Effects of ethnicity on proximal femoral intramedullary nail protrusion—a 3D computer graphical analysis

Harminder Sarai1 · Beat Schmutz1,2 · Michael Schuetz1,2,3

Received: 6 May 2020 / Accepted: 15 July 2020 / Published online: 29 July 2020
© Springer-Verlag GmbH Germany, part of Springer Nature 2020

Abstract

Introduction Antegrade nailing of proximal femur or femoral shaft fractures is a proven treatment with good to excellent results. Nonetheless, clinical evidence from Asia indicates that proximal femur nails can be too proud at the greater trochanter (GT) causing irritation for some Asian patients. This study aimed to identify any significant differences in proximal nail misfit for a set of Asian and Caucasian femora.

Materials and methods Two nails (Gamma3, TFNA) were virtually inserted into 63 femoral 3D models (28 Japanese, 4 Thai, 31 Caucasian). In AP, the entry point was 4° lateral for Gamma3 and 5° for TFNA; laterally the same location was used for both. Insertion depth was controlled by aligning the lag screw centre head. The distance of the nail end from the GT was measured at five (medial, lateral, anterior, posterior and centre) reference points (RPs). The correlation between GT height, CCD angle and proximal nail distance to GT was analysed.

Results There was no significant difference between either nail ($p = 1.0$). The TFNA was overall less prominent than the Gamma3, and significantly less prominent at all RPs except lateral. The Asian femora were 3.76 ($p = 0.016$) times more likely to have the nail protruding proximally. The Asian subjects were shorter ($p < 0.05$) than the Caucasians. Their GT height was slightly shorter and CCD angles larger compared to Caucasian (Asian: 41.1 mm, 128.1°, Caucasian: 42.2 mm, 126.4°), but the differences were not significant ($p = 0.36$). Stature, GT height and CCD angle significantly correlated with nail distance to GT.

Conclusions This study illustrated a significantly increased incidence of proximal nail protrusion in Asian compared to Caucasian femora, corroborating clinical findings. The combination of shorter stature and GT height and a larger CCD angle in Asians likely contributes to this difference.

Keywords Ethnicity · Femur · Nail protrusion · Proximal · Greater trochanter

Introduction

Anterograde cephalomedullary nail (CM nail) fixation is the treatment of choice for femoral subtrochanteric and shaft fractures. Despite the generally good to excellent results, with union rates of 95–99% [20], clinical studies have reported cases of the proximal CM nail end protruding from the top of the greater trochanter (GT) [6, 12, 22]. Proximal protrusion of femoral nails has been linked to the thigh and trochanteric pain by various authors [6, 7, 12, 22].

The current generation CM nails share a number of common traits including both proximal and distal locking screws, and a minimally invasive insertion technique through the GT [2, 4, 15, 19]. Consequently, any anatomical variation of the proximal femur or changes in the design of the proximal part of the nail may contribute to morbidity often associated
with CM nail use, such as hip pain. An understanding of any anatomical variation that may exist with regards to the GT and the effects of subtle differences in the design of current nails may help to prevent complications and improve future nail designs.

The proximal femur itself is well described in the literature; unfortunately the majority of this research has been performed from the perspective of arthroplasty and subsequently, the relevant anatomy and accompanying variation between ethnic groups are well understood in that regard [8, 9, 11, 13, 14]. The anatomy of the GT is less comprehensively described in the literature. However, a limited number of studies have indicated anatomical variation may exist between ethnicities.

Pu et al. prospectively followed 87 patients, from China, who were treated with a PFNA (Synthes GmbH, Oberdorf, Switzerland) and identified at least 11 cases with proximal femur/nail mismatch with the nail protruding 1–2 cm [12]. The implication being that the Chinese proximal femur is shorter than the femora used to design the implant, Caucasian in origin. This inference is supported by the research of Leung et al. who used CT based measurements of 56 Chinese femora to demonstrate that the original Gamma nail (Howmedica International, Kiel, Germany) was nearly four centimetres longer than the GT [10]. For each of the implants, modifications were made in subsequent generations to produce devices that were better suited to the Asian population. A more recent study examining the PFNA II-Asia (Synthes, Solothurn, Switzerland), a nail specifically designed for the Asian population with a shorter and slimmer proximal end, found that out of 56 patients of Chinese descent who were treated with the device, four had proximal protrusion of the nail [22]. Hu et al. reported a higher incidence in a study from 2016, with 87.8% of patients treated with a PFNA II having a protrusion, and 60.8% having protrusion of greater than 5 mm. Moreover, the authors were able to demonstrate a positive correlation between the protrusion and long-standing lateral trochanter pain [6].

