Computed tomography-based navigation system using a patient-specific instrument for femoral component positioning: an experimental in vitro study with a sawbone model

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Purpose

In total hip arthroplasty (THA), intraoperative version of femoral component is conventionally determined through visual assessment of stem position relative to the distal femoral condylar axis [1]. However, several studies reported that the conventional technique had high probability of misinterpretation [2], and it can be causative of malposition of acetabular and femoral components, thus yielding complications such as dislocation, impingement, wear, loosening, and postoperative range of motion. In this study, a computed tomography (CT)-based navigation system with patient-specific instrument (PSI) was proposed to address the issue.

Methods

An in vitro study was performed by using the same 60 femur sawbone models to investigate the accuracy and consistency of the proposed technique that uses a CT-based navigation system with PSI in comparison with the conventional technique by using the surgeon's visual estimation.

For the proposed technique, planning procedures were done after taking CT scan of a sawbone model. 3-D bone model was reconstructed from the CT images using 3D slicer (Brigham and Women's Hospital, Boston, MA, USA). Stem anteversion (θ_{ante}) of the sawbone was determined as follows: a center axis of the femoral neck was first defined using extracted points around the femoral neck; second, a coronal plane was defined using three landmarks which are medial and lateral epicondyles and lesser trochanter; finally, θ_{ante} that is an angle between the center axis and the coronal plane was measured. Measured θ_{ante} was 4.1°. PSI was designed using the Mimics® (Materialise, Leuven, Belgium). Seven landmark points and cutting margins (θ_1, θ_2, θ_3, and d) were defined on PSI for both preregistration and femoral neck osteotomy (Fig. 1a). θ_1, θ_2, and d were measured as 135°, 45°, and 10 mm, respectively. θ_3 is a vertical angle of PSI to the coronal plane and its value was zero, meaning that a planned cutting plane was perpendicular to the coronal plane. Preregistration between the coordinate systems of the 3-D reconstructed bone model and optical tracking system (OTS; Polaris Spectra, Northern Digital Inc., Waterloo, Canada) was performed by using the landmarks on PSI after attaching a marker to PSI [3]. For tracking the tip of a box chisel, pivot calibration was done after attaching a marker to the chisel. After the aforementioned planning procedures was done,

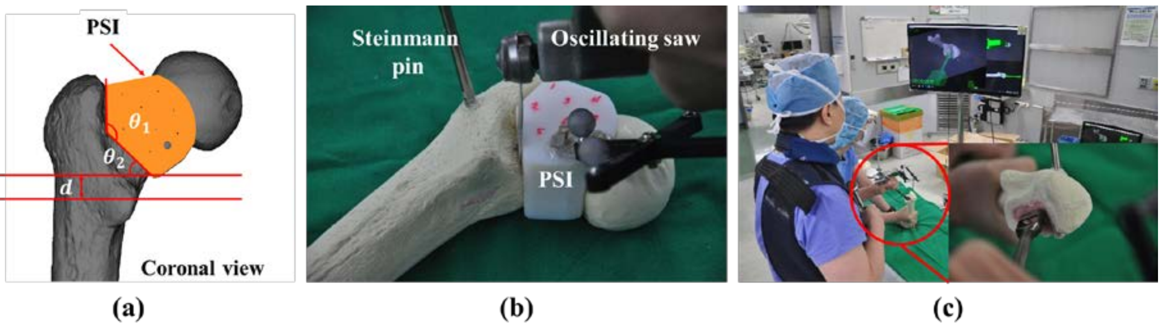

Fig. 1 a Design of patient-specific instrument (PSI) **b** Femoral neck osteotomy using PSI **c** femoral medullary canalizing with the navigation system

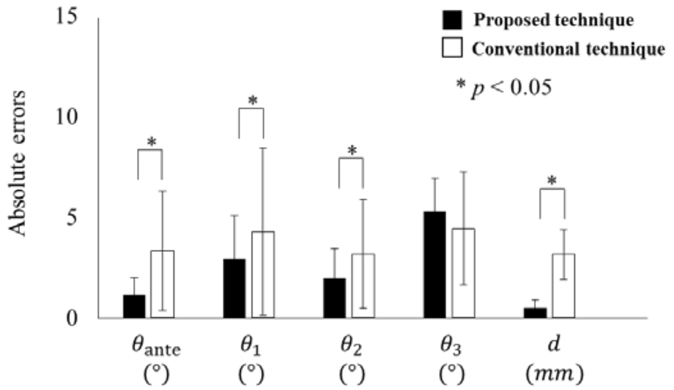

Fig. 2 Comparison between proposed and conventional techniques

we conducted the in vitro study as following steps: first, a Steinmann pin with a marker was firmly fixed around the greater trochanter. Second, PSI was inserted on the planned position (Fig. 1b). Third, image-to-patient registration using PSI was simply performed without additional steps such as picking landmarks with a digitizing probe [3]. Fourth, the femoral neck osteotomy was conducted along the margin of the PSI (Fig. 1b). Finally, femoral medullary canalizing was performed by using the chisel with the navigation system (Fig. 1c).

For evaluation of each technique, the postoperative CT images for the 60 sawbone models were taken and reconstructed to virtual femur models. The registration step between the 60 virtual femur models and the virtual femur model used in the planning step was performed. In every registered virtual model, θ_{ante}, θ_1, θ_2, θ_3, and d were redefined and compared with those obtained in planning step.

Results

Mean error on θ_{ante} was 1.15° with the proposed technique and 3.31° with the conventional technique; mean errors on θ_1, θ_2, θ_3, and d were 2.93°, 1.96°, 5.29°, and 0.48 mm, respectively with the proposed technique and 4.26°, 3.17, 4.43°, and 3.15 mm, respectively with the conventional technique (Fig. 2). For all parameters except for θ_3, there were sigificant differences ($p < 0.05$).

Conclusion

We proposed a femoral component insertion techanique using a CT-based navigation system with PSI. The proposed technique was more accurate and consistent than the conventional technique, except for a vertical error to the coronal plane. Therefore, the CT-based navigation system with PSI can be a good alternative for reducing the surgeon's incorrect assessment of stem position and determining accurate stem anteversion.

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References

1. Woerner M, Sendtner E, Springorum R, Craiovan B, Worlicek M, Renkawitz T, Grifka J, Weber M (2016) Visual intraoperative estimation of cup and stem position is not reliable in minimally invasive hip arthroplasty. Acta Orthop 87(3):225-230
2. Dorr LD, Wan Z, Malik A, Zhu J, Dastane M, Deshmane P (2009) A comparison of surgeon estimation and computed tomographic measurement of femoral component anteversion in cementless total hip arthroplasty. J Bone Joint Surg Am 91(11):2598-2604
3. Oka M, Cho B, Matsumoto N, Hong J, Jinnouchi M, Ouchida R, Komune S, Hashizume M (2014) A preregistered STAMP method for image-guided temporal bone surgery. Int J Comput Assist Radiol Surg 9(1):119-126