**Author’s response to reviews**

**Title:** Errors according to the number of registered markers used in navigation-assisted surgery of the mandible

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**Author’s response to reviews:**

The problem addressed by the authors is important and their approach is technically sound. Below are specific comments.

**C1. Figures 2, 3, 4, 6, & 7 are poor quality**

Reply:

Thank you for reminding us. We took more clear pictures with tiff format of 300 dpi. But we are a bit worried that the quality of the images could be deteriorated as the pictures are converted to a PDF file. If the quality of the figures on the PDF file is not good, you can view the images with good resolution by downloading the files. The resolution of original files are good.

**C2. The conclusion should be more clear and precise, you mentioned in the conclusion**

"It is important to determine the minimum number of image registration markers at which the smallest TRE would be observed for different surgical sites."

This should be consider as question to be answer by your study. How many markers based on your study is enough?

Reply:

We absolutely agree with your comment. The result in our paper can provide the appreciate number of image recognition for the cases of Cbyon navigation equipment and Polaris equipment, but statistical results also depend on the experimental equipment and anatomical site. Therefore, we have added explicit statements regarding the appreciate number of markers for
two system. Cbyon navigation system and Polaris equipment, and the need of additional studies to determine the appreciate number of image registration markers as follow:

(Conclusions, paragraph 2, page 18)

Considering the results of the experiment using Cbyon navigation equipment, it is recommended to use five markers in navigation surgery for condyle head, coronoid process, posterior border, condyle neck and sigmoid notch sites. However, the results of the experiment using the Polaris optical tracker and 3D Slicer S/W represented that the TREs of the remaining anatomical structures excluding the posterior border did not show a significant difference from each other. The measurement results in this paper depend on the experimental equipment and target anatomical site. Therefore, further studies are required to clearly determine the appreciate number of image registration markers for navigation-assisted surgery of the mandible.

C3. You mentioned

"Furthermore, large errors were found at the condylar head and posterior border when four markers were used. At the antilingula, the smallest error was found when seven markers were used. At the mandibular angle, the smallest error was found when four markers were used. The smallest errors were found at all anatomical sites excluding the antilingula and the mandibular angle when registration was performed with five markers. These results demonstrate that an increase in the number of registration markers is not associated with a decrease in the TRE, and that a specific number of registration markers might reduce the TREs at each anatomical site."

this paragraph need to be re-written in more details.

Why large errors foe condylar head with 4 markers while the mandibular angle showed smallest error with 4 markers? And the 7 markers with antilingula showed smallest errors? That is mean if you increase the markers the errors will be decreased which is against your conclusion? You need to explain why the error change per location? It is relation to the bone thickness of the specific anatomical relation or to the morphology of the bone at specific anatomical location?

Reply:

Thank for your thoughtful comments. We need to consider about some other factors which affect measurements. The surgical errors can be reduced by setting markers as close as possible to the surgical site. So large errors can be measured when the marker is distant from the surgical site. Our study focuses on the relation between TREs and the number of markers in the fixed positions of markers. To make clear the relation between TREs and the position of markers, further study is necessary to compare the error variation according to the marker position in the same number of markers. To clarify, we revised the paragraph as following:

(Discussion, paragraph 2, page 14)
The following factor can be considered for why the large TRE was measured with four markers at the condylar head, while the smallest TRE was measured with four markers at the mandibular angle. During the registration process, the surgical errors can be reduced by setting markers as close as possible to the surgical site. For example, since the marker used in this experiment is at the alveolar bone area under the tooth in the oral cavity, the error can be measured large when the marker is distant from the surgical site, like condyle head. However, in the case of mandibular angle, not only its overall errors are small but the TREs are also small even with few numbers of markers, because it is close to the landmark. The same explanation can be applicable to other cases, including the case of antlingula. Our study focuses on the relation between TREs and the number of markers in the fixed positions of markers. To make clear the relation between TREs and the positions of markers, further study is necessary to compare the error variation according to the marker position in the same number of markers.

