Bone Density Projecting Method Assisted 3D Simulation and Printing for Complex Pelvic and Acetabular Fractures: A Comparative Cohort Study

Lee Kai Xing Alvin, MD*; Tsai Chun Hao, MD, PhD; Chen Hsien Te, Professor, MD, PhD*

Purpose: Pelvic and acetabular fractures are considered complex surgeries due to their anatomical structure and mechanism of injuries. This study specifically applied (1) virtual reduction simulation, (2) bone density evaluation, and (3) 3D-printed models and evaluated their impact on intraoperative parameters and postoperative functional recovery and reduction quality of patients with complex comminuted pelvic and acetabular fractures using case-control studies.

Methods: 96 patients (aged 18 years and above) with comminuted pelvic or acetabular fracture (2018 AO/OTA 61C or 62B and above) were prospectively recruited and treated with either 3D printing or traditional approaches between 2017 and 2020 with a follow-up duration of 48 months. Clinical outcomes were evaluated using intraoperative blood loss, surgical duration, EQ-VAS (EuroQol visual analog scale), Majeed pelvic score, and EQ-5D-5L (EuroQol 5 dimensions 5 levels) scores. We further stratified postoperative outcomes by gender, age, ISS, blood loss, and surgical duration. The minimum follow-up duration was 48 months.

Results: 3D simulation and printing did not statistically improve intraoperative blood loss and surgical duration. However, complication rates were significantly lower in the 3D printing group (6.25% vs 23.4%, $P = 0.047$) with 15 patients in the traditional groups requiring revision surgeries. Furthermore, the 3D printing group had higher postoperative outcomes, including EQ-VAS (74.5 ± 19.4 vs 73.4 ± 21.1), Majeed Pelvic Score (77.5 ± 17.4 vs 72.3 ± 23.3), and EQ-5D-5L utility (0.72 ± 0.20 vs 0.58 ± 0.46). There were no differences in the stratification results except for the 6-h group whereby 3D printing had higher EQ-5D-5L scores. The cumulative incidence rate for 48 months was calculated using Kaplan-Meier analysis and 3D printing was reported to reduce complications by approximately 16%.

Conclusion: 3D simulation and printing did not improve intraoperative surgical parameters of patients with complex pelvic and acetabular fractures. However, there were satisfactory improvements in complication rates and postoperative outcomes after 48 months of follow-up.

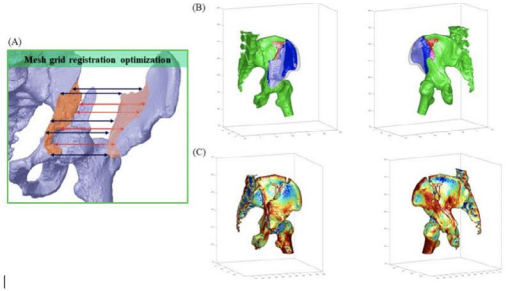

Fig. 1 (A) Mesh grid optimization to identify comminuted fragments and simulate optimal reduction; (B) Pelvis model with the best reduced fit; (C) Evaluation of bone density as converted using Hounsfield unit of CT for evaluation of screw and plate placement

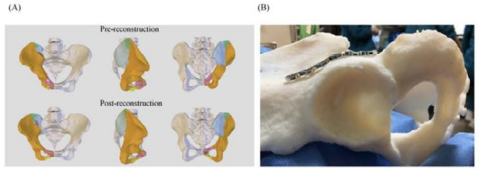

Fig. 2 (A) Pre- and post-reduction of pelvis fractures; (B) Plates and screws were determined and pre-contoured preoperatively using a 3D printing model.

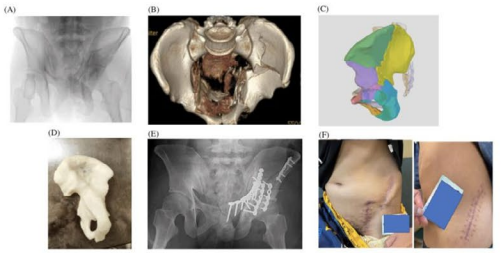

Fig. 3 (A)(B) A 27 years old male with a left pelvic and acetabular fracture with multi-fragmentary anterior column involvement; (C) Post reduction simulation using our grid optimization algorithm; (D) 3D printed reduced hemipelvis; the fracture fault lines, placement of the plates and screws were engrooved onto the model; (E) Our bone density evaluation allows us to multiple screws at places with the thickest cortex; (F) Minimal invasive surgery with pararectus approach anteriorly and direct posterior approach posteriorly was used on this patient. The length of the incision was approximately about 8.5 cm in length (the length of a credit card) on both sides.

