# Relationship between Target Registration Error (TRE) and Fiducial Registration Error (FRE), a clinical study and statistical analyses


## Amin Javer, Marwan AlQunaee and Ahmad Kolahi

Director/Head, St. Paul's Sinus Centre, Clinical Professor of Surgery and Research Co-Director, UBC, Vancouver, Canada



## Abstract

### Background:

This paper studies the impact of the number of registration landmarks on the navigation accuracy in image guided sinus surgery. We demonstrate that lower Fiducial Registration Error (FRE) does not necessarily lead to better Target registration Error (TRE).

### Method:

The commercially available optical navigation system (Navient Image guided navigation system - ClaroNav Kolahi Inc., Toronto, Canada) was used on 10 patients from Sept-2019 to Mar-2020. Each patient was registered using 7 anatomical landmarks.

Since mounting CT fiducials on the real patients is invasive and impractical, we developed a novel noninvasive method to measure the distance from the navigation probe to the patient's skin as a new metric to quantify navigation accuracy. The measurements were taken from multiple points on the patient's forehead, temples and base of nose. These anatomical locations were chosen carefully to represent navigation accuracy in all three planes. Our method also eliminates Target Localization Error (TLE), which is the main source of error in TRE studies.

Post-operatively we reduced the number of registration landmarks to 4, and using computer simulation computed the navigation accuracy.

### Results:

When compared to 4 landmarks for registration, 7 landmarks had significant improvement on the TRE. The additional time spent for marking 3 additional landmarks was insignificant.

### Conclusion:

We successfully demonstrate that using more landmarks for registration leads to a better TRE (Target registration Error). Furthermore, we demonstrated that lower FRE (fiducial registration error) does not necessarily equate to better TRE, and deleting a landmark to improve FRE is wrong practice.

## Introduction

In 1972, Godfrey Hounsfield and Allan Cormack invented a method to acquire and process X-ray projections from many directions to produce a 3D representation of the patient's anatomy. This new type of device was later called computerized tomography, or CT.

Initially, brain surgeons used CT images to guide needles into specific locations in the head using a mechanical guide in the form of a large metal "stereotaxic frame", screwed to the patient's skull. In the late 1980s, four different research groups (at Dartmouth, Aachen, Tokyo and Vanderbilt) concurrently and independently developed prototypes that could register a patient's head with its CT images, then dynamically show the tip of a pointer mapped to its corresponding location in those images.

During 1990-94, a Canadian company (ISG Technologies) developed and launched the first surgical navigation product, the Viewing Wand. Shortly after the introduction of the Viewing Wand, other companies introduced similar products, and in the following 5 years, research into the use of surgical navigation systems rapidly expanded to other anatomical regions, including sinuses. By the early 2000s, surgical navigation had become standard-of-care in neurosurgery, and was starting to become increasingly popular in endoscopic sinus surgery as well.

Studies show that Surgical Navigation Systems would allow more complete dissection, thereby improving surgical outcomes and reducing the need for revision surgery. It helps surgeons make more informed decisions and enables better patient outcomes [1]. It has become a valuable aid for many endoscopic sinus and skull base surgeries, and the American Academy of Otolaryngology – Head and Neck Surgery (AAO-HNS) endorses the use of image-guided surgery for various ENT procedures [2]. In addition, there is an increased value of image guided system in training. Trainees using IGS have an increased understanding of sinus and skull base anatomy and enhancement of their learning curve in endoscopic sinus surgery. (5)

Navigation accuracy is, perhaps, the most important feature of all navigation systems. The accuracy is highly dependent on registration methods and the type of tracking system used. The registration method used in most navigation systems is point to point skin landmark registration, surface-based registration or a combination of both. Target registration error (TRE) is the error of interest to the surgeon and is a complex statistical measure. Many studies have been conducted about TRE and how it can be impacted by various registration technics. TRE is not the same for all points within the image. It varies depending on position relative to the fiducial markers and on the configuration of those markers. Guidelines for fiducial placement to minimize TRE have been previously reported. In summary, it is recommended to avoid collinear placement of markers, use as many markers as possible, keep markers as far apart as possible, and place markers so that they surround the surgical target of interest [3, 4].