C4. The discussion is too long and many of the paragraphs need to be moved to the introduction

Reply:

Thank you! We found your comment extremely helpful and have revised accordingly. We have moved some paragraphs(square brackets) of discussion to the introduction as following:

(Discussion → Background, paragraph 5, page 4)

In image-guided computer-assisted surgery, computer-generated images such as computed tomography (CT) scans are overlaid with the actual anatomical environments of the patients. This technique is widely used in craniofacial surgeries, but to a limited extent in mandibular surgery [9]. Although anatomically connected to the cranium through the temporomandibular joint, the mandible moves independently of it. The soft tissue of the mandible has a small area and is subject to frequent movements of the lips and cheek, compared with other cranio-maxillofacial areas.

[During the navigation-assisted surgery of the oral and maxillofacial region, the cranio-maxilla including the upper and lower jaws, continuously move for the surgeon’s convenience or needs. Its position must be maintained even after osteotomy to prevent the loss of its reference point. Hence, a frameless fixator navigation is required. Additionally, the RF located on the jawbone must not interfere with the surgical site or the handling of surgical tools, while being recognized by the navigation system in real time.]

In mandibular surgery using computer-assisted navigation, special sensor frames are attached to the mandible to allow the surgeon to optically track its location, thereby adjusting the independent and continuous movement of the mandible during surgery. To increase the accuracy of navigation, the location of the mandible is directly monitored rather than being monitored relative to the location of other cranial structures. During this process, the sensor frame must be affixed close to the surgical site such that the surgeon can monitor the positional changes. Once the frame is affixed, the registration process, in which the patient’s actual location coordinates
with the lower jaw are matched against the coordinates on the rendered CT scan of the mandible, begins.

(Discussion → Background, paragraph 8, page 5)

During the registration process, a number of markers that overlay two coordinates are selected. Several errors can arise during the image-guided computer-assisted surgery. Errors that occur during the image-guided surgery can be classified as technical, image, registration, application, and human errors. Registration errors arise during the process of coupling image data to the patient’s anatomical parts. Registration errors are typical errors in image-guided surgery. A paired fiducial point is the point at which a given image data matches the patient’s anatomical parts.

[In the head and neck area, template marker-based registration using bite splints may be performed using a registration method involving noninvasive markers [17,18]. An external registration frame that uses fiducial markers in the form of a denture-fixation acrylic template, and a template mouth piece around the jawbone, have been reported to exhibit similar registration accuracies as invasive markers that are implanted on the bone. The latter does not require an invasive procedure such as the implantation of screws used as markers. However, it has the disadvantage of requiring a marker template prior to the imaging process and having the patient bite onto the device while CT scans are being obtained.]

It is important to reduce registration errors. As they are affected by the number of registration points as error factors, it is necessary to measure the errors and determine the appropriate number of registration points to reduce patient burden during image-guided surgery using a navigation system. Because target registration errors (TREs) reflect the accuracy of the navigation equipment in representing the target anatomical markers, this study aims to evaluate the accuracy of navigation according to the number of markers in terms of TREs at each anatomical location during the registration process of the navigation system for the mandible.

C5. In the discussion section you need to add an explanation for your results and its better if you compare your results with other studies results to explain why your results is different. For example you mentioned in the discussion

"In this study, the number of markers for the tooth image overlay was set between 3 and 7. However, to resolve the registration errors, at least three nonplanar markers are required. Theoretically, the registration markers should be placed over a large area around the surgical site, and as close to the surgical site as possible to increase the accuracy when five or more markers are used".

what is the relation between the first paragraph highlighted in red with the second one highlighted in blue.

Reply:
Thank you for your good advice. What we want to say on this paragraph is why we set the number of markers from three to seven. According to previous studies, at least three nonplanar markers are required for registration procedure in the navigation surgery, and registration markers(>5) should be placed over a large area around the surgical site. Considering with these factors, the number of markers was set from three to seven in this study. To further clarify the meaning what we want to say, we revised the sentence in this revision as following:

(Discussion, paragraph 2, page 13)

It has known that three nonplanar markers are required for the registration procedure in the navigation surgery [8,10]. In addition, the registration markers should be placed over a large area around the surgical site, and as close to the surgical site as possible to increase the accuracy when five or more markers are used [11,12]. Considering with these two factors, the number of markers for tooth image overlay was set from three to seven in this study.