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# A comprehensive analysis on contributing factors for varus or valgus malposition of femoral stems in uncemented total hip arthroplasty via DAA

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ABSTRACT

*Background:* Varus or valgus malposition of uncemented femoral stems have been described to have detrimental effects for long term implant survival. Various pre- and intra-OP factors have been suggested to be relevant, one of them being the approach to the hip. The aim was to investigate several pre- and intra-OP factors associated with femoral stem malpositioning in a large series of DAA hips.

*Methods:* A series of 400 consecutive patients (416 hips) who underwent navigated (Brainlab) cementless Total Hip Arthroplasty (THA) in 2022 (Corail or Actis stem DePuy Synthes) via a direct anterior approach (DAA) was analyzed. Preoperative data were collected based on patients' demographics, radiographic information [critical trochanteric angle (CTA), centrum collum diaphyseal (CCD) angle, greater trochanter overhang, femoral neck resection angle, femoral neck resection height and Door classification], and these were correlated with the postoperative stem position. Univariable and multivariable linear regression were carried out to determine significant factors that contribute to varus and valgus stem malalignment.

*Results:* With the DAA approach, 56.5 % of stems were placed in an optimal neutral position, 38.4 % were in acceptable position of 0.1°–2° varus/valgus and only 5 % had a deviation larger than 2° varus/valgus. The critical trochanteric angle (CTA) was statistically significant in determining varus stem placement whereas centrum collum diaphyseal angle (CCD) was found to affect valgus stem malpositioning. All other factors have shown no relevant effect on stem placement using stepwise regression method.

*Conclusion:* In DAA, 95 % of stems were found in a varus/valgus position of 2° or less. In pre-operative measurement, only femoral morphology (e.g. CTA & CCD) were found to be relevant, affecting varus/valgus stem malposition. All other tested modifiable and non-modifiable factors had no significant effect. Therefore, pre-OP templating including measurement of CTA and CCD, intra-operative assessment as well as proper operative techniques are paramount to prevent excessive varus/valgus mal-position of femoral stem in DAA.

## 1. Introduction

Primary Total Hip Arthroplasty (THA) has been described to be one of the most successful surgeries in the medical field. Nonetheless, varus/valgus mal-positioning of the femoral stem has been found to have deleterious outcomes.[1,2] Therefore, optimal stem placement is of great relevance for long term survival.

Varus placement of a cemented stem may result in an abnormal strain distribution and load transfer whereby insufficient cement mantle at Gruen Zone 1 & 5 result in implant subsidence, component loosening and even periprosthetic fractures.[3–5] Such mal-alignment may also affect offset and limb length restoration.

Likewise, for a varus mal-positioned uncemented stem, increased risk of revision as well as poorer outcome and survivorship have been reported in multiple studies.[6–9] On the other hand, valgus stem deviation did not seem to have a less detrimental effect. It may subject the proximal femur to undergo more stress shielding,[10] reduces femoral offset resulting in an unstable hip and increases wear in the long term.[11,12]

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Therefore, surgeons must be aware of various factors that may predispose to varus or valgus stem mal-position.

Several authors have mentioned that patients with a *low* Centrum Collum Diaphyseal angle (CCD) & Critical Trochanteric angle (CTA) (coxa vara) are at risk to have a varus positioned stem; whereas *high* CCD & CTA angle (coxa valga) are more inclined to have a valgus positioned stem.[13–15] Other factors, such as the length of the femoral neck cut (high/low) and the amount of greater trochanter overhang[16–20] have been described to also contribute to varus stem placement.

Beside anatomical factors, other factors such as implant design may play an important role.[21] While some of those factors are modifiable (stem type, collared or collarless stems, neck cut angle, and level of neck resection (height), others are non-modifiable.[9–17] Non-modifiable factors are age, gender and femoral bone morphology (CCD angle, CTA angle, GT overhang and Dorr classification). The approach to the hip has also been described to affect stem position.[22–24] Wazzan et al.,[24] recently stated that a posterior approach has a higher incidence of varus stem placement. In direct anterior approach (DAA) a "shoulder" type/shape of uncemented stem tends to skew into varus; while an "anatomical" type/shape does not go into varus.[23] On the contrary, research from Japan showed that different approaches did not affect the coronal plane but it did have an effect on sagittal stem alignment.[22]

In this retrospective study, we analyzed several modifiable and non-modifiable predisposing factors leading to varus/valgus mal-alignment of uncemented THR done via a navigated DAA. The first hypothesis was that in DAA, stem placement can be performed in more than 90 % of cases with no varus/valgus malalignment (relatively neutral). The second hypothesis was that femoral bony anatomy has an effect on stem placement.

