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The femoral canal fill of two different cementless stem designs

The accuracy of radiographs compared to computed tomographic scanning

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Abstract In 19 cadaver femora we compared the fill of two types of femoral stems (plastic replica) using computed tomographic (CT) scan with a border detecting computer program and conventional radiographs. In the metaphyseal area the fill of the two types was surprisingly similar. In the diaphysis the straight stem filled significantly more than the proximally anatomic and distally over-reamed stem. Using conventional radiographs the fill measures were from 1.2 to 2.1 times higher than the values of CT scan, depending on the method of calculation. When both anteroposterior and lateral views were used, the fill as measured by radiographs correlated well with the fill as measured using CT scan. When conventional radiographs are used for evaluation of the canal fill, the calculation based on hypothetical rectangular areas at each level seemed to provide the most accurate results.

Résumé Sur 19 fémurs de cadavre nous avons comparé le remplissage par deux types de tiges fémorales (une droite et l'autre anatomique) en utilisant la tomodensitométrie avec un programme informatique adapté à l'étude des zones limites et les radiographies conventionnelles. Dans la région metaphysaire le remplissage par les deux types était étonnamment semblable. Dans la région diaphysaire la tige droite a rempli nettement plus que la tige anatomique en région proximale et avec sur-alésage en zone distale. En utilisant les radiographies conventionnelles les mesures du remplissage étaient de 1.2 à 2.1 fois plus hautes que les valeurs de la tomodensitométrie, dépendantes de la méthode de calcul. Quand les incidences frontale et latérale ont été utilisées, le remplissage mesuré par radiographies avait une bonne corrélation avec le remplissage mesuré par tomodensitométrie. Quand les radiographies conventionnelles sont utilisées

pour l'évaluation du remplissage du canal, le calcul basé sur la section rectangulaire hypothétique à chaque niveau a paru fournir les résultats les plus exacts.

Introduction

The postoperative canal fill of cementless femoral stems has been evaluated using plain radiographs in several studies [4, 8, 9, 12, 13] and in clinical work it is practically the only choice. Rubin et al. [18] reported that computed tomography (CT) is superior to plain radiographs in studying femoral canal. However, Iguchi et al. [7] presented a surprisingly accurate method by using radiographs for custom hip stem design. To optimize the prediction of canal geometry, they successfully used a model of average sectional shape of femur. However, simple radiological methods continue to be the basic tool in clinical series to evaluate the canal fill of the femoral stems. Therefore, it would be valuable to establish the degree of error and to determine the regions where the radiographic information of the fill is grossly false and where it is adequate.

The purpose of the present study was (1) to compare the fill of two different designs of cementless femoral stems, a straight second generation (Bi-Metric) and a proximally anatomic and distally over-reamed third generation (ABG), and (2) to define the accuracy of postoperative radiographs in estimating the endosteal fill of cementless femoral stems by using plastic stem replicas implanted into cadaver femora.

Materials and methods

Twenty cadaver femora were collected and preserved in alcoholic solution (2–6 weeks) before stem insertion. There were 11 male and nine female donors, whose age ranged from 50 to 90 years and averaged 70 years. Preoperative radiographs (in neutral rotation, i.e., posterior surfaces of distal condyles on the table, perpendicular anteroposterior and mediolateral views, and standard magnification of 20%) were obtained. The femoral canal shape de-

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scribed by canal flare index [16] averaged 4.0 (SD 1.0). The femora were randomly divided into two study groups. Plastic replicas of ten straight Bi-Metric (Biomet) and ten anatomic ABG (Howmedica) cementless stems were to be implanted, and appropriate stem sizes were templated by restoring the rotational center. Epoxyplastic was selected as the material of the stems in order to avoid an artifacting effect of metal implants on CT [6]. An epoxyplastic stem can also be appropriately inserted into the femoral canal and is clearly visible in radiographs. Standard instrumentation was used. One femur fractured during insertion of the Bi-Metric

Fig. 1 Postoperative anteroposterior radiographs of two femora with implanted plastic copies of Bi-Metric stem (*left*) and ABG stem (*right*)

Fig. 2 Schematic drawing of radiographic measurements from AP- and lateral views. The lesser trochanter mid-point (T) is the zero-level in vertical axis. An example of the measuring at level 20 mm below T (T-20 mm): AB and CD refer to femoral canal width, and EF and HG refer to stem width in the anteroposterior and lateral views. The cross-section refers to the margins identified from the anteroposterior and lateral radiographs and explains the idea of hypothetical rectangular areas. The canal fill according to anteroposterior view only $\frac{EF}{AB}$. The canal fill as an average of the fills from anteroposterior and lateral views = $\left(\frac{EF}{AB} + \frac{GH}{CD}\right) : 2$. The canal fill from hypothetical rectangular areas $\frac{EF \times GH}{AB \times CD}$

stem and was excluded. Thus, there were nine cases in the Bi-Metric group and ten cases in the ABG group. Permission for the use of cadaver femora was obtained from the Institutional Ethical Committee.

