Original Article

Evaluating the Accuracy of the SMART Taylor Spatial Frame Software – Comparison with Manual Radiographic Analysis Methods

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Abstract

Background: The accuracy of hexapod circular external fixator deformity correction is contingent on the precision of radiographic analysis during the planning stage. The aim of this study was to compare the SMART Taylor spatial frame (TSF) *in suite* radiographic analysis methods with the traditional manual deformity analysis methods in terms of accuracy of correction. **Methods:** Sawbones models were used to simulate two commonly encountered clinical scenarios. Traditional manual radiographic analysis and digital SMART TSF analysis methods were used to correct the simulated deformities. **Results:** The final outcomes of all six analysis methods across both simulated scenarios were satisfactory. Any differences in residual deformity between the analysis methods are unlikely to be clinically relevant. All three SMART TSF digital analyses were faster to complete than manual radiographic analyses. **Conclusion:** With experience and a good understanding of the software, manual radiographic analysis can be extremely accurate and remains the gold standard for deformity analysis. *In suite* SMART TSF radiographic analysis is fast and precise to within clinically relevant parameters. Surgeons can with confidence trust the SMART TSF software to provide analysis and corrections that are clinically acceptable.

Keywords: *Accuracy, deformity correction, fracture, hexapod, malunion, Taylor spatial frame*

Introduction

Hexapod circular external fixators such as the Taylor spatial frame (TSF) (Smith and Nephew, Memphis, Tennessee) can produce extremely accurate corrections when used appropriately.[1-5] These devices rely on the input of deformity and mounting parameters to generate correction schedules that are accurate to within fractions of a degree and millimeter. However, this accuracy is reliant on meticulous radiographic analysis and a thorough understanding of the intrinsic "rules" or software assumptions for each device.[6,7]

Recent advances have seen the introduction of web-based *in suite* radiographic analysis tools to hexapod software. One such advance is the SMART TSF software that allows radiographs to be imported and analyzed using three different methods within the software itself.

This study aimed to compare the SMART TSF *in suite* radiographic analysis methods with the traditional manual deformity analysis methods in terms of accuracy of correction. Secondary objectives were to measure the time used for planning with the different analysis methods.

Methods

Sawbones models SKU:1125 (normal tibia) and SKU:1159-5 (20 oblique plane malunion) were used to simulate two commonly encountered clinical scenarios where TSFs are frequently used.

Simulated fracture scenario

A midshaft tibia fracture was simulated by applying a neutral TSF frame to an intact tibia sawbones model. TSF constructs using two 155 mm full rings (7107-5114) and six medium Fast Fx struts (7107-0720) in outer mount positions without offset plates or dynamization modules were prepared. Each ring was secured to the bone model using one tensioned wire and two half pins. A "fracture" was created by dividing the bone in the mid-diaphysis with a saw, after which the TSF struts were temporarily unlocked to allow a deformity to be created [Figure 1].

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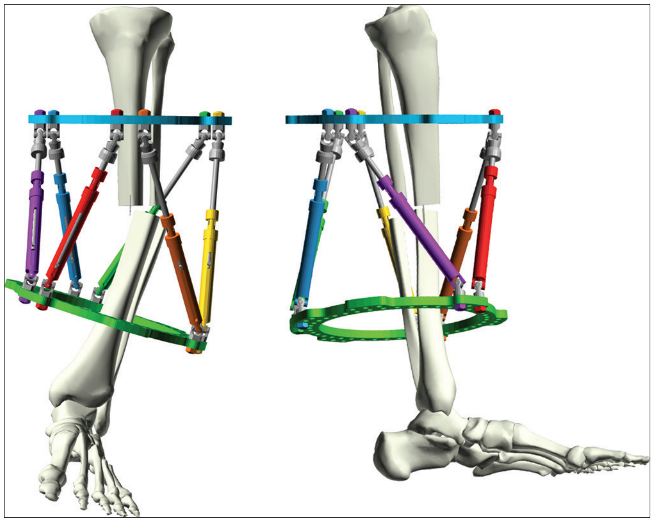

Figure 1: Graphic representation of midshaft tibia fracture with posterolateral translation and apex posterolateral angulation. (SMART Taylor spatial frame rendered image)