These findings are juxtaposed to a CT based study utilising 90 femora, 47 of Caucasian heritage and 43 of Asian heritage examining anthropomorphic differences of the proximal femur. This research specifically examined the height of the GT as measured from where the neck axis, ideal position for the proximal lag screw, intersected with the axis of the proximal CM nail, finding no significant difference between the two groups [17]. However, the authors acknowledged the results of the clinical studies, suggesting further research on the positions of implanted CM nails to determine a cause for the clinical observations.

Therefore, our study aimed to evaluate the proximal fit of two currently available CM nails with slightly different proximal designs, specifically examining proximal nail protrusion. In particular, the effects of stature, GT height and collodiaphyseal (CCD) angle was analysed with respect to the amount of nail protrusion from the GT. Moreover, to identify any differences in the amount of protrusion that may exist between ethnic groups when the nails have been inserted. Understanding the influence of each of the above-mentioned variables on proximal nail protrusion may improve future nail design whilst also alerting current clinicians to factors that impact on a device’s prominence above the GT.

**Materials and methods**

The 3D bone and nail models used for the present work were available from a previous study [16], where the nail models were virtually inserted into the femora utilising computer graphical methods.

**3D bone models**

All 63 3D models representing the outer and inner cortex surfaces of femora were utilised from the previous study [16]. Details of the study subject demographics are listed in Table 1. There were 45 right and 18 left femur. Based on visual inspection, all the bone models were of normal appearance.

**3D nail models**

Computer models of two different nail designs, with different radius of curvature (ROC) of the anterior bow, were inserted into the above-mentioned femoral models. The Gamma 3 long nail (Stryker Trauma GmbH, Schönkirchen, Germany) (G3N) with ROC of 1.5 m and the TFN-Advanced™ proximal femoral nailing system (TFNA) (DePuy Synthes, West Chester, PA, USA) with a ROC of 1 m were utilised. The clinically appropriately sized TFNA and G3N designs encompassed the nail dimensions of lengths 300–420 mm, diameters 10 mm and 11 mm, with a CCD angle of 125° and 130°. Femora with a CCD ≤ 120° were implanted with 125° nails while all other bones received a 130° nail.

There are also differences between the proximal diameter of each device, with the Gamma3 having a diameter of 15.5 mm whilst the TFNA is marginally larger with a diameter of 15.6 mm. Finally, each of the implants differs with regards to proximal length as measured from the top of the lateral lag screw hole. The TFNA is 41.3 mm long for nails with 125° CCD and 45.0 mm for nails with 130° CCD whilst the Gamma3 measures is 42.0 mm long for nails with 125° CCD and 46.0 mm for nails with 130° CCD in length [4, 19]. Each of these differences has the potential of impacting on the proximal prominence of the nail and the
risk of iatrogenic fracture, especially when coupled with any anatomical variation that may exist between ethnic groups.

### Nail positioning

Utilising a customised software tool [1], the nail models had been optimally positioned inside the inner cortex surface models by minimising the nail’s surface area protruding from the bone model [16]. The entry-point for both nails was defined as the middle of the GT in a lateral plane mitigating any bias that may occur with a more anterior entry point (Fig. 1).

![Fig. 1 Nail insertion entry points shown for the right femur: lateral (left) and antero-posterior (right) views. Abbreviations: EP nail entry point, W width, PT point of tangency, NA neck axis, GT height distance EP to NA, PLB proximal lateral bend (modified from [16, 17])](image)

### Measurement of proximal nail protrusion

The combined 3D models with nails in-situ were analysed, specifically focusing on the GT and the proximal part of

