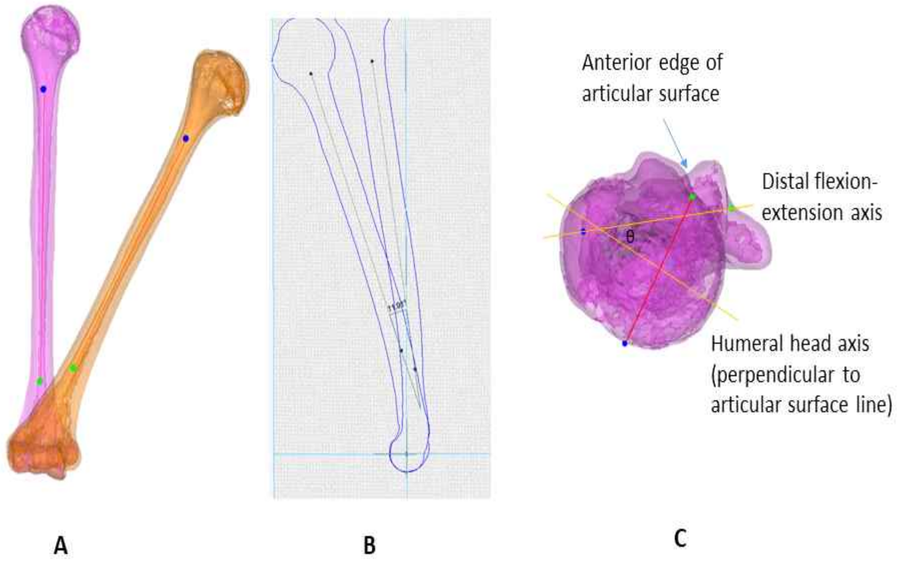

Fig. 2. In three-dimensional measurements of cubitus varus, the anteroposterior view of the varus deformity angle (A) was obtained by measuring the angle between the humeral axes of the affected and normal humeri. Lateral view of the extension deformity angle (B). The internal rotation deformity angle was measured as the difference in retroversion angles (θ) of the affected and normal humeri (C).

3. Radiographic evaluation of cubitus varus

For the anteroposterior view of the elbow, the forearm was positioned supine (palm up) on the radiographic table, with the elbow joint fully extended. On the anteroposterior radiograph, the humerus-elbow-wrist angle (HEW-A) was defined by a line passing the longitudinal humeral axis and a line passing through the proximal and

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distal midpoints of the radius and ulna (Fig. 3A).[13,23] For the lateral view of the elbow, the forearm rested on its ulnar side on the radiographic cassette, with the joint flexed 90 degrees and the thumb positioned upward. On the lateral radiograph, the tilting angle (TA) was determined by the anterior tilt of the articular condyles with respect to the long axis of the humerus on a lateral radiograph (Fig. 3B).[23] To establish the interobserver reliability for the radiographic measurements, two experienced hand surgeons (IHK and YRC) evaluated all radiographs, and the mean value of each measurement was used in this study. Varus deformity angle and extension deformity angle were calculated as the differences in HEW-A and TA between the normal and affected sides, respectively.

4. Physical evaluation of cubitus varus

We took photos of all patients at the time of physical examination to measure the carrying angle, the range of elbow flexion, and the internal rotation angle (IRA) of the humerus (Fig. 3C–E). The extension deformity was determined by the difference in maximal elbow flexion by comparing the affected elbow with the contralateral one.[19,21] The carrying angle was measured as the angle formed by the forearm and the humerus with elbow extension and forearm supination. For measurement of elbow flexion, a goniometric axis was laterally placed and aligned with the lateral epicondyle of the humerus. The stationary arm was positioned parallel to the longitudinal axis of the humerus, pointing toward the tip of the acromial process, and the movable arm was positioned parallel to the longitudinal axis of the forearm, pointing toward the styloid process

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of the radius. The IRA, obtained according to the method of Yamamoto et al.,[20] was based on the difference in the rotational range of shoulder motion between the affected and normal sides. We defined the difference in IRA between the normal and affected sides as being the internal rotation deformity angle of the humerus. To establish the interobserver reliability for the physical evaluations, two experienced hand surgeons (IHK and YRC) evaluated each measurement, and the mean value was used in this study.