## Principle of operation

Optical navigation system’s guidance function is based on CT image data acquired prior to the procedure, combined with optical measurements of the pose of navigated instruments relative to the patient’s head. The Patient Tracker is attached to the patient’s forehead to enable tracking of the patient’s head, and the image data is loaded by the navigation software. The image data is then spatially registered with the patient’s head by point to point registration, followed by trace-based registration. Once the registration process is completed, the system presents the location of a navigated instrument tip overlaid on the image data.

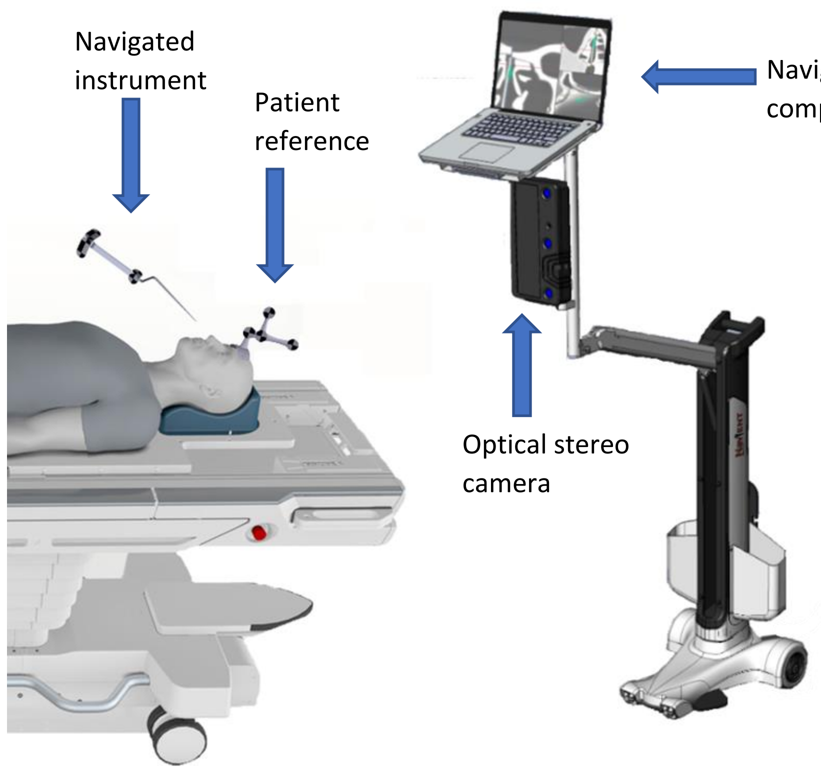



**Figure1, Main components of an optical navigation system**

The optical tracking Camera box contains a stereoscopic camera and an infrared (IR) light source, both operating in the near infrared (NIR) light spectrum. The tacking software identifies target marker mounted on the navigation instruments. Software processes the stereoscopic video images to detect and triangulate the positions of the markers. The location and orientation of the tip of each instrument relative to its markers is stored in the marker template and is used in mapping the tip to the CT image.

## Set up

Standard operating room setup for endoscopic trans-nasal and skull base surgery were used. The Navient navigation system was placed next to the endoscope cart. Navigation screen was casted to the endoscope monitor screen and displayed side-by-side with the endoscope view. It eliminates the head movement when switching the view between the two monitors.

**Figure 2, Optical image-guided navigation placed next to the endoscope tower**

## Study protocol

Several studies have been conducted to assess the accuracy of navigation systems on cadaver heads, while fewer studies have evaluated the accuracy on real patients. This is in due to impracticality of mounting CT fiducials or screws on the patient to measure TRE. We have developed a new non-invasive approach to measure TRE reliably and quantify navigation accuracy on real patients.

The approach is based on tracing a pattern on the patient's face using the navigation pointer and measuring the distance from the pointer tip to patient's skin. The measurement is taken on over hundred points on the patient's face, including forehead, temples and base of the nose. These points are carefully chosen to represent coronal, sagittal and axial planes respectively. Therefore, any inaccuracy in any of the three planes will be detected in our measurements. Furthermore, unlike the conventional TRE measurement approach, which is prone to human error by inaccurately identifying the fiducial and placing the pointer tip on it, our approach eliminates human error substantially.