Postoperatively the femora with implanted stems were radiographed in the same projections as preoperatively (Fig. 1). The fill was studied at several levels: with 5-mm intervals in the metaphysis and 10-mm intervals in the diaphysis. The lesser trochanter mid-point (T) was the 0-level in the bone's vertical axis (Fig. 2). In addition to the previous stem fill measurements in (a) anteroposterior plane only as the ratio between the implant width to canal width or (b) calculating the average of the fills in anteroposterior and mediolateral planes [9, 12, 13, 15], we calculated (c) the cross-sectional hypothetical rectangle areas of the stem and canal from the radiographs in both planes (Fig. 2).

The femora with implanted stems were then studied by CT, whereby the physical pixel size was 0.83×0.83 mm. The 0-level of the vertical bone axis was defined as the lesser trochanter mid-point (T). Horizontal 2-mm-thick slices were taken with 5-mm slice intervals from 20 mm above (the neck osteotomy level, T+20) to 20 mm below the 0-level (T-20). Distally, 10-mm slice intervals were used down to the tip of the stem. Thus, the levels studied were identical to the radiographic measurements. The canal fill of the stems was studied using an image segmentation program [11]. The fill was defined in a cross-sectional slice as a proportion between a stem area and endosteal area (Fig. 3).

Fig. 3 From the original CT image the image segmentation program detects the canal and stem borders. The fill was computed as a proportion between stem area and canal area

Table 1 The differences of the fill between the straight (*Bi-Metric*) and the proximally anatomic and distally over-reamed (*ABG*) stems according to CT-measurements. Statistical difference between the designs according to paired *t*-test

Level or region	Average fill, CT-method	
	Bi-Metric (<i>n</i> =9; %)	ABG (<i>n</i> =10; %)
Metaphysis		
T+20	37	40
T+15	37	41
T+10	39	40
T+5	41	45
T	41	44
T-5	40	40
T-10	40	39
T-15	39	36
T-20	41*	34
Diaphysis		
T-30	41	35
T-40	45**	35
T-50	44*	35
T-60	47*	37
T-70	46	40
T-80	43	42
T-90	42**	30 (<i>n</i> =6)
T-100	39	36 (<i>n</i> =4)
Metaphysis	40	40
Upper metaphysis	39	42
Lower metaphysis	40	37
Diaphysis	42*	36

P*<0.05 *P*<0.01

The fill on CT scans was compared between the straight stems and the proximally anatomic stems, comparing means with *t*-test as statistical method. The accuracy of the radiographic fill was compared to that measured by CT at all the individual levels and also when the levels were divided into the metaphyseal and diaphyseal region. This was studied by comparing means with paired-samples *t*-test and by Pearson linear correlation. The fill values were normally distributed.

Results

The average area fill of the implants as measured by CT varied from 34% to 44% in the metaphysis and from 30% to 47% in the diaphysis. The overall differences in fill between the two different stem designs were relatively small. In the diaphysis the straight Bi-Metric stems filled significantly more of the femoral canal than the ABG stems, in which the canals were over-reamed before the stem insertion. There were no significant differences at any of the metaphyseal levels between the two stem designs (Table 1).

All the radiographic methods resulted in remarkably greater fill values than the values on CT scans (Table 2). When the fill was measured from the anteroposterior views only, the fill values were 1.9–2.1 times greater than those on the CT scan. If the fill was calculated as an average of the fills in anteroposterior and lateral views, the values were still 1.7–2.0 times greater. When the radiological fill was estimated according to the hypothetical rectangle areas, the fill values were reduced to be

Table 2 Differences between the canal fill according to the CT method and different radiological calculations of the fill (*n*=19). Statistical difference between the CT method and each radiographic method according to paired *t*-test