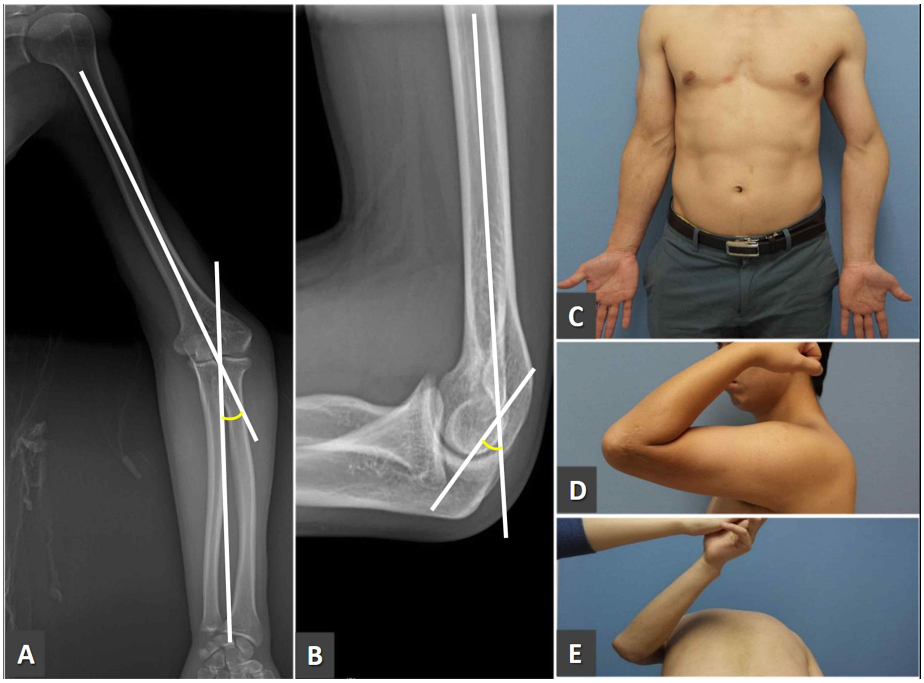

Fig. 3. In radiographic measurements, the humerus-elbow-wrist angle (A) comprised the angle between the humeral axis and a line passing through the proximal and distal midpoints of the radius and ulna. The tilting angle (B) was determined by the anterior tilt of the articular condyles with respect to the humeral axis on a lateral radiograph. For physical

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measurements, the carrying angle (C), elbow flexion (D), and shoulder internal rotation (E) were estimated.

5. Statistical Analysis

We performed a Wilcoxon signed-rank test to compare the varus, extension, and internal rotation deformity angles among the three measurement methods. Intraclass correlation coefficients were used to assess the reliability of radiographic and physical measurements for varus, extension, and internal rotation deformity angles to 3-D measurements. The reliability was rated as ‘‘acceptable’’ if the correlation coefficient was 0.75 or greater. A *P* value less than 0.05 was considered significant. Data were analyzed with MedCalc software, version 12.7 (MedCalc, Ostend, Belgium).

III. **RESULTS**

The mean varus deformity angle was 29.4 ± 5.6° when measured according to carrying angle difference, 28.7 ± 6.1° when measured according to HEW-A difference, and 25.1 ± 7.8° when measured according to the 3-D modeling method. When the 3-D measurement was considered accurate, intraclass correlation coefficients for the carrying angle and HEW-A methods for the 3-D measurement were 0.539 and 0.796, respectively. Only the HEW-A method indicated good reliability (Table 1).