## 2. Materials and methods

This study was approved by the institution's internal review board (Ref: 22-2812-104) and each patient provided written informed consent prior to participation. This was a retrospective cross-sectional study, through evaluation of medical records of 400 consecutive patients, who underwent cementless THA in 2022. A total of 416 hips received either a collared or collarless Actis or Corail stem (DePuy Synthes, Warsaw, IN, USA) combined with a cementless hemispheric cup (Pinnacle®, Depuy Synthes) and ceramic or metal on polyethylene bearing were included in this study.

All THA were performed by 1 senior (HG) and 1 junior consultant (PH) utilizing computer navigation (Hip 5.1, BrainLAB, Feldkirchen, Germany), and carried out via minimally invasive DAA. This navigation system delivered information on cup position, leg length and lateral offset but not on stem position. Preoperative planning was performed by using dedicated software (mediCAD; Hectec GmbH, Altdorf, Germany) [Fig. 1]. Stem size and position as well as cup position was re-confirmed again by single use of intraoperative image intensifier.

The Corail® stem is a straight, tapered, HA coated titanium cementless meta-diaphyseal filling stem. Actis, on the other hand has a triple taper geometry design and the proximal portion of the stem contains Duofix® (DePuy Synthes, Warsaw, IN, USA), which consists of a coating composed of titanium sintered beads with the addition of a hydroxyapatite layer. The choice of stem was dependent on hospital guidelines. In general, younger patients with good bone quality received Actis stems and patients above 65 years or poorer bone quality received Corail stems. In cases of possible under-sizing which was noticed intraoperatively (image intensifier final check), upsizing to a proper fitting stem was performed. Intra-operative limb length and offset restoration were re-confirmed again with Brainlab navigation.

Inclusion criteria for DAA in this study were end stage osteoarthritis of the hips, avascular necrosis of femoral head and Crowe I and II dysplastic hips. Exclusion criteria were previous hip surgeries, revision surgery, infection, abnormal excessive femoral bowing and dysplastic Crowe III and IV. Pre-operative and post-operative anteroposterior (AP) pelvic radiographs were analyzed by two arthroplasty clinical fellow (HLT & AM - who were not involved with the index surgery) using (mediCAD; Hectec GmbH, Altdorf, Germany) software twice six weeks apart and a mean was taken. Each investigator was blinded to the measurement of the other investigator. The AP pelvic standing radiographs were taken with 20° internal rotation of hip joints to achieve a standardized and reproducible image.

**CCD angle** [Fig. 2] – Centrum collum diaphyseal angle was measured and classified as Coxa Vara (<125°), Neutral (125–135°) and Coxa Valga>135°.

**CTA angle** [Fig. 2] – Critical trochanteric angle was measured as described by Haversath et al.[14] An intersection between the femoral neck axis and shaft axis is defined. Then, the angle is measured between the femoral shaft axis and a leg bisecting the lateral and superoposterior