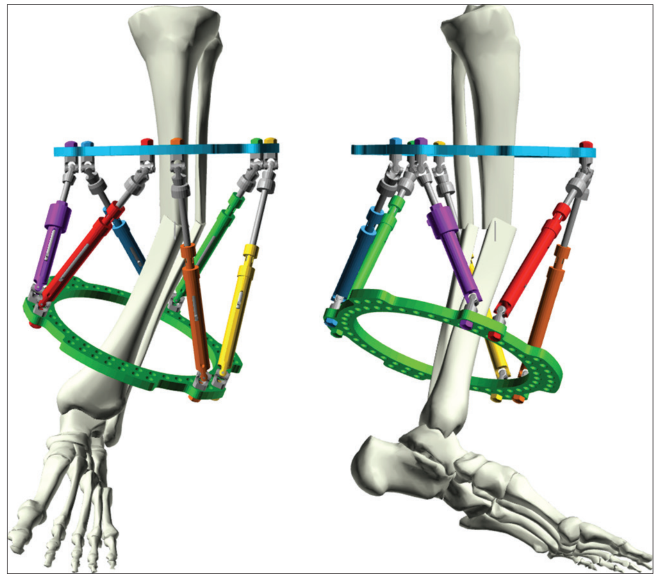

Figure 2: Graphic representation of midshaft tibia oblique plane deformity. (SMART Taylor spatial frame rendered image)

Simulated malunion scenario

A two-ring TSF construct was applied to the oblique plane deformity model with each 155 mm ring (7107-5114) firmly affixed to the respective bone segment using the rings first method. Fixation consisted of one tensioned wire and two half pins on each ring. The proximal and distal rings were then connected by Fast Fx TSF struts with a resultant frame that mimicked the model. Due to the severity of the deformity, four medium struts (7107-0720) and two short struts (7107-0710) were required to connect the rings. All struts were placed in the outer mount positions without offset plates or dynamization modules [Figure 2].

Following frame application, anteroposterior and lateral radiographs orthogonal to the proximal (reference) segment were taken for both models. A 25 mm calibration marker was applied to each model adjacent to the level of the fracture/deformity to be used during manual radiographic analysis. A three-dimensional (3D) printed fiducial (Beacon v1.0, Smith and Nephew, Memphis, Tennessee) was printed using a Zortrax M300 Dual (Zortrax, Olsztyn, Poland) commercial printer and affixed to proximal ring at the tab for strut 3 and 4. The same anteroposterior and mediolateral images were used for radiographic analysis using the appropriate planning methods for each simulated clinical scenario; this entailed the Fracture, SuperDot, and TraumaDots methods for the fracture scenario and the CORAgin, CORAsponding point and Origin and Corresponding point methods for the malunion scenario.[8] Manual analyses using the Fracture, CORAgin, and CORAsponding point methods were performed using the annotative analysis/measurement tools of the Philips IntelliSpace (Philips, Amsterdam, Netherlands) Picture Archiving and Communication System software.[8] Digital analyses were performed in the SMART TSF web-based software using the SuperDot, TraumaDots, and the Origin and Corresponding point methods. Total residual mode was used in all cases, and no structure at risk parameters was entered. Extrinsic lengthening of 10 mm was included in all three malunion correction methods. The time to perform each analysis was measured from the start of patient detail entry to the generation of the prescription and expressed in minutes and seconds.

The final strut settings for each generated prescription were applied to the relevant frame to produce the final correction position. Any residual deformity was measured with a vernier caliper for translational malalignment and a goniometer for angular malalignment.

Results

The final outcomes of all six analysis methods across both simulated scenarios were satisfactory. Any differences in residual deformity between the analysis methods are unlikely to be clinically relevant.

