

Abstract

Materials and Methods

Results

Background: Robots are automatically operated machines that have replaced humans in performing various tasks. With advancements in robotic technology, a robotic system, the da Vinci Robot (Intuitive Surgery, Sunnyvale, CA, USA), has been gaining popularity for helping surgeons deliver a less invasive approach in the medical fields across gynecology, urology, and general surgery.^{1,2} Proven advantages of robot-assisted surgery include precise execution of technically demanding procedures and elimination of human tremors.²

Aim: This study aimed to evaluate the tracking accuracy of a robot-guided implant surgery system and compare the spatial accuracy of robot-assisted implant surgery with that of static stent-guided implant surgery for implant placement.

Materials and Methods: The tracking accuracy of the robot system was evaluated by measuring the discrepancy between the robot arm and actual programmed position. Dental implants were placed on 3D printed human phantom models using static stent-guided and robot-assisted surgeries. The top, apex, angular, and depth deviations of the placed implant positions were measured relative to the planned position, and the values were compared between the robot and surgical guide groups. The results were analyzed using the Mann-Whitney U test ($\alpha = .05$).

Results: The tracking accuracy of the robot system showed a linear deviation of 0.13 ± 0.04 mm and an angular deviation of $0.77 \pm 0.02^\circ$ at the drill tip. Deviations at the top and apex of the implants were 0.61 ± 0.29 mm and 0.50 ± 0.14 mm in the robot group and of 0.49 ± 0.39 mm and 0.72 ± 0.39 mm in the surgical guide group, respectively. Angular and depth deviations were of $2.38 \pm 0.62^\circ$ and 0.17 ± 0.12 mm, respectively, in the robot group, and of $3.16 \pm 2.36^\circ$ and 0.15 ± 0.11 mm, respectively, in the surgical guide group. No statistically significant differences were found between the robotic and surgical guide groups ($p > .05$).

Conclusion: The accuracy in implant placement using robot-assisted implant surgery was comparable to that of static-guided surgery. Robot-assisted implant surgery and static-guided surgery tended to result in minor deviations at the apex and top of the implants, respectively.

Components of implant surgical robot

The workflow of robot-assisted implant surgical system and accuracy evaluation procedure is shown in Fig. 1. The implant surgical robot system consists of a robot arm (Puloon, Seoul, Korea), a robot operating software (MI2RL, Seoul, Korea), and an optical tracker (Polaris Vega; NDI, Waterloo, Canada) and positioning markers. The robot arm had a working range of 850 mm with 6 degrees of freedom, a load capacity of 5 kg, and a position repeatability of ± 0.1 mm. The optical tracker had a maximum frame rate of 250 Hz with the volumetric accuracy of 0.12 mm. Four spherical markers (OptiTrack M3 Marker; NaturalPoint Inc., Corvallis, USA) were connected to the implant handpiece and four to the patient device. The marker fixing device mounted on the patient's mouth consists of an intraoral securing part and an extraoral marker supporting part. The marker fixing device mounted on the robot arm was designed to have a handpiece securing part and a marker supporting part.

Implant planning and surgical guide stent

Implants were placed by two methods: robot-assisted surgery and surgical guide surgery. The position of the implant was set in the implant planning software [(MI2RL) for the robot group (Fig. 2), and (Implant Studio; 3shape, Copenhagen, Denmark) for the surgical guide group] using the DICOM data obtained by taking CBCT (DENTRI; HDXWILL, Seoul, Korea) scan of the printed patient phantom.(Fig. 3A) An internal connection implant (TSIII; OSSTEM IMPLANT Co. Ltd., Seoul, Korea) with a size of 4.5mm width x 10mm height was used for implant placement. After designing the sleeve part of the surgical guide using the sleeveless library, surgical guide was 3D printed with clear resin (Dental LT Clear Resin; Formlabs)(Fig. 3B).