---

### Table 1 Demographics of study subjects

| Ethnicity | Gender | Age, mean ± SD, (range), years | Height, mean ± SD, (range), cm |
|-----------|--------|-------------------------------|--------------------------------|
| Caucasian | Male (n=8) | 78 ± 6.7 (70–88) | 174 ± 3.3 (168–178) |
|           | Female (n=23) | 80 ± 10.3 (66–103) | 161 ± 8.2 (145–175) |
|           | All (N=31) | 80 ± 9.4 | 165 ± 9.0 |
| Japanese  | Male (n=6) | 76 ± 5.4 (71–83) | 160 ± 4.0 (155–167) |
|           | Female (n=22) | 73 ± 5.0 (65–84) | 150 ± 4.6 (143–159) |
|           | All (N=28) | 74 ± 5.1 | 152 ± 5.9<sup>a</sup> |
| Thai      | Male (n=1) | 85 | 159 |
|           | Female (n=3) | 73 ± 4.5 (68–77) | 151 ± 2.6 (148–153) |
|           | All (N=4) | 76 ± 7.2 | 153 ± 4.5<sup>b</sup> |

<sup>SD</sup> standard deviation

<sup>a</sup><sup>p</sup> = 0.000 (2-tailed) between Caucasian and Japanese data

<sup>b</sup><sup>p</sup> = 0.019 (2-tailed) between Caucasian and Thai data

In the antero-posterior plane, the entry-point was specific to each nail as they each have different proximal lateral bends relative to the proximal femoral axis of 4° for the G3N and 5° for the TFNA. Axial rotation and depth for each nail were determined by the ideal placement of the proximal locking screw with its axis passing through the centre of the femoral head. Each femur had two subsequent combined 3D models, one with a G3N in situ and another with the TFNA.
each nail. Measurements were taken from the outer cortex of the femur to the most prominent part of each nail at five individual reference points (RP) (Fig. 2).

These RPs were referred to as medial, lateral, anterior, posterior and centre. They were identified using the axis of the proximal part of each nail. This axis was utilised to create a medial–lateral plane (ML plane) and an anterior–posterior plane (AP plane) that were perpendicular to each other, and where the AP plane was parallel to the most posterior aspects of the femoral condyles. The centre RP was the located at the intersection of the ML plane, the AP plane, and a plane produced to sit flush with the proximal end of the femur. The combined models were then sliced along the AP plane and the ML plane producing outlines of the nail and the outer cortex of the proximal femur. Measurements were then taken from the previously designated points on these silhouettes to a corresponding point on the femur which was located using the axis of the proximal part of the femoral nail. These measurements were recorded as either being negative, located below the cortex, or positive, located outside to the cortex.

As an individual’s height of the GT has a direct influence on proximal nail protrusion, we have obtained the distance entry point (EP) to the neck axis (NA) (Fig. 1), to determine whether there are any significant differences between our Asian and Caucasian samples. Together with stature and CCD angles, these measurements were available from our previous anatomical study of a larger dataset, where the points EP and NA were labelled E and F, respectively [17].

Statistical methods

The collated data were statically analysed using SPSS version 22 (IBM Corp., Version 22.0. Armonk, NY) with the level of statistical significance set to $p < 0.05$. Due to non-normal distributions of several measurements, the Mann–Whitney U test for two related samples was used to test for significant differences between G3N and TFNA protrusions. While the Mann–Whitney U test for two independent samples was used to evaluate the effect of ethnicity on stature and the degree of protrusion at the previously defined RPs, and to investigate the effect of the CCD angle of each nail on the extent of the protrusion at the RPs. Linear regression was used to determine the correlation between stature, distance EP-NA, CCD angle and proximal nail distance at the RPs to the GT. Finally, a binary logistical analysis was used to examine any correlation between ethnicity, CCD angle and the risk of any protrusion of the nail.

Results

In most models, there was some protrusion of the proximal part of the CM nail with 48 instances of protrusion when the G3N was inserted and 38 instances of the protrusion with the TFNA, see Tables 2 and 3. There was no statically significant difference between either nail in this cohort as a whole (odds ratio = 1, 95% CI 0.385, 2.6, $p = 1$). The TFNA was overall less prominent than the G3N and was significantly less prominent at all RPs except at the lateral RP, see Table 4.