Simulated fracture scenario

Comparative deformity and mounting parameters as assessed by the *in suite* SuperDot and TraumaDots methods and manually using the fracture method are presented in Table 1. As these three methods, in essence, follow the same projective geometric strategy for correction, the resultant deformity and mounting parameters are very similar; the SuperDot and TraumaDots methods differing by <1.5 mm and 1.5° in all parameters. The fracture method showed more significant differences in measured parameters, predominantly as a result of frame angulation that cannot be accounted for in the traditional Spatial Frame software; in this example, the reference ring was mounted with 0.5° medial angled proximal and 3.9° anterior angled distal angulation, as measured in the

Table 1: Comparative deformity and mounting parameters for simulated fracture case

	SuperDot (digital analysis)	TraumaDots (digital analysis)	Fracture method (manual analysis)
		Time	
	07:45	**07:42**	**08:05**
Deformity parameters			
AP view angulation (°)	17.5 Varus	18.1 Varus	17 Varus
AP view translation (mm)	17.3 Lateral	17.9 Lateral	16 Lateral
Lateral view angulation (°)	3.6 Apex posterior	2.5 Apex posterior	4 Apex posterior
Lateral view translation (mm)	2.9 Posterior	3.8 Posterior	3 Posterior
Axial view angulation* (°)	10 External	10 External	10 External
Axial view translation (mm)	7.8 Long	6.4 Long	10 Long
Mounting parameters			
AP view frame angulation (°)	0.3 Medial angled proximal	0.5 Medial angled proximal	-
AP view frame offset (mm)	0.9 Medial to origin	0.4 Medial to origin	5 Medial to origin
Lat view frame angulation (°)	3.9 Anterior angled distal	3.9 Anterior angled distal	-
Lat view frame offset (mm)	17.5 Posterior to origin	19 Posterior to origin	21 Posterior to origin
Rotary frame offset (°)	0.5 External	0.5 External	0 External
Axial frame offset (mm)	80.4 Proximal to origin	82.1 Proximal to origin	81 Proximal to origin
Axial translation view	AP	AP	AP

*Measured clinically. AP: Anteroposterior

SMART TSF digital software. A clinically imperceptible amount of frame rotation (0.5° external) was also identified by the digital software, which was not entered during the fracture method.

End of correction images is shown in Figure 3, while the residual deformity parameters are presented in Table 2. All three methods required 20 days of strut adjustments and showed clinically acceptable correction with less than 1 mm translational differences between the three methods. These differences would not be clinically significant.

Simulated malunion scenario

The comparative deformity and mounting parameters assessed by the *in suite* Origin and Corresponding point method and traditional CORAgin and CORAsponding point methods are presented in Table 3. In this scenario, the reference ring was mounted with 1.1° medial angled distal and 0.8° anterior angled distal angulation. As the Origin and Corresponding point and CORAgin methods follow a similar corrective strategy, the differences in deformity and mounting parameters can be attributed to the frame angulation. The CORAsponding point method employs an extrinsic origin point that influences all translational deformity and mounting parameters and the effects of frame angulation. A small degree of frame rotation (3.3° internal) was identified by the digital software. This amount of frame rotation is difficult to identify and quantify clinically.

End of correction images is shown in Figure 4, while the residual deformity parameters are presented in Table 4. Correction schedules ranged from 21 to 24 days, with all three programs producing clinically acceptable results.

Discussion

The accuracy of hexapod circular external fixator deformity correction is contingent on the precision of radiographic analysis during the planning stage. The aim of this study was to compare the SMART TSF *in suite* digital radiographic analysis methods with traditional manual deformity analysis methods in terms of accuracy of correction and speed of analysis.

The principal finding of this study demonstrates the accuracy of the new SMART TSF *in suite* analysis and planning methods. All three methods show end-of-correction results comparable to the traditional planning methods, and any differences between the

Table 2: Residual deformity parameters postcorrection for simulated fracture case

End of correction alignment	SuperDot (digital analysis)	TraumaDots (digital analysis)	Fracture method (manual analysis)
Days of correction	20	20	20
AP view angulation (°)	0	0	0
AP view translation (mm)	0.5 Lateral	0	0
Lateral view angulation (°)	0	0	0
Lateral view translation (mm)	0.5 Posterior	0.5 Posterior	0.5 Posterior
Axial view angulation (°)	0	0	0
Axial view translation (mm)	0.5 Short	1 Long	0

Table 3: Comparative deformity and mounting parameters for simulated malunion case