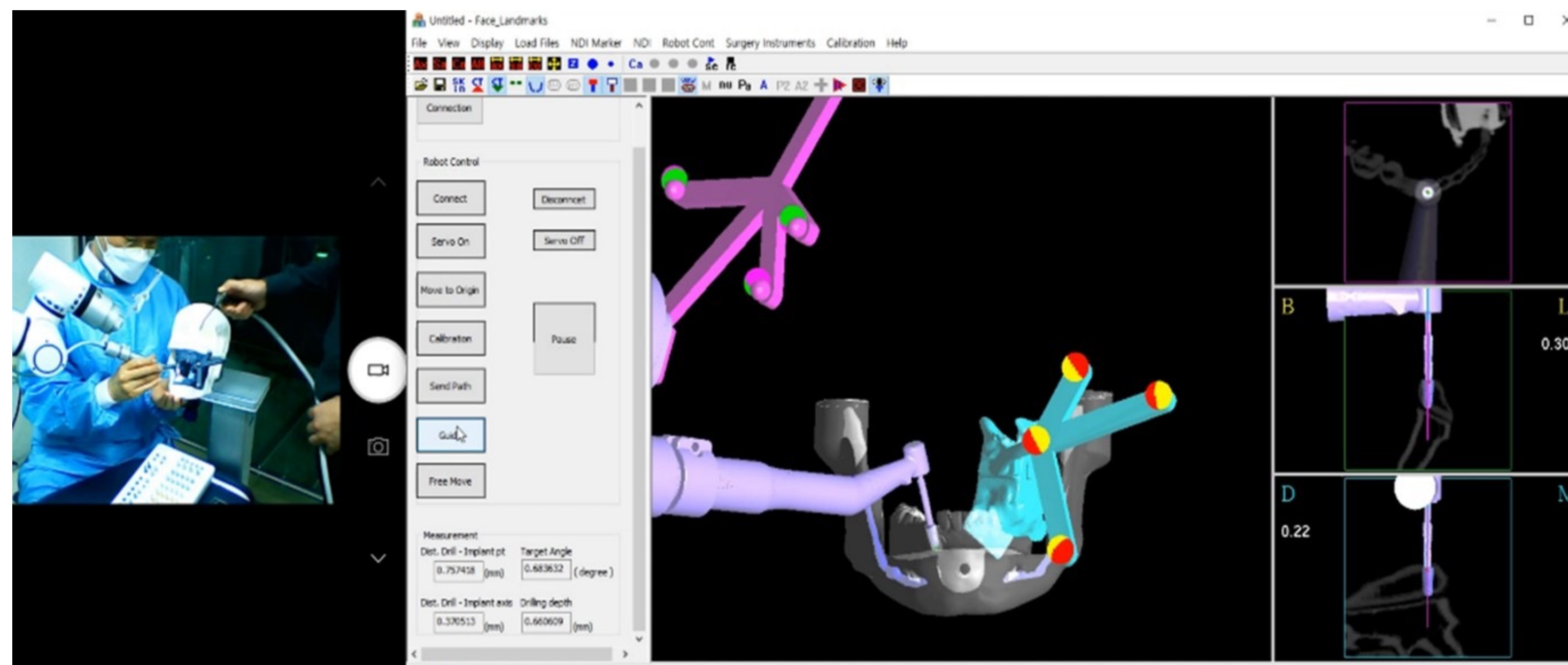


Fig. 2. Robot-assisted implant socket drilling while tracking positions of robot end effector and patient's jaw in real-time with robot manipulation software.