There was a notable difference in the number instance of protrusion between ethnic groups (Tables 2, 3) which reached statistical significance with binary regression analysis. The Asian femora were 3.76 (odds ratio = 3.77, 95% CI 1.28, 11.11, $p = 0.016$) times more likely to have part of the femoral nail protruding from the proximal part of the femur. In the Caucasian cohort there were in total
15 combined models in which the nail was wholly located within the femur, eight of which were from models with a TFNA implanted and seven where the G3N had been implanted. In the Asian cohort, there were a total of five combined models in which the device was wholly located within the femur, two of these models had the TFNA in-situ whilst the remaining three had a G3N positioned. Significant differences between ethnicities were seen at all RPs when the TFNA had been implanted, with the nail being less prominent in the Caucasian than the Asian population, see Table 5. For the G3N, however, this only reached statistical significance at the lateral and posterior RP.

Nine femoral models were suitable for receiving nails with a 125° CCD, as such, in total there were 18 combined models, nine with a G3N inserted and nine with a TFNA inserted, of these 10 of the models had the nails that were located within the proximal femur, five for each nail. The remaining 108 combined models all had nails inserted with 130° CCDs, with 10 models were the nails were located within the proximal femur, again five for each nail. These differences were statistically significant with nails with a 130° CCD 1.65 (odds ratio = 1.65, 95% CI 1.32, 2.07, \( p = 0.00001 \)) times more likely to have some proximal protrusion of the nail. In a subgroup analysis of Asian who had a 130° nail inserted the adjusted odds of having a nail protrusion was 1.41 (95% CI 1.08, 1.83, \( p = 0.01 \)).

### Table 2: Incidences (n) of proximal nail protrusions of Gamma3 and TFNA in Asian

|          | Gamma3 | TFNA |
|----------|--------|------|
|          | >0     | >5   | >10  | >0   | >5   | >10  |
| Medial   | 27     | 24   | 24   | 24   | 21   | 18   |
| (%)      | (84.4) | (75.0)| (75.0)| (75.0)| (65.6)| (56.3)|
| Lateral  | 21     | 15   | 5    | 24   | 16   | 3    |
| (%)      | (65.6) | (46.9)| (15.6)| (75.0)| (50.0)| (9.4) |
| Anterior | 25     | 17   | 8    | 23   | 15   | 6    |
| (%)      | (78.1) | (53.1)| (25.0)| (71.9)| (46.9)| (18.8)|
| Posterior| 24     | 15   | 5    | 23   | 14   | 4    |
| (%)      | (75.0) | (46.9)| (15.6)| (71.9)| (43.8)| (12.5)|
| Centre   | 21     | 13   | 5    | 21   | 10   | 3    |
| (%)      | (65.6) | (40.6)| (15.6)| (65.6)| (31.3)| (9.4) |

### Table 3: Incidences (n) of proximal nail protrusions of Gamma3 and TFNA in Caucasian

|          | Gamma3 | TFNA |
|----------|--------|------|
|          | >0     | >5   | >10  | >0   | >5   | >10  |
| Medial   | 21     | 19   | 16   | 18   | 17   | 10   |
| (%)      | (67.7) | (61.3)| (51.6)| (58.1)| (54.8)| (32.3)|
| Lateral  | 16     | 5    | 3    | 15   | 5    | 2    |
| (%)      | (51.6) | (16.1)| (9.7) | (48.4)| (16.1)| (6.5) |
| Anterior | 19     | 10   | 4    | 16   | 8    | 3    |
| (%)      | (61.3) | (32.3)| (12.9)| (51.6)| (25.8)| (9.7) |
| Posterior| 14     | 6    | 2    | 14   | 4    | 2    |
| (%)      | (45.2) | (19.4)| (6.5) | (45.2)| (12.9)| (6.5) |
| Centre   | 14     | 6    | 4    | 10   | 5    | 3    |
| (%)      | (45.2) | (19.4)| (12.9)| (32.3)| (16.1)| (9.7) |

### Table 4: Mean proximal Gamma3 and TFNA nail distances (mm) to greater trochanter (+ve indicating protrusion)

|          | Gamma3 | TFNA |
|----------|--------|------|
| Medial   | 13.2   | 7.3  |
|          | 11.2   | 14.1 |
|          | Range  | Range|
|          | −20.6–35.5 | −27.0–35.5 |
| Lateral  | 3.0    | 3.1  |
|          | 7.6    | 8.5  |
|          | Range  | Range|
|          | −18.4–30.9 | −18.1–31.4 |
| Anterior | 4.8    | 2.1  |
|          | 7.8    | 8.0  |
|          | Range  | Range|
|          | −18.2–31.4 | −17.4–42.4 |
| Posterior| 3.3    | 2.1  |
|          | 8.8    | 8.0  |
|          | Range  | Range|
|          | −17.0–45.1 | −17.5–42.4 |
| Centre   | 3.2    | 1.2  |
|          | 9.0    | 8.6  |
|          | Range  | Range|
|          | −19.5–35.6 | −19.3–33.7 |

