APPENDIX

A1. Evaluate the accuracy of navigation by defining the "corner deviation" and "front angle"

In order to evaluate the accuracy of navigation or resection, we must be able to measure quantitatively the navigation error and the resection error. The *navigation error* is defined by the deviation of the drawn osteotomy lines on the bone surface with respect to the preoperative plan in coronal view. Similarly, the *resection error* is defined by the deviation of the resected surface with respect to the target osteotomy lines of the preoperative plan. Three types of imaging scans are used to evaluate the accuracy of navigation or resection.

(S1) Preoperative CT scan: It provides in 3D solid model the position and orientation of the target planes in the global frame, as well as the location of the corner points and three osteotomy line segments in the coronal plane view.

(S2) Post-operative surface scan: After the osteotomy path is drawn by either conventional or 3D-LAD method, a 3D light scanner scans the anterior surface of the bone, where the osteotomy lines marked by the surgeon can be recognized.

(S3) Post-operative CT scan: The bone after resection is scanned by a CT scanner, where the three planes of the resected bone can be captured and analyzed in a 3D solid model.

The three images are processed using *Geomagic* with the help of *standard alignment function*.

The *navigation error* quantifies the discrepancy between the preoperative osteotomy plan and the osteotomy lines marked on the bone surface by the surgeon, either by the traditional or 3D-LAD method, and is obtained based on the deviation between the images of the preoperative CT scan (a 3D solid) and the post-operative surface scan (a surface image). Hence, two measures are defined to quantify the navigation errors, as follows:

(*i*) *Corner deviation*: The corner deviation is defined as the linear displacement of the two corner points (B and C) found in the preoperative CT scan (S1) and the post-operative surface scan (S2), as illustrated in Fig. 6A.

(*ii*) *Front angle*: The front angle is defined as the angular displacement between the line segment AB or CD of the preoperative plan (S1) and the line segment AB, BC or CD marked by the surgeon captured in surface scan (S2). Fig. 6A illustrates the front angle of CD line segment as an example.

Table A1 includes the experimental results from 9 femur bones. The maximum/minimum deviation in mm and the average, along with the standard deviation of data, are listed for both conventional and 3D-LAD methods. The *p* value is smaller than 0.001 and is deemed as significant. The average of the data with both B and C points are under "All" in the table.

Table A2 tabulates the front angles in degrees, as defined in Fig. 6, for line segments AB, BC, CD, and their average. The maximum/minimum angles and their average, along with the standard deviation of data, are listed for both conventional and 3D-LAD methods. The *p* value is 0.001 and is deemed as significant. The average of front angles is listed under "All."

	Corner Deviation (unit in mm)					
	Conventional method			3D-LAD method		
	B	C	**All**	B	C	**All**
AVG	2.07	2.99	**2.53**	1.15	0.92	**1.04**
MAX	3.02	4.86	**4.86**	1.65	1.54	**1.65**
MIN	0.81	1.09	**0.81**	0.38	0.13	**0.38**
STD	0.73	1.26	**1.13**	0.40	0.43	**0.43**
p-value	$p<0.001$ (calculated with respect to all corners)					

Table A1- Navigation error assessed by the corner deviation at points B and C (cf. Figure 6A)

	Front Angle (unit in degrees)							
	Conventional method				3D-LAD method			
	AB	BC	CD	**All**	AB	BC	CD	**All**
AVG	0.93	1.24	4.12	**2.10**	1.19	0.49	0.71	**0.80**
MAX	3.20	2.71	6.16	**6.16**	2.33	0.90	1.83	**2.33**
MIN	0.01	0.54	0.45	**0.01**	0.12	0.14	0.01	**0.01**
STD	0.96	0.65	1.59	**1.83**	0.66	0.23	0.74	**0.66**
p-value	***p*=0.001** (calculated with respect to all line segments)							

Table A2 – Navigation error assessed in terms of the front angle (cf. Figure 6A)

A2. Evaluate the accuracy of resection by defining the "maximum deviation" and "surgical error margin"

The *resection error*, on the other hand, quantifies the discrepancy between the preoperative osteotomy plan and the bone surface after the actual resection is done by the surgeon, and is obtained based on the deviation between the images of the preoperative CT scan (S1) and the post-operative CT scan (S3). Both imaging scans are 3D solids. Two measures are defined to quantify the resection errors, as follows:

(i) *Maxium deviation* of resection: The deviation of resection is measured by imposing the preoperative CT scan (S1) on post-operative CT scan (S3) to find the linear distance between the corresponding points on S1 and S3. Many points are sampled, each with a deviation, along

AB, BC or CD, as illustrated in Fig. 6B. Among all such deviations of resection for many sampled points along the line segment, the largest deviation is call the "maxium deviation."

(ii) *Surgical error margin*: In a bone tumor resection, a negative margin is necessary to ensure that all tumor is removed. This negative margin is affected by the maximum deviation of resection. When a certain surgical error margin is required, we can determine the perentage of resection operation that will successfully maintain the negative margin, given the maximum deviation from the experiments conducted in this study.

Table A3 lists the maximum deviation along the line segments AB/BC/CD for the conventional and 3D-LAD methods for comparison, as well as the average maximum devation of all 3 line segments. The *p* values are 0.003 and deemed as significant.

Table A4 tabulates the surgical error margins from 1 to 7 mm, as related to the percentage of successful resection to remove the entire tumor section in bone wide resection. The 3D-LAD method can reach 100% success in resection with as low as 4mm surgical error margin, as compared with the conventional method which requires at least 6mm of error margin.

Maximum deviation (unit in mm)	Conventional method	3D-LAD method	*p*-value
AB	4.01	1.67	-
BC	3.13	1.43	-
CD	5.79	3.99	-

Table A3- Maximum deviation of line segments AB,BC, and CD (cf. Figure 6B)

Surgical error margin	1 mm	2 mm	3 mm	4 mm	5 mm	6 mm	7 mm
Conventional method	0%	11.1%	33.3%	55.6%	77.8%	100%	100%
3D-LAD method	0%	11.1%	77.8%	100%	100%	100%	100%

Table A4- Percentage of successful resection within the surgical error margin from 1 to 7mm