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Table 1.Comparison of measurements for each component of cubitus varus

Variables	Measurements		
	Three-dimensional	Radiographic	Physical
Deformity angle (°)			
Varus[a]	25.1 ± 7.8	28.7 ± 6.1*	29.4 ± 5.6
Extension[b]	8.2 ± 12.0	10.2 ± 12.1*	1.6 ± 3.6
Internal rotation[c]	12.5 ± 11.7	-	8.5 ± 12.8

Notes: Values are means ± standard deviations. [a]Varus deformity angle was assessed by humerus-elbow-wrist angle on radiographs and by carrying angle in physical measurement. [b]Extension deformity angle was assessed by tilting angle on radiographs and by maximum flexion of the elbow in physical measurement. [c]Internal rotation deformity angle was assessed by maximum internal rotation of the shoulder in physical measurement. *A correlation coefficient between the measured and three-dimensional values greater than 0.75 indicated good reliability.

Mean extension deformity was 1.6 ± 3.6° when measured according to a difference in flexion, 10.2 ± 12.1° when measured according to a difference in TA, and 8.2 ± 12.0° when measured according to 3-D modeling. When the 3-D measurement was considered accurate, intraclass correlation coefficients for a difference in flexion and a difference in TA for the 3-D measurement method were 0.164 and 0.791, respectively. Only the TA method indicated good reliability.

Mean internal rotation deformity angle was 8.5 ± 12.8° when measured according to IRA and 12.5 ± 11.7° when measured according to the 3-D modeling method. When the 3-D measurement was considered

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accurate, intraclass correlation coefficients for the IRA method was 0.466, indicating poor reliability.

IV. DISCUSSION

The purpose of this study was to evaluate the accuracy of conventional radiographic and physical measurements of three components of cubitus varus deformities in comparison to those from 3-D measurements using customized software from high-resolution CT data. Based on our results, only the varus component of cubitus varus could be measured accurately by physical and radiological evaluations; the extension component was measured accurately only by radiologic evaluation; and the internal rotation component of the deformity could not be measured accurately preoperatively using conventional methods.

This study had several limitations. First, we included a relatively small number of patients. Second, measurements of the three components of the cubitus varus deformity using 3D reconstruction models were believed to reflect a real cubitus varus deformity. According to a study by Takeyasu et al.,[23] the intra- and interobserver reliabilities for the 3D varus, extension, and internal rotation measurements were almost perfect with more than 0.90 of intraclass and interclass correlation coefficients. Despite these limitations, this is the first report on the 3D morphological analysis of the cubitus varus deformity in adult patients. We believe that the information obtained in this study will improve the understanding and surgical planning of the 3D deformity pattern in adult cubitus varus.

Several investigators have tried to analyze 3D components of the

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varus deformity using conventional radiography and physical examination in comparison with those of the contralateral arm. For the varus component, HEW-A radiography and the carrying angle on physical examination have been used. In this study, mean varus deformity angle was approximately 29° as measured by HEW-A, and a mean carrying angle difference of 4° to the angle was measured by the 3D method. Measuring the varus component of the cubitus varus deformity in adults based on radiography, not on physical examination, showed acceptable reliability in this study. This finding suggests that preoperative planning using the varus component of the cubitus varus deformity in adults measured only by radiography seems to be acceptable to obtain true correction of the varus component of the deformity. This results is similar to the findings of Takeyasu et al. in 2011 who analyzed 3D patterns of cubitus varus deformities in children mainly (92%).[23]

The extension component of the cubitus varus deformity has been measured by comparing TA on lateral radiographs and the range of elbow movement of the affected side with that of the contralateral side. If patients with a cubitus varus deformity have limited elbow flexion due to extension malunion along with varus deformity, correction of the extension deformity is recommended along with varus correction. Our results showed that only the TA measurement had acceptable reliability and reflected the true extension deformity in adult patients with the cubitus varus deformity, which differs from the findings of Takeyasu et al. who found that radiographic measurements of the extension component were inaccurate.[23] These authors showed a relatively low interobserver reliability and that the radiographic measurement of the extension deformity (TA) was not always accurate in their patients. This difference might be because the subjects in our study were all adult cubitus varus patients. We believe that detection of reference points to measure TA is easier and more accurate in adult patients than in children. Therefore, surgeons should not correct an extension deformity based only on a difference in the range of elbow movement between the affected and contralateral elbows.