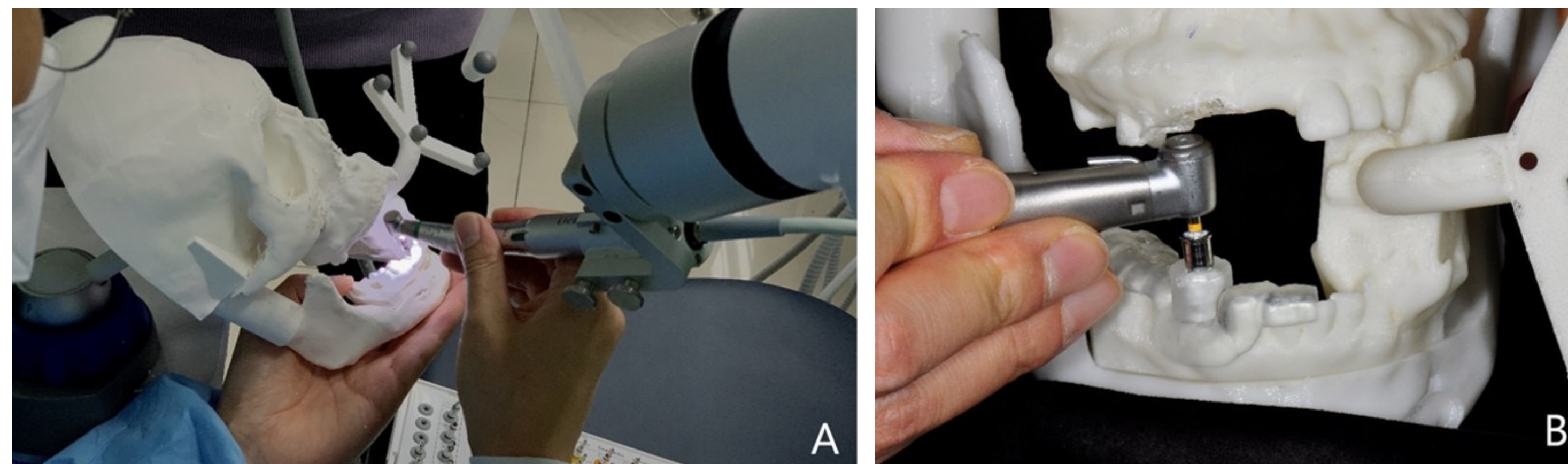


Fig. 3. Phantom setting for implant placement. (A) Robot-assisted bone removal with haptic feedback of robotic arm and real-time tracking, (B) Drilling with 3D printed implant surgical guide.

The robotic system tended to show fewer deviations at the implant apex and guide system at the implant top. The difference in none of the top, apex, angular, or depth deviations was statistically significant between the robot and surgical guide groups ($p > .05$)(Fig. 4,5).