10 endoscopic sinus and skull base surgeries were performed during the course of this study. Standard CT scans of the patients with slice thickness of 0.30mm to 1.3mm were acquired prior to surgery. Navient image-guided system was used. Navient offers point to point landmark-based registration followed by traced-based registration. Both approaches were used to collect data in our study. Data from the landmark-based approach was used to compute the registration while data from the trace-based method was used to evaluate registration accuracy in a postoperative software analysis.

Below is the protocol we followed during the study:

1. Marked 7 anatomical landmarks on the CT scan. The landmarks were placed on the right lateral canthus, right medial canthus, left medial canthus, left lateral canthus, left intersection of alar facial crease with alar base, columellar base, right intersection of alar facial crease with alar base. Figure 3 demonstrates the location of the 7 anatomical landmarks.
2. Performed point-to-point landmarks registration using the above 7 anatomical landmarks. Average Landmarks registration error was calculated.
3. Gently traced navigation pointer on the patients face resulting a collection of over hundred points. The points were collected from patient's face in areas with thin skin and bony structure. This was to minimize the human error due to pushing the instrument tip into soft tissue or skin. Figure 4 shows the trace pattern.
4. Average error from the trace points to the closest skin point were calculated.
5. The registration error for each individual landmark was calculated.
6. Identified the 3 landmarks with highest registration error and removed them from the point-to-point registration list.
7. Recomputed registration using the remaining 4 landmarks.
8. Recomputed TRE using the trace points.