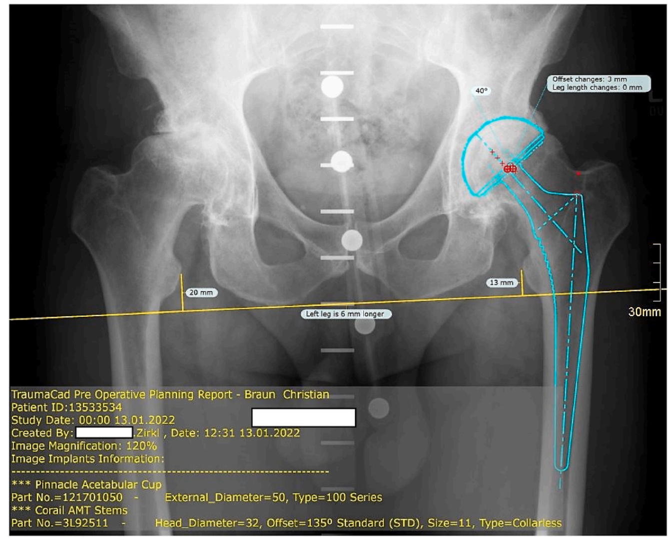


**Fig. 1.** Pre-operative digital templating using MediCAD software.

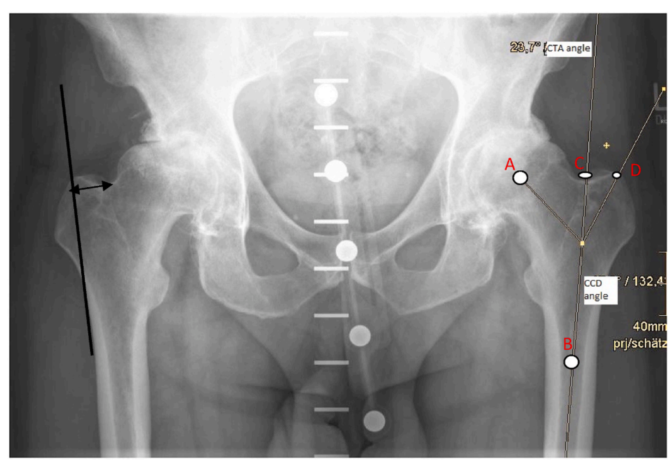


**Fig. 2.** Measurement of CTA & CCD angle of left femur; measurement of GT medial overhang and identification of GT morphology
Left femur:
CCD angle: An angle established adjoining Point A (center of the femoral head) + Point B (a line bisecting the femoral shaft axis)
CTA angle: An angle between the femoral shaft axis Point C and a leg bisecting the lateral and superoposterior facet of the trochanter Point D
Right femur:
A line was drawn along the lateral most region of proximal femur; and a second perpendicular line was drawn medial to the first line to the most medial edge of greater trochanter. The length of the second line was measured in (mm) & type of GT overhang was determined.

facet of the trochanter.

**Greater trochanter overhang** [Fig. 2] – Distance from medial overhang of the greater trochanter to a line 90° perpendicular to the lateral femur diaphysis; described by Morgan Bayley et al.[20] and were classified as Type I - Small (<20 mm), Type II – medium (20–30 mm) and Type III - large (>30 mm).

**Dorr classification (A,B,C)** - radiographic femoral morphology was classified according to Dorr classification.[25]

**Femoral neck osteotomy angle** – Angle measurement by drawing a line between the tear drop/ischial tuberosity and second line across the femoral neck cut. This gives the femoral cut angle [Fig. 3].

**Femoral neck resection height** – Distance between two lines drawn between lowest point of resection line and proximal base of lesser trochanter; described by Worliceket al.[26] [Fig. 3].

**Stem tilt angle/varus-valgus tilt** -Measurement of the alignment of the implant in relation to the femoral shaft axis in the coronal plane. Red line represents the femoral shaft axis, yellow line represents the implant shaft axis; described by Worliceket al.[26] [Fig. 4]. Varus/Valgus tilt of femoral stem was then measured.

### 2.1. Statistical analysis

Descriptive analysis was carried with continuous variables reported in mean and standard deviation while categorical variables reported in frequency and percentage. Univariable and multivariable linear regression was carried out to determine significant factors that determine varus and valgus malalignment. Univariable linear regression was carried out to determine factors associated with varus and valgus malalignment. All variables with p value < 0.20 were included in the preliminary multivariable model, using stepwise regression method, to determine the final model of factors associated with varus and valgus mal-alignment. The correlation between stem mal-alignment with other continuous variables, femoral neck resection height, CCD, CTA and GT Overhang was determined using Pearson Correlation analysis. All analysis was carried out with Statistical Program for Social Statistics (SPSS) Ver 24.0, with p value of <0.05 considered to be significant.