Level	Average canal fill (%)			
	CT method	Radiographs		
		Rectangular areas according to AP and lateral views	Average of AP and lateral views	AP-view only
Metaphysis				
T+20	39	45***	67***	71***
T+15	39	49***	70***	75***
T+10	39	51***	71***	78***
T+5	43	55***	74***	82***
T	42	56***	75***	82***
T-5	40	56***	75***	81***
T-10	40	57***	75***	79***
T-15	38	57***	76***	79***
T-20	37	58***	76***	79***
Diaphysis				
T-30	38	61***	78***	81***
T-40	39	63***	80***	83***
T-50	39	63***	79***	85***
T-60	42	66***	82***	88***
T-70	43	65***	81***	88***
T-80	41	62***	79***	88***
T-90	42	63**	80***	89***
T-100	41	62**	79***	89***
Metaphysis	40	51***	73***	79***
Upper metaphysis	39	57***	72***	78***
Lower metaphysis	40	54***	76***	80***
Diaphysis	39	64***	80***	86***

***P*<0.01

****P*<0.001

Table 3 Correlation of the different radiological calculations of the fill with the canal fill according to CT ($n=19$). Statistical difference between the methods according to Pearson linear correlation. AP anteroposterior

* $P<0.05$
 ** $P<0.01$
 *** $P<0.001$

Region	Correlation between the radiological methods and CT-scanning		
	Square areas of AP and lateral views	Average of AP and lateral views	AP view only
Metaphysis	0.76***	0.80***	0.66**
Upper metaphysis	0.77***	0.77***	0.53*
Lower metaphysis	0.80***	0.76***	0.60**
Diaphysis	0.65**	0.64**	0.59**

1.2–1.6 times greater than those obtained using the CT method (Table 2).

The radiological evaluations using both the anteroposterior and lateral views correlated well with the CT scans ($r=0.76$ – 0.80) in the metaphyseal region, but in the diaphysis the correlations were lower ($r=0.64$ – 0.65). If the anteroposterior view measurement alone was used, the correlations were reduced markedly in the metaphysis ($r=0.53$ – 0.66) and slightly in the diaphysis ($r=0.59$; Table 3).

The errors of the radiological methods and the correlations with CT values were similar for the two stems, i.e., the shape of the stem was not found to affect the accuracy of the methods.

Discussion

The comparison of canal fill between the two different cementless femoral stems resulted in surprisingly small differences. Only in the diaphysis did the second generation stem, Bi-Metric, seem to fill the diaphyseal canal more profusely than the third generation stem, ABG. Despite the anatomic design in the metaphyseal part of the ABG stem, there were no differences in the fill of the metaphyseal region. In our previous clinical series ABG stems filled the metaphyseal canal slightly but to a significantly greater degree than Bi-Metric stems, and ABG also yielded a beneficial pattern of bone remodeling more often during a 5-year follow-up [12]. In the ABG multicenter study, an increase in bone density in the lower metaphysis was observed in as many as 54% of cases [20]. Early and mid-term results of both of the stem designs studied have been excellent [2, 14, 17, 20, 21].

The image segmentation program used has been previously described in detail and appropriately tested [11]. We decided to use plastic stem models to avoid metal artifacts on CT. However, recent metal artifact reduction techniques in CT are aiming to reach a sufficient degree of accuracy, at least with titanium implants [5, 19].

The femoral rotation is difficult to standardize in radiographs and, when assessing the shape and dimensions of the femoral canal, it is one of the main causes of error [3]. Likewise, the femoral rotation and especially the anteversion of an implanted stem strongly affects the radiological estimation of the cross-sectional area in the upper part of the stem. The variation in X-ray magnifications is

also statistically significant [10]. In the present study, the rotation of the femora and the magnification of the radiographs could be standardized. The corticocancellous border may be difficult to determine on radiographs and is another cause of error. The femoral bone with a CT density beyond 500–600 HU cannot be removed by conventional reamers [1]. This border also corresponds to that detected on radiographs [7].

In the present study, the fill values obtained by simple methods under optimal conditions for conventional radiographs were excessive. When the fill values are modeled to represent the ratio of cross-sectional areas of the stem and the canal, the values are reduced closer to the actual ones. However, the correlations between the fill values from CT and those obtained from radiographs were high, which justifies use of these methods, for example, in clinical studies comparing different stem designs and when the effect of the canal fill on bone remodeling changes is assessed. If normal radiographs are used to evaluate the fill of the cementless femoral stems, both the anteroposterior and lateral views must be used, and the calculation method based on hypothetical rectangles at each level seemed to provide the most reliable results.

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