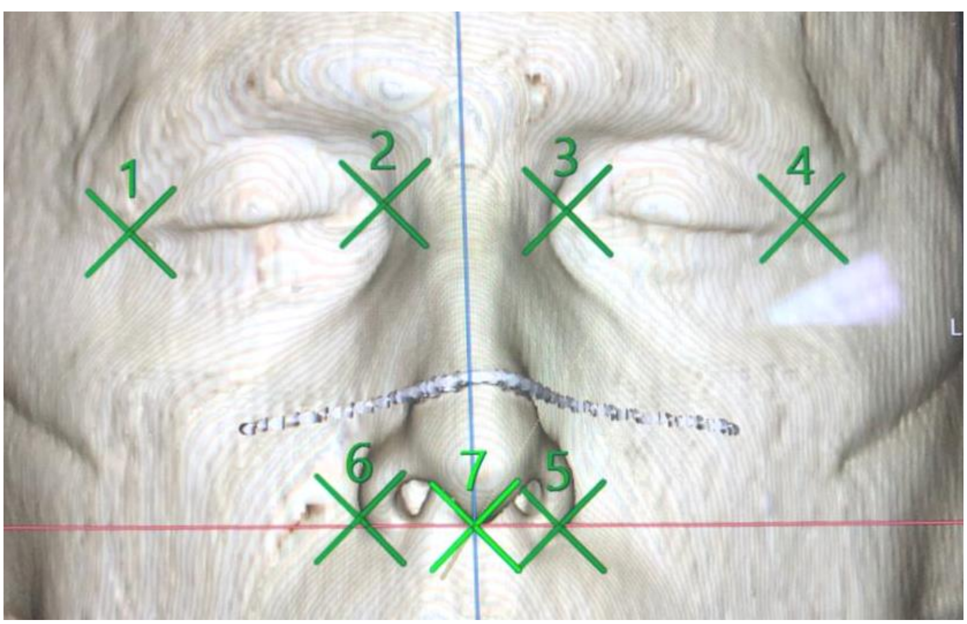



**Figure 3, Anatomical landmarks used for point-to-point registration**

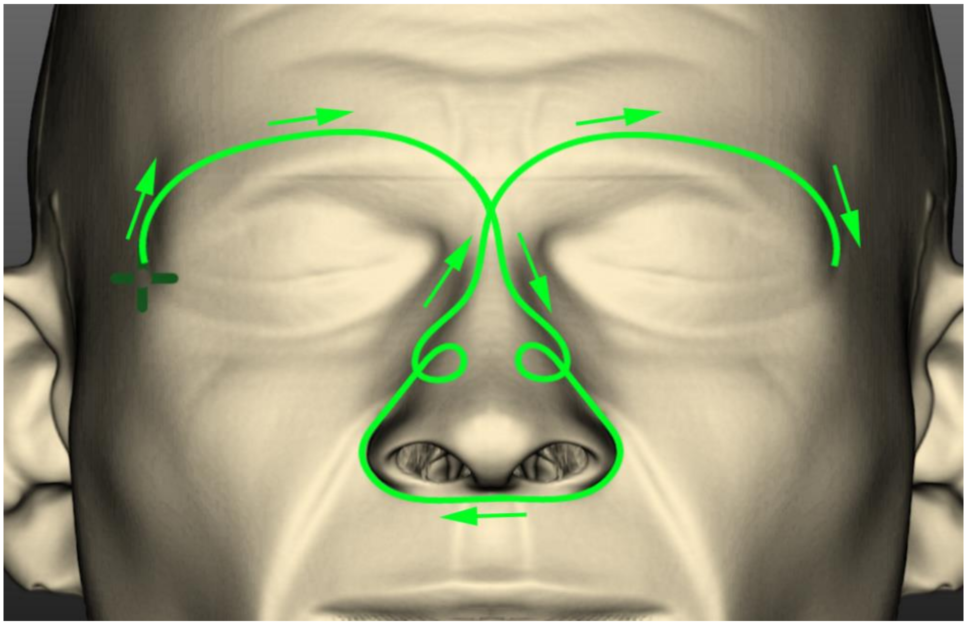


**Figure 4, Trace pattern which covers forehead, temples and base of the nose.**

## Data analysis

The table below summarizes the results of the data collected during the study. It contains:

- **FREs (7 LMs):** Registration error of each individual landmark after point-to-point 7 landmarks registration.
- **Average FRE (7 LMs):** Average registration error after point-to-point 7 landmarks registration.
- **TRE (using 7 LMs):** Target Registration Error (TRE) calculated by taking an average on over hundred trace points. It is computed after performing point-to-point 7 landmarks registration.
- **Largest 3 FREs:** Lists the 3 landmarks with highest registration error.
- **Average FRE (of 4 LMs):** Average registration error after point-to-point 7 landmarks registration (After removing the 3 landmarks with largest registration error).
- **TRE (using 4 LMs):** Target Registration Error (TRE) calculated by taking an average on the trace points. It is computed after performing point-to-point 4 landmarks registration (After removing the 3 landmarks with largest registration error).

| Patient no. | FREs (7 LMs) | Average FRE (7 LMs) | TRE (using 7 LMs) | Largest 3 FREs | Average FRE (of 4 LMs) | TRE (using 4 LMs) |
|---|---|---|---|---|---|---|
| 1 | 2.77, 3.11, 1.26, 4.29, 2.34, 4.13, 3.29 | 3.03 | 1.63 | LM #4: 4.29, LM #6: 4.13, LM #7: 3.29 | 1.63 | 1.61 |
| 2 | 3.06, 4.73, 2.40, 3.51, | 3.22 | 2.06 | LM #2: 4.73, LM #7: 4.48, LM #4: 3.51 | 2.03 | 1.93 |