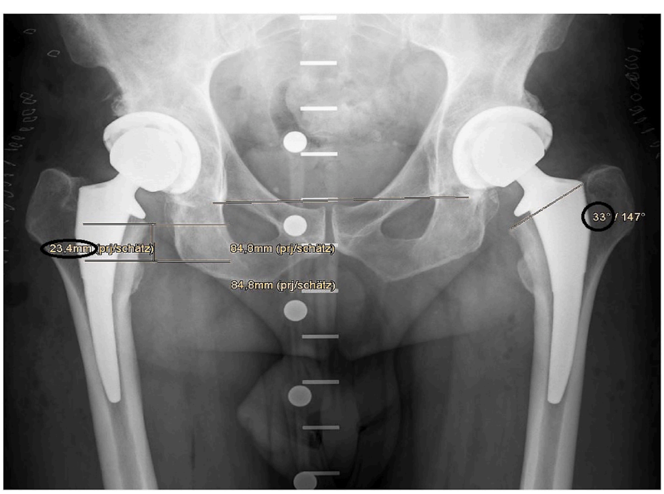


**Fig. 3.** Measurement of femoral neck osteotomy angle of the left hip and femoral neck osteotomy height on the right hip.
Left hip: A line was drawn along the resected femoral neck and a second line was drawn adjoining the tear drop of bilater acetabulum. An angle° was generated.
Right hip: A horizontal line was drawn at the superior most region of the femoral neck cut, and a second horizontal line was drawn at the superior tip of the lesser trochanter. The distance between these two lines was measured in (mm).

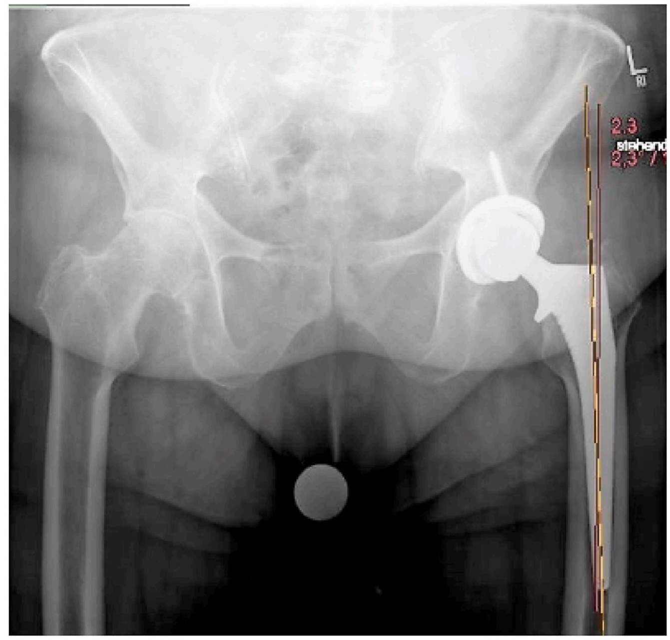


**Fig. 4.** Measurement of femoral stem deviation from anatomical axis of femur (e.g.: 2.3° varus). Red line represents the femoral shaft axis (a line bisecting the femoral medullary canal), yellow dotted line represent the implant shaft axis(a line bisecting the coronal half of stem).

## 3. Results

The mean age of the patients in this study was 67.9 years. 39.9 % (166) of hips were neutral (125°–135°), 22.6 % (94) of hips were Coxa Vara (<125°) and 37.5 % (156) of hips were Coxa Valga (>135°). The mean deviation of stem position in 416 hips were +0.46° Varus (range: +2.83 to −2.82) with 56.5 % of stems placed in neutral.

Frequency & percentage of stem placement from varus (0.1–1°) to (>2°), neutral, and valgus.

(−0.1 to −1°) to (>-2°) is shown in Table 1.

Among all the possible factors associated with varus positioning of femoral stem, **only CTA angle** was found to be statistically significant in final multiple variable linear regression analysis (Table 2).

Although CTA angle was found to be a significant determinant for valgus positioned stem in univariable linear regression analysis, stepwise multi-regression analysis showed **only CCD angle** to be statistically significant (Table 3).