	Origin and corresponding point (digital analysis) 06:47	CORAgin method (manual analysis) 10:37	CORAsponding point method (manual analysis) 09:18
Deformity parameters			
AP view angulation (°)	22.4 Varus	22 Varus	22 Varus
AP view translation (mm)	4.1 Medial	4 Lateral	0
Lateral view angulation (°)	14.5 Apex anterior	15 Apex anterior	15 Apex anterior
Lateral view translation (mm)	11.2 Anterior	13 Anterior	8 Anterior
Axial view angulation* (°)	0	0	0
Axial view translation (mm)	9.9 Short	9 Short	10 Short
Mounting parameters			
AP view frame angulation (°)	1.1 Medial angled distal	-	-
AP view frame offset (mm)	5.1 Medial to origin	2 Medial to origin	1 Medial to origin
Lateral view frame angulation (°)	0.8 Anterior angled distal	-	-
Lateral view frame offset (mm)	16.9 Posterior to origin	15 Posterior to origin	19 Posterior to origin
Rotary frame offset (°)	3.3 Internal	-	-
Axial frame offset (mm)	69.4 Proximal to origin	67 Proximal to origin	77 Proximal to origin
Axial translation view	AP	AP	AP

*Measured clinically. AP: Anteroposterior

different analysis methods are unlikely to be clinically relevant. As with the conventional methods, all three digital methods can be used for any clinical scenario but are intrinsically better suited for specific clinical applications. The SuperDot method places a hinge point around which the moving segment is manipulated to correct alignment in the AP and lateral views. The TraumaDots method traces the fracture line on both bone segments, which is then realigned by the software; the user can then make minor adjustments until they are satisfied with the result. The Origin and Corresponding point method is similar to the traditional CORAsponding point method. It relies on creating reciprocal points and axes on the reference and moving segments which are used to align to segments. We chose to use the SuperDot and TraumaDots methods in the simulated fracture scenario and the Origin and Corresponding point method in the simulated malunion scenario. While the TraumaDots method is better suited for fracture reduction, the SuperDot and Origin and Corresponding point methods would work equally well for any clinical application. One distinct advantage of the SuperDot and TraumaDots methods is the graphic

Table 4: Residual deformity parameters postcorrection for simulated malunion case

End of correction alignment	Origin and corresponding point (digital analysis)	CORAgin method (manual analysis)	CORAsponding point method (manual analysis)
Days of correction	24	22	21
AP view angulation (°)	0	0	0
AP view translation (mm)	0	0	0
Lateral view angulation (°)	0	0	0
Lateral view translation (mm)	0.5 Anterior	0	1 Anterior
Axial view angulation (°)	2 Apex anterior	2 Apex anterior	2 Apex anterior
Axial view translation (mm)	2.5 Long	1 Long	1 Long

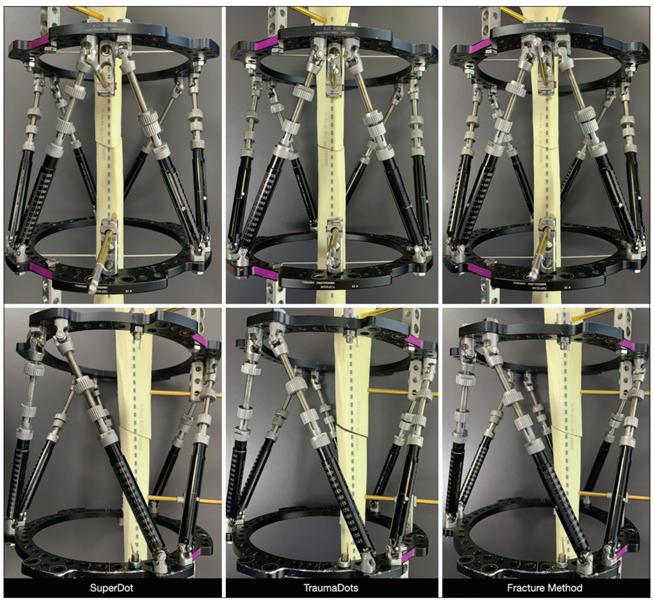

Figure 3: Coronal and sagittal plane images showing postcorrection results for SuperDot (digital analysis), TraumaDots (digital analysis), and Fracture methods (manual analysis)

representation of the end of correction result, which the Origin and Corresponding point method does not provide.