To quantify the internal rotational component of the cubitus varus deformity, Yamamoto et al. proposed to use the difference in the internal rotation of shoulder motion.[20] They reported that all of their patients had an internal rotational deformity of greater than 20°. The accuracy of the method for estimating the rotational component of the deformity proposed by Yamamoto et al. is unclear, however. According to Takeyasu et al.,[23] that method is relatively inaccurate, a finding that was also confirmed in our study. According to our study, measuring the internal rotation deformity using the difference in the internal rotation of the affected and contralateral shoulders showed no reliability in revealing the true internal rotational deformity of cubitus varus in adults. The limited range of the shoulder motion in addition to a bony malunion could affect the extent of passive internal rotation. Previously, Hindman et al. proposed the use of axial humerus CT images to estimate the rotational deformity angle in patients with cubitus varus after supracondylar fracture.[28] The use of CT images was also recommended to estimate rotational deformity of the distal humerus preoperatively for accurate planning.[23] Others have

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developed an operative method with use of a custom-made surgical guide, designed on the basis of 3-D computer simulation with CT data, and have described its accuracy and usefulness for the treatment of cubitus varus deformity.[29,30]

V. CONCLUSION

The varus and extension components of cubitus varus appear to be measured accurately by HEW-A and TA measurements on plane radiographs, compared to physical measurements in adults. However, conventional methods to measure the rotational deformity component of the cubitus varus deformity in adults appear to be unreliable. Thus, if correction of the rotational component of the deformity is considered, CT images should be taken to quantify the rotational component of the deformity preoperatively.

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<국문초록>

성인 내반주 변형에 대한 고식적 계측법의 정확성: 삼차원적 입체 영상 분석과의 비교

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연구배경: 내반주는 상완골 원위부 골절 후 발생하는 주관절의 변형으로 내반, 신전 및 내회전이 조합된 3차원적 변형이다. 내반주에 대한 교정 수술 시 이들 3가지 요소에 대한 수술 전 계측이 필요하다. 내반주 변형의 방사선 및 신체 검사에서 측정된 내반, 신전, 내회전 계측 값을 삼차원적 골 모델에서의 계측치와 비교하여 고식적 계측법의 정확도를 분석하고자 한다

방법: 소아기 상완골 과상부 골절 후 발생한 성인의 편측성 내반주 환자 20명을 대상으로 양측 상완골 전산화 단층 촬영 영상을 이용해 삼차원 골 형상을 얻고 건측 모델의 거울상 영상을 환측에 중첩하여 내반주의 변형 요소들을 분석한다. 이를 단순 방사선 및 신체 검사상에서 얻은 계측치와 비교하여 고식적 계측법의 정확도를 분석하도록 한다. 계측법 각각의 신뢰도는 상관 계수(correlation coefficient,CC)로 평가한다

결과: 방사선 상에서의 내반, 신전 변형의 계측치는 삼차원 골 모델에서의 측정값과 비교하여 높은 신뢰도 (상관계수=0.796, 0.791)를 보였으며 신체 검사상의 내반 계측치는 중등도의 신뢰 수준(상관계수=0.539)을 나타내었다. 하지만 신체 검사상의 신전 및 내회전 변형의 계측치는 삼차원적 분석과 비교하여 낮은 신뢰도 (상관계수=0.164, 0.466)를 보였다.

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결론: 내반주의 내반, 신전 변형은 전후방 및 외측 단순 방사선 사진을 이용하여 비교적 정확하게 계측할 수 있다. 하지만 내회전 변형의 정도는 신체 검사에만 의존하였으며, 계측값을 일관되고 정확하게 측정할 수 있는 고식적인 방사선적 방법이 없다. 따라서 성인 내반주 환자의 수술 시 회전변형의 교정을 고려하고 있다면 수술 전 전산화 단층촬영을 촬영하여 회전변형의 정도를 정확하게 계측해야 한다.

핵심되는 말 :내반주. 수술전 측정, 삼차원 계측