In the entire cohort, 48.3 % of femoral stems were Actis while 51.7 % were Corail stems. Stem type whether collared or collarless implants did not predispose to stem mal-positioning.

Mean femoral osteotomy angle in this study was 40.54° (range, 25.80°–59.95°), SD = 5.91.

There was no significant correlation between varus/valgus alignment and femoral neck osteotomy angle.

**Table 1**
Stem positioning.

| Stem Position | Frequency | Percent (%) |
|---|---|---|
| **Varus(>2°)** | **13** | **3.1** |
| **Varus(1.1–2°)** | 48 | 11.5 |
| **Varus (0.1–1°)** | 61 | 14.7 |
| **Neutral (0°)** | 235 | 56.5 |
| **Valgus(-0.1 to -1°)** | 40 | 9.6 |
| **Valgus(-1.1 to-2°)** | 11 | 2.6 |
| **Valgus(>-2°)** | **8** | **1.9** |
| Total | 416 | 100.0 |

**Table 2**
Univariable linear regression analysis for **Varus** stem mal-alignment and analysis for **Varus** stem mal-alignment.

| | | Odds Ratio | 95 % Confidence Interval | | p value |
|---|---|---|---|---|---|
| | | | Lower Limit | Upper Limit | |
| Sex | Male | 0.081 | −0.194 | 0.357 | 0.560 |
| | Female | 1.000 | – | – | |
| Age | | 0.010 | −0.005 | 0.025 | 0.210 |
| **CTA** | | **−0.044** | **−0.070** | **−0.017** | **0.002** |
| CCD | | −0.016 | −0.034 | 0.002 | 0.074 |
| GT Overhang | 1 | −0.514 | −1.399 | 0.371 | 0.253 |
| | 2 | −0.247 | −0.521 | 0.027 | 0.077 |
| | 3 | 1.000 | – | – | |
| DORR | A | −0.071 | −1.159 | 1.016 | 0.897 |
| | B | 0.177 | −0.898 | 1.251 | 0.745 |
| | C | 1.000 | – | – | |
| Stem Type | ACTIS | −0.079 | −0.423 | 0.265 | 0.650 |
| | Corail | 1.000 | – | – | |
| Collared/ Noncollared | Collar | −0.147 | −0.420 | 0.126 | 0.288 |
| | Collarless | 1.000 | – | – | |
| Neck Cut Angle | | 0.011 | −0.010 | 0.032 | 0.315 |
| Level of neck cut | | 0.006 | −0.018 | 0.031 | 0.619 |

Final stepwise multiple linear regression analysis:

| | Odds Ratio | 95 % Confidence Interval | | p value |
|---|---|---|---|---|
| | | Lower Limit | Upper Limit | |
| **CTA** | −0.044 | −0.070 | −0.017 | **0.002** |

**Table 3**
Univariable linear regression analysis for **Valgus** stem mal-alignment and analysis for **Valgus** stem mal-alignment.

| | | Odds Ratio | 95 % Confidence Interval | | p value |
|---|---|---|---|---|---|
| | | | Lower Limit | Upper Limit | |
| Sex | Male | −0.338 | −0.770 | 0.093 | 0.122 |
| | Female | 1.000 | – | – | |
| Age | | −0.012 | 0.010 | −0.035 | 0.270 |
| CTA | | 0.041 | 0.004 | 0.078 | 0.030 |
| **CCD** | | **0.049** | **0.026** | **0.071** | **<0.001** |
| GT Overhang | 1 | 0.239 | −0.499 | 0.978 | 0.519 |
| | 2 | −0.003 | −0.604 | 0.598 | 0.992 |
| | 3 | 1.000 | – | – | |
| DORR | A | −0.255 | −1.509 | 1.000 | 0.686 |
| | B | −0.198 | −1.433 | 1.037 | 0.749 |
| | C | 1.000 | – | – | |
| Stem Type | ACTIS | 0.196 | −0.305 | 0.697 | 0.437 |
| | Corail | 1.000 | – | – | |
| Collared/ Noncollared | Collar | 0.273 | −0.185 | 0.731 | 0.238 |
| | Collarless | 1.000 | – | – | |
| Neck Cut Angle | | 0.018 | −0.020 | 0.056 | 0.344 |
| Level of neck cut | | 0.004 | −0.043 | 0.052 | 0.852 |