\( p \) value

|          | Gamma3 | TFNA |
|----------|--------|------|
| Medial   | 0.000  |      |
| Lateral  | 0.332  |      |
| Anterior | 0.002  |      |
| Posterior| 0.000  |      |
| Centre   | 0.000  |      |
protruding from the GT increased to 4.48 (odds ratio = 4.48, 95% CI 1.31, 15.34, \( p = 0.017 \)). In femora with a TFNA in situ there were statistically significant differences at all RP, between nails with a 125° CCD and those with a 130° CCD, see Table 6. In particular, the cohort with 125° TFNA nails in situ were on average positioned with the nail buried within the femur. A similar trend could be seen in those models with G3Ns in situ, again with models with the 125° G3N being less prominent at all points, however, this did not reach statistical significance at any RP.

While on average the distance entry point (EP) to the neck axis (NA) was slightly smaller in Asians (41.1 mm ± 3.8 mm) compared to Caucasians (42.2 mm ± 5.5 mm), the difference was not significant (\( p = 0.36 \)). Similarly, on average the CCD angles in Asian femora were larger (128.1 ± 6.7°) compared to Caucasian (126.4 ± 7.4°) samples, but the difference was also not significant (\( p = 0.36 \)).

The protrusion measurements showed negative correlations with both stature and the distance entry point to neck axis (EP-NA), ranging from low to moderate but reaching significance only for the lateral and posterior RPs, see Table 7. However, all proximal protrusion measurements for both nails displayed positive, significant and strong correlations with the femoral CCD angles of the Asian and Caucasian samples (Table 7). Both EP-NA and CCD angle did not correlate with stature.

### Table 5 Mean proximal Gamma3 and TFNA nail distances (mm) to greater trochanter based on ethnicity (+ve indicating protrusion)

|          | Gamma3 | p value | TFNA | p value |
|----------|--------|---------|------|---------|
|          | Caucasian | Asian |      | Caucasian | Asian |
| Medial   | 11.5   | 14.6   | 0.147 | 3.6     | 10.8   | 0.033 |
| (SD)     | (12.6) | (9.8)  | (0.043) | (15.4)  | (11.9) |
| Lateral  | 1.5    | 4.3    | 0.259 | 0.7     | 3.7    | 0.019 |
| (SD)     | (9.4)  | (5.5)  | (10.2) | (5.7)   |
| Anterior | 4.0    | 5.5    | 0.018 | 0.3     | 3.8    | 0.004 |
| (SD)     | (9.6)  | (6.0)  | (9.9)  | (5.2)   |
| Posterior| 1.5    | 4.8    | 0.002 | -0.5    | 2.7    | 0.012 |
| (SD)     | (10.8) | (6.5)  | (10.7) | (5.7)   |
| Centre   | 2.1    | 4.2    | 0.082 | 2.1     | 4.2    | 0.005 |
| (SD)     | (11.2) | (6.9)  | (10.7) | (5.7)   |

### Table 6 Mean proximal Gamma3 and TFNA nail distances (mm) to greater trochanter based on CCD angle (+ve indicating protrusion)

|          | Gamma3 | p value | TFNA | p value |
|----------|--------|---------|------|---------|
|          | 125°   | 130°    | 125° | 130°    |
| Medial   | 3.3    | 14.1    | 0.088 | - 6.7   | 9.7    | 0.001 |
| (SD)     | (13.6) | (10.6)  | (11.4) | (13.1)  |
| Lateral  | 1.3    | 3.2     | 0.537 | - 2.1   | 3.0    | 0.017 |
| (SD)     | (6.5)  | (7.7)   | (4.7)  | (7.2)   |
| Anterior | - 0.1  | 5.3     | 0.150 | - 4.0   | 4.4    | 0.005 |
| (SD)     | (7.2)  | (7.8)   | (7.1)  | (8.1)   |
| Posterior| - 2.2  | 3.8     | 0.059 | - 3.0   | 3.0    | 0.011 |
| (SD)     | (5.8)  | (8.9)   | (5.3)  | (8.1)   |
| Centre   | - 2.6  | 3.8     | 0.100 | - 5.2   | 2.2    | 0.008 |
| (SD)     | (6.6)  | (9.1)   | (5.7)  | (8.6)   |