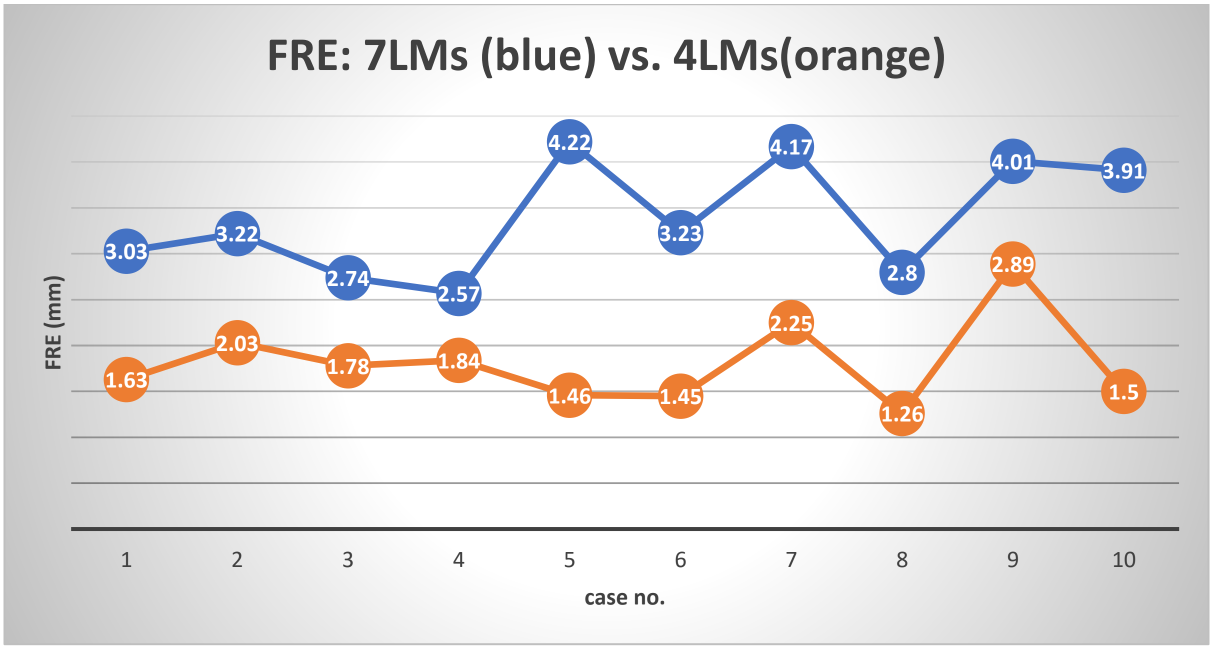
| | | | | | | |
|---|---|---|---|---|---|---|
| | 2.06, 2.29, 4.48 | | | | | |
| 3 | 3.87, 2.82, 3.47, 2.30, 2.97, 1.33, 2.43 | 2.74 | 1.56 | LM #1: 3.87, LM #3: 3.47, LM #5: 2.97 | 1.78 | 1.52 |
| 4 | 3.35, 3.45, 2.52, 1.45, 2.61, 2.86, 1.77 | 2.57 | 2.15 | LM #2: 3.45, LM #1: 3.35, LM #6: 2.86 | 1.84 | 2.14 |
| 5 | 7.94, 4.54, 2.21, 3.04, 2.57, 4.91, 4.32 | 4.22 | 1.75 | LM #1: 7.94, LM #6: 4.91, LM #2: 4.54 | 1.46 | 1.85 |
| 6 | 4.43, 3.63, 4.40, 5.07, 2.42, 1.56, 1.07 | 3.23 | 1.43 | LM #4: 5.07, LM #1: 4.43, LM #3: 4.40 | 1.45 | 1.67 |
| 7 | 4.99, 6.03, 4.18, 3.83, 4.20, 4.17, 1.81 | 4.17 | 2.05 | LM #2: 6.03, LM #1: 4.99, LM #5: 4.20 | 2.25 | 2.23 |
| 8 | 1.08, 3.05, 5.38, 3.49, 3.17, 2.57, 0.83 | 2.8 | 1.26 | LM #3: 5.38, LM #4: 3.49, LM #5: 3.17 | 1.26 | 2.18 |
| 9 | 6.48, 4.30, 1.87, 4.77, 3.75, 4.81, 2.09 | 4.01 | 1.86 | LM #1: 6.48, LM #6: 4.81, LM #4: 4.77 | 2.89 | 2.17 |
| 10 | 2.10, 5.73, 6.38, 2.04, 5.39, 2.32, 3.43 | 3.91 | 1.78 | LM #3: 6.38, LM #2: 5.73, LM #5: 5.39 | 1.5 | 2.09 |