Final stepwise multiple linear regression analysis:

| | Odds Ratio | 95 % Confidence Interval | | p value |
|---|---|---|---|---|
| | | Lower Limit | Upper Limit | |
| **CCD** | 0.049 | 0.026 | 0.071 | **<0.001** |

Mean femoral neck resection height was 13.77 mm (2–48.25 mm), SD = 5.01. There was a poor correlation between degree of varus and valgus alignment with femoral neck resection height using Pearson Correlation analysis.

The mean GT overhang in this study was 26.60 mm (11.45–42.65 mm), SD = 5.62. In terms of GT morphology, 65 hips (15.6 %) were type I, 243 hips (58.4 %) were type II and 108 hips (26 %) were type III. For Door classification of femur, 50.2 % were Door A, 47.8 % were Door B and 1.9 % were Door C. None of these were statistically significant to affect stem position.

The mean CCD angle in this study was 133.19° (range, 127.11°–151.26°).

There is a poor correlation between CCD angle with varus stem positioning, but strong correlation was found between CCD angle with **valgus** position of stem with $p < 0.001$ [Fig. 5]. $R^2 = 0.177$.

The mean CTA angle in this study was 22.78° (range, 15.75°–30.04°). A strong correlation was found between CTA angle with **varus** position of stem with $p < 0.005$ [Fig. 6]. $R^2 = 0.176$.

## 4. Discussion

The most important finding in this study was that only bony anatomical factors (CTA and CCD) predispose to varus or valgus stem placement in DAA, while all other modifiable and non-modifiable factors have no effect. This finding shows the importance of pre-OP analysis and confirms the second hypothesis of this study. The first hypothesis was also confirmed by the fact that 95 % of all stems were placed in less than 2° of varus or valgus. This finding demonstrates that varus/valgus stem placement is minimal in DAA.

Varus or valgus position of femoral stem and its long-term clinical implication has been extensively debated. Varus positioning of both cemented and cementless stem was found to have inferior outcome and survivorship.[6–8,27] Furthermore, it may also contribute to higher incidence of cortical hypertrophy and thigh pain2. Valgus stem malposition may subject the proximal femur to undergo more stress shielding,[10] reducing its femoral offset, rendering the hip unstable and increases wear in the long term. Therefore, surgeons must be aware of various factors that may predispose to varus or valgus stem mal-position to ensure a better outcome and extrapolate good longevity of the implants for their patients.

We have conducted the largest THA series identifying various factors mentioned in the literature which may predisposed to varus-valgus position of femoral stem. All surgeries were performed via direct anterior approach with Brainlab navigation assistance. Both Actis and Corail stems provide similar and comparable good clinical and radiological outcomes.[28] Furthermore, the Corail® hip system has an Orthopaedic Data Evaluation Panel (ODEP) rating of 10A.

Our study shows that CTA was inversely correlated with varus positioning of the stem ($P < 0.05$) [Table 2]. Haversath et al.[14] mentioned that for stem malpositioning of 2° and above, the mean CTA was 17.2° for varus and 31.6° for valgus. They recommended intraoperative image intensifier to verify correct implant positioning in patients with a CTA under 20° or above 30°. The result of our series was comparable to theirs, in that in stem malpositioning of 2° and above, the mean pre-operative CTA was 15.75° in the case of varus and 30.04° for valgus aligned hips. Likewise, Lugeret al.[15] also mentioned that a low CTA and low CCD angle may predispose towards varus positioning. However, in our study, higher CTA angle does not predispose to a