The accuracy of stereophotogrammetric analysis is conditional on knowing the relationship and scale of the two-dimensional images used to extract 3D data. The use of a frame-mounted fiducial (Beacon) dramatically improves the precision of this process as image scaling, and relationship can now be measured accurately. In both our examples, the anteroposterior and lateral images were taken 94° relative to each other, which falls within acceptable parameters. Conventionally, there was no way, beyond visual impression, that the radiographs were adequate. The fiducial also allows accurate measurement of rotatory frame offset, which traditionally was challenging to measure clinically. The use of a frame-mounted fiducial also provides for precise measurement of coronal and sagittal frame alignment relative to the reference segment axis. Analysis following nonorthogonal frame mounting was traditionally addressed by the "virtual grid" method, but since the SMART TSF software can now accommodate for this, it is no longer necessary making analysis in these scenarios easier and more accurate. As seen in our examples, the effect of even very small mounting errors is evident in the differences in mounting and deformity parameters of the simulated cases.

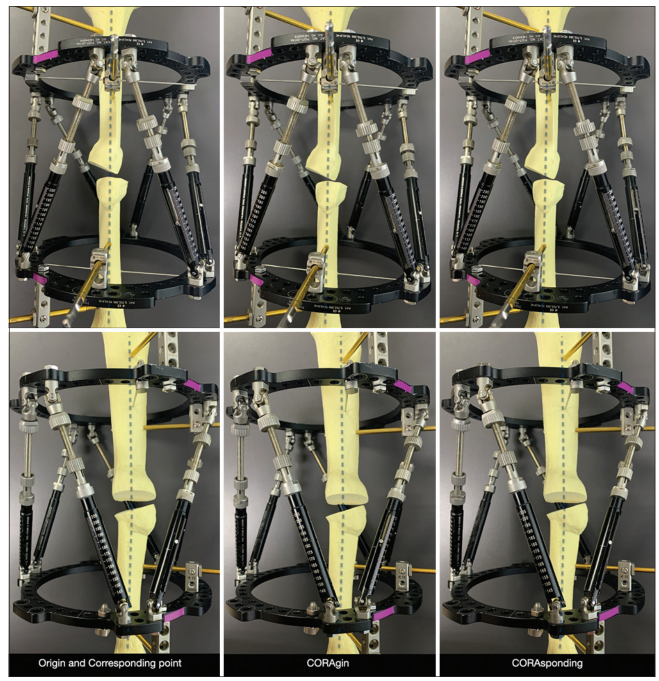

Figure 4: Coronal and sagittal plane images showing postcorrection results for Origin and Corresponding point (digital analysis), CORAgin (manual analysis), and CORAsponding point methods (manual analysis)

Although the speed of analysis and data entry is secondary in importance to correction accuracy, software ergonomics is of paramount importance for surgeons to continue using these systems. All three SMART TSF analyses proved to be faster than manual analysis methods, albeit not by much. It is conceivable that a shorter analysis time might be an indicator of a more intuitive system that would be appreciated by physicians.

This study represents the first independent analysis of the new SMART TSF software in two simulated clinical scenarios. Limitations include using a fiducial that was printed in-house by a commercial quality 3D printer that might have minor tolerance imperfections that would be negated by commercially manufactured beacons provided by Smith and Nephew (Smith and Nephew, Memphis, Tennessee). Two experienced limb reconstruction surgeons performed radiographic analysis and data entry, and outcomes might differ in terms of accuracy and speed when executed by the occasional TSF user. The SMART TSF software is also still relatively new, and more experience with its use may increase speed and accuracy. Time measurements included computing time for calculations, and although all planning was performed on a single computer with no additional programs running in the background, internet speed and the different software versions (Spatial Frame versus SMART TSF) may influence computing time.

Conclusion

With experience and a good understanding of the software, manual radiographic analysis can be extremely accurate and remains the gold standard for deformity analysis. *In suite* SMART TSF radiographic analysis is fast and accurate to within clinically relevant parameters. Surgeons can with confidence trust the SMART TSF software to provide analysis and corrections that are clinically acceptable.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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