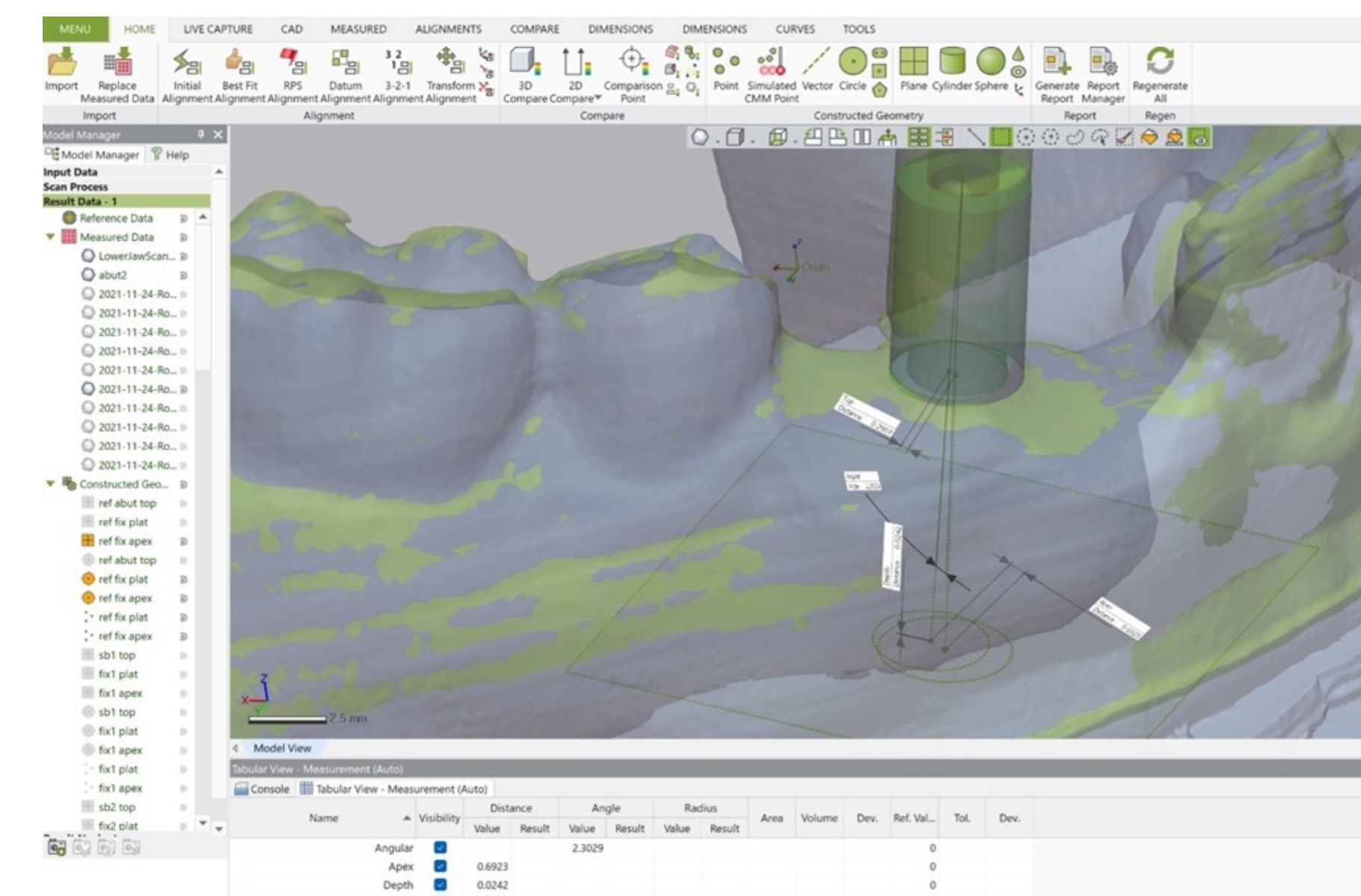


Fig. 4. Accuracy measurement by reverse engineering placed implant through scan body and comparing with planned implant.

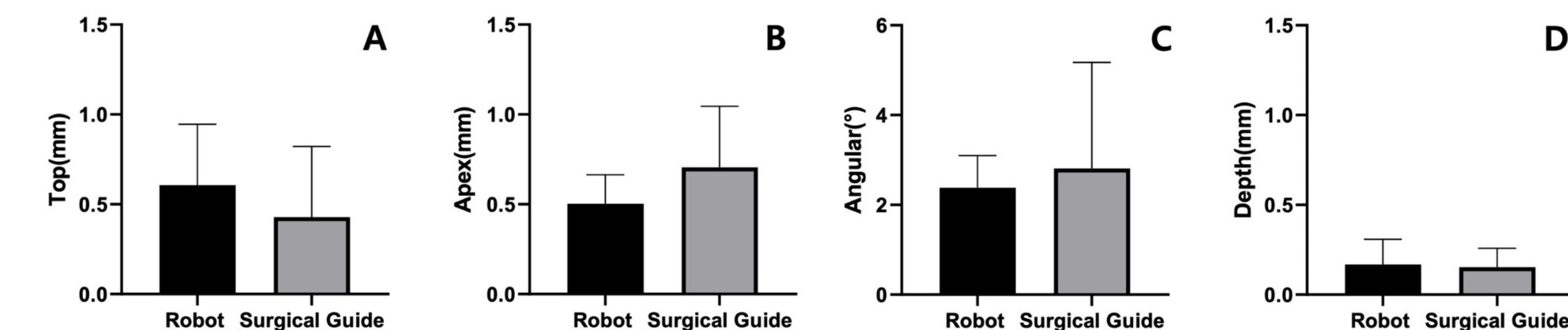


Fig. 5. Bar graph showing mean and standard deviation of deviations of robot and surgical guide groups. (A) Top deviation, (B) Apex deviation, (C) Angular deviation, (D) Depth deviation.

Conclusion

The accuracy in implant placement using robot-assisted implant surgery was comparable to that of static stent-guided surgery. Robot-assisted implant surgery and static-guided surgery tended to result in minor deviations at the apex and top of the implants, respectively.

References

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Fig. 1. Workflow of robot-assisted implant surgical system and accuracy evaluation procedure.