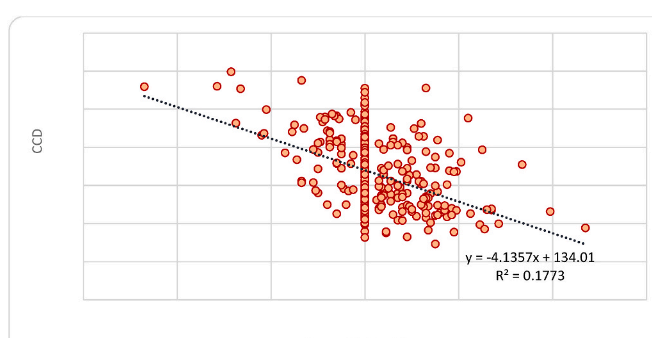


**Fig. 5.** Scatter plot graph showing relationship of CCD with varus/valgus malposition of stem.

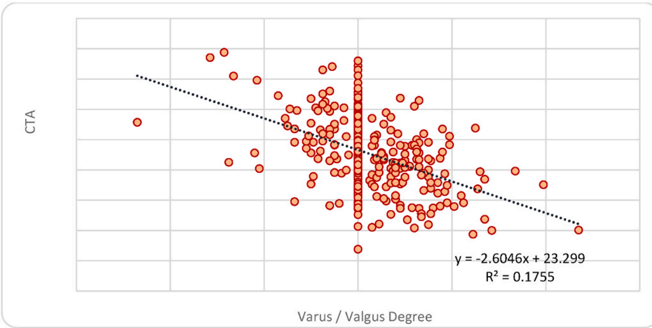


**Fig. 6.** Scatter plot graph showing relationship of CTA with varus/valgus malposition of stem.

statistically significant valgus stem position via final stepwise multiple linear regression analysis.

CCD angle on the other hand is positively correlated with valgus positioning of stems ($P < 0.001$) [Table 3] in our study. However, a lower CCD angle does not have a predilection towards a statistically significant varus positioned stem. This result was dissimilar with Murphy et al.[13] whereby coxa vara with a high CCD angle results in statistically significant varus stem mal-alignment via posterior approach. Haversath et al.[14] had their mean CCD of 125.7° in the varus group, neutral group 129.3° and in the valgus group 133.7°, respectively via DAA approach. Whereas we had a mean CCD of 127.11° in the varus group, neutral group 133.32° and in valgus group 151.26°. Valgus skew of femoral stem occurred at a higher degree in coxa valga with larger CCD angle in our study.

The degree of deviation from neutral to be considered as varus/valgus has yet to be standardized. De Beer et al.[29] & Khalily et al.[30] consider varus malalignment when stem alignment is > 5°, whereas Zang J et al.[6] and Aldinger PR et al.[31] defined varus-valgus malalignment of the stem as deviation of the longitudinal femoral axis more than 2°. On the contrary, Batailler et al.[32] consider coronal alignment greater or equal than 3° as varus placed stem. Fortunately, we did not have any varus/valgus stem deflection of more than 5°. In order to standardize varus/valgus angle, we considered a valgus of more than 2° and varus of more than 2° as significant.

In our study, we found that factors such as age, gender, Dorr classification, GT overhang, collared or collarless stems, femoral neck resection angle and height were all statistically insignificant in determining femoral stem malalignment. This finding was almost comparable with the literature[6,20] whereby age, gender and Door classification/Canal flare index has no direct relationship with stem placement. The dissimilarity was that the magnitude of varus displacement corresponded with increased GT overhang.[20] Similar results were also reported by Murphy CG et al.[13] and Haojun Wang et al.[33] These surgeries[13,20,33] were performed via a lateral or posterior approach. This may suggest that DAA is less vulnerable to GT overhang compared to other approaches.

In contrast to our study, Batailler et al.[32] had 40 % of collared corail stem placed in varus via DAA approach. They found a strong correlation with broach shape (prominent proximal lateral edge) as a predictive factor responsible for varus stem deviation. However, this phenomenon was not observed in our study, in which no difference between collared and collarless stem exists and the overall rate of varus placement is only 3.1 %.

The role of femoral neck resection height remains controversial. Floerkemeier et al.[16] found that a higher incidence of varus stem malposition and increased horizontal offset were seen with high resection height (>10 mm). Our study was comparable with Worlicek et al.[26] whereby femoral neck resection height ranging between 0 and 20.1 mm did not correlate with the final position of a collarless straight tapered stem design (Corail®) via DAA approach. On the contrary, Dimitriou et al.[18] proved that level of resection affects coronal stem placement whereas femoral neck resection angle affects stem version, via the posterior approach.