**Discussion**

This research is novel because it has assessed proximal fit at multiple points on the nail end through the utility of the 3D modelling, providing a more accurate representation of the proximal fit. This is demonstrated by the total of 10 femora which were identified where the nail was only prominent at the medial RP, in a clinical setting this would be located in the trochanteric fossa and consequently may appear to be buried on radiographs. Further, there were 21 femora with the proximal nail centre inferior to the GT while at least one of the other RPs was protruding. Similarly, many of them may appear to be buried on clinical radiographs.

On average, the TFNA was protruding less than the G3N, with multiple factors of the implant design likely contributing to this finding. Firstly, the G3N is approximately 1 mm longer than the TFNA proximally which would predispose it to higher protrusion. Additionally, there are differences in

---

**Table 5** Mean proximal Gamma3 and TFNA nail distances (mm) to greater trochanter based on ethnicity (+ve indicating protrusion)

**Table 6** Mean proximal Gamma3 and TFNA nail distances (mm) to greater trochanter based on CCD angle (+ve indicating protrusion)
lateral bend with the TFNA having a 5° lateral bend compared to a 4° lateral bend in the G3N. The TFNA, with its more pronounced lateral bend results in a more laterally located proximal part of the nail with foreseeably more bony coverage. The clinical relevance of this finding is uncertain as entry point position and hence the end location of the proximal part of the nail is determined by the operating surgeon. However, this result is still clinically relevant as it demonstrates that the TFNA is likely to be less prominent that the G3N and thus in keeping with the reported results from Hu et al. less likely to experience insertional site pain [6]. Equally, these findings are relevant to future CM nail design, as it suggests that a lateral bend of five degrees produces less prominence, future studies focusing on the effect of lateral bend on proximal fit would provide a basis for CM nail redesign.

The obtained results demonstrate statistically significantly higher incidences of proximal nail protrusion in Asians compared to Caucasians, which concurs with reported clinical findings [6, 12, 22]. Both G3N (2 RPs) and TFNA (all 5 RPs) were protruding significantly less in Caucasian compared to the Asian femora. This research is the first to demonstrate that the Asian cohort was 3.76 times more likely to have a femoral nail protrude from the GT.

In our Asian sample, 65.6% for each nail had protrusions, where 40.6% of the G3N group and 31.3% of the TFNA group had protrusions at the nail centre > 5 mm. Compared to Hu et al. [6] who reported protrusions in 87.8% of Chinese patients treated with a PFNA-II, with 60.8% having protrusion > 5 mm, the protrusions of the newer nail designs presented in our study have been reduced by about 20%. However, in our Caucasian cohort the incidences of nail protrusions > 5 mm were close to half that of the Asian sample. Surprisingly, the incidences of centre nail protrusions > 10 mm in our Asian cohort (G3N: 15.6%, TFNA: 9.4%) were similar to the Caucasian cohort (G3N: 12.9%, TFNA: 9.7%). These values are also comparable to the 12.6% of PFNA nail protrusions greater than 1–2 cm reported for 87 Chinese patients [12].

Some of the observed differences may be related to the shape of the GT, a convex structure, consequently the centre of the nail is most likely to be buried. The periphery of the nail is most likely to protrude from the bone and, therefore, the level of protrusion around the edge of the nail is likely to be the most clinically relevant. These findings may infer that ethnicity related anatomical differences in the proximal femur, specifically the GT height, may be responsible for the difference, in keeping with suggestions in the literature [3, 6, 10]. While the EP-NA distance in our Asian sample was slightly shorter compared to the Caucasian, the difference did not reach statistical significance, which is in line with the finding of the same distance in a larger sample [17]. Therefore, the observed greater nail protrusion in Asian femora is unlikely solely explained by their non-significantly shorter GT height. The low to moderate correlations between EP-NA and nail protrusions in our study appear to confirm this.

In contrast, the samples CCD angles strongly and significantly correlated with a protrusion at all RPs for both nails. However, as the CCD angle in our Asian sample was non-significantly larger compared to the Caucasian, it is also unlikely that this is the main contributing factor for the larger nail protrusion in Asian.