**Results of FRE and TRE before and after removing LMs with largest error.**

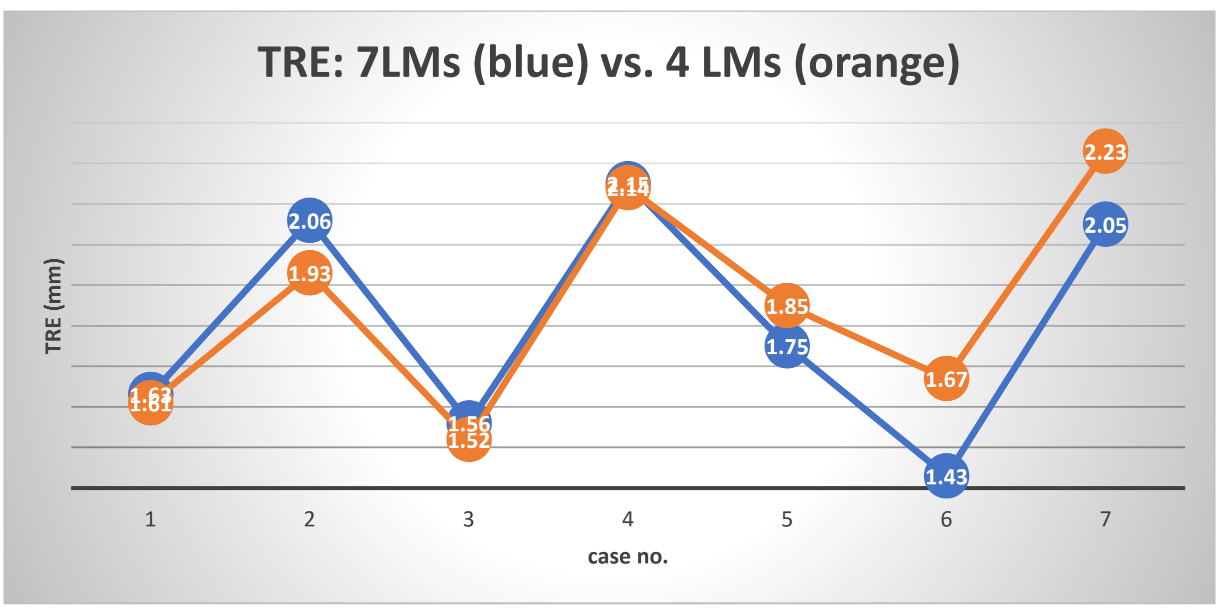
In 6 out of 10 patients we observed that using more landmarks for registration leads to a better TRE. This observation is valid even if we eliminate the landmarks with largest errors. In 4 out of 10 patients we observed that eliminating landmarks with largest error would improve the TRE. However, the amount of improvement is small. The average TRE error with 7 LMs is 1.75mm while the average TRE with 4 LMs is 1.94mm. Therefore, it is safe to conclude that deleting landmarks to improve FRE is wrong practice.

## Results

The average FRE of the 10 patients using 7 landmarks is 3.39mm.  After eliminating 3 landmarks with the largest FRE, the average FRE reduces to 1.81mm. It improves FRE by 47%, however the average TRE increases from 1.75mm to 1.94mm, which is an 11% reduction in accuracy. Since TRE is the error of interest to the surgeon, eliminating landmarks with the largest errors is not recommended.




**Comparison of FRE between registration with 7LMs vs. 4 LMs**




**Comparison of TRE between registration with 7LMs vs. 4 LMs**

## Conclusion

We have developed a new non-invasive approach to measure TRE reliably and quantify navigation accuracy on real patients. In conclusion, even though eliminating landmarks with the largest registration error reduces FRE, it does not necessarily reduce the all-important TRE. In fact, it is very likely that eliminating landmarks with large FRE could degrade TRE. Therefore, it is not recommended to eliminate landmarks solely because it has large FRE.

## References


1. Robert F. Labadie and J. Michael Fitzpatrick (new edition March 2016) Image-Guided Surgery: Fundamentals and Clinical Applications in Otolaryngology. Plural Publishing Inc;
2. http://www.entnet.org/content/intra-operative-use-computer-aided-surgery
3. West JB, Fitzpatrick JM, Toms S, et al. Fiducial point placement and the accuracy of point-based, rigid-body registration. Neurosurgery 2001; 48: 810–817.
4. Robert F. Labadie, Bryan M. Davis and J. Michael Fitzpatrick (2004) Image-guided surgery: what is the accuracy? Current Opinion in Otolaryngology & Head and Neck Surgery 2005, 13:27–31.
5. Fokkens W.J., Lund V.J. , Hopkins C., Hellings P.W., Kern R., Reitsma S., et al. European Position Paper on Rhinosinusitis and Nasal Polyps 2020 Rhinology. 2020 Suppl. 29: 1-464