In our series, we had a significant lower mean deviation from neutral (+0.46° varus) and lower range of varus/valgus mal-alignment (range: +2.83 to −2.82°) compared to other series[14,26] which may be due to a number of reasons:

1. First and foremost, the use of pre-op digital templating software to determine ideal stem size and targeted offset restoration prior to surgery may reduce the incidence of undersized stems. This may prevent poor fitting of femoral stems into femoral canal which can predispose towards varus/valgus malalignment.
2. From a technical point of view, bone nibbling, curettage, and/or burring to remove posterolateral cancellous bone at the proximal femoral neck & trochanteric bed after neck resection may enhance true anatomical initiation of broaching.
3. Additionally, we also implemented one-time utilization of image intensifier intra-OP to reconfirm stem size/position before final implant insertion. At this point, upsizing a femoral stem or broaching in a more neutral position could still be executed in time.
4. The use of computer assisted navigation for limb length and offset restoration may reduce the incidence of undersized stems and indirectly limit the chance of varus/valgus malposition. Several articles have proven better offset and limb length restoration in navigation assisted THA.[34–37] It must be cautioned that navigation is not essentially a device to prevent varus/valgus placement of stem and final stem positioning is still operator and patient's femoral morphological trait dependent.
5. Finally, utilizing a direct anterior approach may contribute to a lower incidence of varus stem malpositioning. Tian S et al.[38] had 98.3 % of uncemented stem placed in neutral position (<3° of varus). Utilization of the DAA may also facilitate stem insertion in patients with greater trochanteric overhang. During preparation of the femur via a posterior approach in the lateral decubitus position, the GT lays antero-superior to the canal with the gluteus medius overlying it. This configuration predisposes to more challenging intended lateralization of the broach. On the contrary, in the supine direct anterior approach, the femur is externally rotated, taking the GT posterior to the femur, and allowing the gluteus medius to fall backwards in the operative field. This facilitates removal of lateral bone stock and does not lead to the operative field being obscured by overhanging soft tissues.

## 5. Limitations

We are aware that this is a plain radiograph analysis of coronal malpositioning of femoral stems. CT-scan analysis could be a better radiological tool to assess coronal as well as sagittal stem deviation. However, arranging 400 patients to undergo CT-scanning may result in exhaustion of imaging facilities and subject patients to higher radiation. Secondly, we only utilized two types of femoral stems (Actis and Corail). Larger sample studies with different types of uncemented and cemented stems may yield different results. In addition, we have eliminated a small number of patients ($n < 10$) who had excessive femoral bowing. In such cases, perhaps slight varus positioning of the stem may be the only choice to allow adequate and optimum fitting of the femoral stem. All patients were Caucasians. The rate of bowing is higher in Asian population and the effect of CTA and CCD may be different. All of our THA surgeries were performed via navigation assisted direct anterior approach. In future, other approaches such as Watson Jones, direct lateral and posterior approach could be evaluated, and comparison conducted with regards to varus or valgus malpositioning of stems.

## 6. Conclusion

To our knowledge, this is the first and largest single center series identifying various possible factors associated with varus/valgus femoral stem malpositioning performed via navigated direct anterior approach. It is imperative for surgeons to pay extra caution in patients who have anatomical variability such as excessively low or high CTA or CCD angles. The risk of varus stem malpositioning increases with smaller CTA angle; and the risk of valgus stem mal-positioning increases with larger CCD angle.

### Consent statement

This study was approved by the institution's internal review board (Ref: 22-2812-104) and each patient provided written informed consent prior to participation.

### Funding

This study did not receive any funding

### CRediT authorship contribution statement

**Hak Lian Teh:** Data collection and writing paper. All authors read and approved the final manuscript. **Mostafa Abounouh:** Data collection, Formal analysis, paper writing. **Philip Haibock:** Writing – review & editing. **Veenesh Selvaratnam:** Writing – review & editing, Formal analysis. **Shubash Shander Ganapathy:** Statistics, Formal analysis. **Heiko Graichen:** Writing, Writing – review & editing.

### Declaration of competing interest

All authors have no conflicts of interests.

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