The average heights of our Caucasian and Japanese male and female subjects were close to values reported for representative samples of German and Japanese populations of similar age ranges [18, 21]. Therefore, although small, our datasets can be considered to represent the difference in average height between the two populations to some extent. Hence, despite the significant stature difference, due to the low to moderate correlations between stature and nail protrusions (only lateral and posterior), stature is also unlikely the major contributor to the observed nail protrusion differences. Particularly, as EP-NA and CCD angle did not correlate with stature in our sample. Therefore, it is more likely that the difference in nail protrusions is resulting from a combination of a shorter stature and GT height and a larger CCD angle in Asians compared to Caucasians.

Another design feature of modern CM nails is the relationship between the CCD angle of the lag screw and the length of the proximal nail, with a more valgus angle being coupled to a shorter proximal nail. This research has
uniquely demonstrated that patients who require implants with a CCD angle of 125° have a statistically significant reduction in proximal protrusion at all RPs with the TFNA is in situ, and at the medial RP when the G3N has been inserted. Furthermore, the models where a device with a 130° CCD angle had been inserted were 1.65 times more likely to experience proximal protrusion of the nail, and this increased when examining the Asian cohort with proximal protrusion being 4.48 times more likely when a nail with a 130° CCD had been inserted. These novel findings could be anticipated as both the TFNA and the G3N with 125° CCD angles are shorter proximally and more closely approximate the height of the GT as described in the literature [17] and reported here. Hence, our findings infer that both the TFNA and the G3N with 130° CCD angle would be less likely to protrude from the GT if they were shorter proximally. While manufacturers strive to reduce nail length proximal to the lag screw [10], this effort is limited by the distance dictated by the specific mechanical and manufacturing requirements related to the insertion handle’s and end cap’s attachments to the nail, and the lag screw’s locking mechanism.

Despite providing a novel 3D computer graphical assessment of proximal femoral nail protrusion, our study may have been limited by small specimen sample sizes in the ethnic subgroups. Further, there were nine femora with CCD angle > 135°, which if implanted with a 135° CCD nail would have resulted in lower proximal nail protrusions. For equal experimental conditions, we have aligned both nail designs with the lag screw axis passing through the centre of the head in the AP view. However, the operative technique guide of the G3N recommends aligning the lag screw axis with the lower half of the femoral neck [4]. As a clinical study demonstrated that a sliding hip screw positioned in the middle or inferior to the head centre had a lower screw cut out rate [5], there are clinicians who preferentially position the lag screw inferiorly resulting in the proximal part of the CM nail also being positioned more inferiorly within the GT.

Conclusions

The higher likelihood in Asian femora to experience protrusion of the proximal part of the nail above the GT is likely explained by the combination of a smaller GT, a shorter stature and entry point to neck axis distance, and a larger CCD angle, compared to Caucasian. The 3D measurements of proximal nail protrusions indicate that, even though the nail may appear to be buried on a radiograph, it is possible that parts of the nail’s proximal end are protruding from the GT, particularly in the trochanteric fossa. In the light that no specific nail design is currently available to address the outlined problem of our findings, we recommend preoperative templating at this time, which enables estimating proximal nail protrusion and assists in choosing the nail design which CCD angle and proximal lateral nail bend closest matches the patient’s proximal anatomy.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Ethical approval The CT data utilised were available from studies previously published.

References

1. Amarathunga JP, Schuetz MA, Yarlagadda PK, Schmutz B (2014) Automated fit quantification of tibial nail designs during the insertion using computer three-dimensional modelling. Proc Inst Mech Eng [H] 228(12):1227–1234
2. Blauth M, Finkemeier C (2015) TFN-advanced proximal femoral nailing system (TFNA). AOTK Syst Innov 1:4–10. https://issuu.com/aofoundation/docs/tk_news_2015_2011_hires/2016 Accessed 4 Apr 2020
3. Chang S-M, Hu S-J, Ma Z, Du S-C, Zhang Y-Q (2018) Femoral intertrochanteric nail (f1m): a new short version design with an anterior curvature and a geometric match study using post-operative radiographs. Injury 49(2):328–333
4. Stryker Trauma GmbH (2014) Hip Fractures—Gamma3® Long Nail R1.5 and R2.0 Operative Technique https://www.strykermedi.com/media/1310/gamma3-long-nail-r15-and-r20-3320peratietechiniques.pdf. Accessed 28 Mar 2020
5. Hsueh K-K, Fang C-K, Chen C-M, Su Y-P, Wu H-F, Chiu F-Y (2010) Risk factors in cutout of sliding hip screw in intertrochanteric fractures: an evaluation of 937 patients. Int Orthop 34(8):1273–1276
6. Hu S-J, Chang S-M, Ma Z, Du S-C, Xiong L-P, Wang X (2016) PFNA-II protrusion over the greater trochanter in the Asian population used in proximal femoral fractures. Indian J Orthopaed 50(6):641–646
7. Jang Y, Kempton LB, McKinley TO, Sorkin AT (2017) Insertion-related pain with intramedullary nailing. Injury 48(Supplement 1):S18–S21
8. Kang G, Choi K, Kim C-S, Yang J, Bae T-S (2003) A study of Korean femoral geometry. Clin Orthop Relat Res 406:116–122
9. Kim KM, Brown JK, Kim KJ et al (2011) Differences in femoral neck geometry associated with age and ethnicity. Osteoporos Int 22(7):2165–2174
10. Leung KS, Procter P, Robioneck B, Behrens K (1996) Geometric mismatch of the gamma nail to the Chinese femur. Clin Orthop Relat Res 323:42–48
11. Mahaisavariya B, Sittisiriripatik K, Tongdee T, Bohez ELJ, Vander Sloten J, Oris P (2002) Morphological study of the proximal femur: a new method of geometrical assessment using 3-dimensional reverse engineering. Med Eng Phys 24(9):617–622
12. Pu J-S, Liu L, Wang G-L, Fang Y, Yang T-F (2009) Results of the proximal femoral nail anti-rotation (PFNA) in elderly Chinese patients. Int Orthop 33(5):1441–1444
13. Rawal B, Bhattacharjee N, Ribeiro R, Malhotra R (2012) Anthropometric measurements to design best-fit femoral stem for the Indian population. Indian J Orthopaed 46(1):46–53
14. Rubin PJ, Leyvraz PF, Aubaniac JM, Argenson JN, Esteve P, DeRoguin B (1992) The morphology of the proximal femur.
a three-dimensional radiographic analysis. J Bone Jt Surg 74-B:28–32
15. Russell TA (2011) Intramedullary nailing: evolutions of femoral intramedullary nailing: first to fourth generations. J Orthop Trauma 25:S135–S138
16. Schmutz B, Amarathunga J, Kmiec S, Yarlagadda P, Schuetz M (2016) Quantification of cephalomedullary nail fit in the femur using 3D computer modelling: a comparison between 1.0 and 1.5m bow designs. J Orthopaed Surg Res 11(1):1–7
17. Schmutz B, Kmiec S, Wullschleger ME, Altmann M, Schuetz M (2017) 3D Computer graphical anatomy study of the femur; a basis for a new nail design. Arch Orthop Trauma Surg 137(3):321–331
18. Statistisches-Bundesamt (2018) Mikrozensus—Fragen zur Gesundheit—Körpermaße der Bevölkerung 2017. Statistisches Bundesamt, pp 1–17
19. Synthes (2017) TFN-advanced proximal femoral nailing system (TFNA)—surgical technique. https://synthes.vo.llnwd.net/o16/LLNWMB18/US%2520Mobile/Synthes%2520North%2520America/Product%2520Support%2520Materials/Brochures/3936_DSUSTRM06140109-06140107_TFNA_Core_rev06140101.pdf. Accessed 2 Mar 2020
20. Wolinsky P, Tejwani N, Richmond JH, Koval KJ, Egol K, Stephen DJ (2002) Controversies in intramedullary nailing of femoral shaft fractures. Instr Course Lect 51:291–303
21. Yong V, Saito Y (2012) How accurate are self-reported height, weight, and BMI among community-dwelling elderly Japanese?: evidence from a national population-based study. Geriatr Gerontol Int 12(2):247–256
22. Zhang S, Zhang K, Jia Y, Yu B, Feng W (2013) InterTan nail versus proximal femoral nail antitrotation-Asia in the treatment of unstable trochanteric fractures. Orthopedics 36(182–183):e288–e292

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.