Table 2. Postoperative outcome comparing between 32 cases of patients with 3D printing and 64 cases of patients with traditional approaches using linear regression

	3D Printing N = 32		Traditional N = 64		Crude			Adjusted		
	Mean	SD	Mean	SD	Estimate	(95% CI)	p-value	Estimate	(95% CI)	p-value
EQ-VAS	74.5	19.4	73.4	21.1	1.06	(-9.38, 11.5)	0.841	-1.63	(-10.6, 7.35)	0.719
Majeed	77.5	17.4	72.3	23.3	5.11	(-6.00, 16.2)	0.362	2.82	(-7.36, 13.0)	0.583
EQ-5D-5L	0.72	0.20	0.58	0.46	0.13	(-0.07, 0.34)	0.199	0.08	(-0.10, 0.26)	0.385

Table 1. Demographics of patients comparing between 32 cases of patients with 3D printing-model assisted and 64 cases of patients with traditional approaches.

	3D Printing N=32		Traditional Approaches N=64		
					p-value
Mean age, year (SD)	40.5	(16.0)	47.0	(17.4)	0.083
Gender, n (%)					0.371
Women	14	(43.8)	22	(34.4)	
Men	18	(56.2)	42	(65.6)	
AO 2018 classification, n (%)					0.356
61C	10	(31.3)	29	(46.0)	
62B	13	(40.6)	23	(36.5)	
62C	4	(12.5)	7	(11.1)	
Multiple	5	(15.6)	4	(6.35)	
Complication, n (%)	**2**	**(6.25)**	**15**	**(23.4)**	**0.047***
ISS score,					0.302
<16	15	(46.9)	23	(35.9)	
16+	17	(53.1)	41	(64.1)	
Mean (SD)	19.4	(11.0)	17.9	(9.09)	0.457
Blood loss, cc					0.835
<500	13	(40.6)	22	(34.4)	
500-999	10	(31.3)	22	(34.4)	
1000+	9	(28.1)	20	(31.3)	
Mean (SD)	729.7	(629.5)	800.5	(613.5)	0.599
Surgery time, hour					0.648
< 4	13	(40.6)	32	(50.0)	
4-5	8	(25.0)	15	(23.4)	
6+	11	(34.4)	17	(26.6)	
Mean (SD)	5.09	(2.37)	4.40	(1.98)	0.190

Table 3. Postoperative outcome stratified by gender and age comparing between 32 cases of patients with 3D printing and 64 cases of patients with traditional approaches using linear regression

	3D Printing		Traditional		Crude			Adjusted		
	Mean	SD	Mean	SD	Estimate	(95% CI)	p-value	Estimate	(95% CI)	p-value
Men	N=18		N=42							
EQ-VAS	69.4	24.9	72.0	21.2	-2.56	(-18.4, 13.2)	0.747	-3.02	(-17.1, 10.7)	0.668
Majeed	75.8	21.4	71.1	23.6	4.75	(-12.0, 21.5)	0.571	4.37	(-11.3, 19.7)	0.577
EQ-5D-5L	0.70	0.21	0.54	0.47	0.16	(-15.7, 0.48)	0.314	0.14	(-0.14, 0.43)	0.316
Women	N=14		N=22							
EQ-VAS	78.6	13.2	76.2	21.1	2.45	(-11.3, 16.2)	0.719	-2.68	(-12.6, 7.27)	0.587
Majeed	78.8	14.4	74.9	23.0	3.96	(-11.0, 18.9)	0.593	-0.66	(-13.1, 11.7)	0.915
EQ-5D-5L	0.73	0.19	0.66	0.44	0.07	(-0.20, 0.34)	0.598	-0.03	(-0.23 0.17)	0.751
Age<60	N=28		N=44							
EQ-VAS	75.6	18.3	77.9	18.7	-2.37	(-12.7, 7.92)	0.646	-4.44	(-14.0, 5.08)	0.353
Majeed	78.9	15.4	76.4	21.8	2.50	(-8.64, 13.6)	0.655	0.70	(-9.93, 11.3)	0.896
EQ-5D-5L	0.73	0.19	0.69	0.36	0.04	(-0.14, 0.22)	0.645	0.01	(-0.16, 0.18)	0.911
Age>=60	N=4		N=20							
EQ-VAS	65.0	35.4	64.3	23.1	075	(-33.8, 35.3)	0.965	7.80	(-18.5, 33.2)	0.542
Majeed	64.5	37.5	64.1	24.4	0.45	(-36.1, 37.0)	0.980	6.24	(-25.8, 37.4)	0.691
EQ-5D-5L	0.61	0.30	0.36	0.57	0.24	(-0.56, 1.05)	0.535	0.38	(-0.26, 1.03)	0.231

Table 4. Postoperative outcome stratified by ISS, blood loss and surgical duration comparing between 32 cases of patients with 3D printing and 64 cases of patients with traditional approaches using linear regression

	3D Printing		Traditional		Crude			Adjusted		
	Mean	SD	Mean	SD	Estimate	(95% CI)	p-value	Estimate	(95% CI)	p-value
Surgery time <4 hour	N=13		N=32							
EQ-VAS	82.5	16.7	81.2	17.9	1.33	(-14.2, 16.8)	0.863	0.19	(-15.3, 15.7)	0.980
Majeed	90.2	14.2	78.7	20.6	11.4	(-5.92, 28.8)	0.185	11.2	(-6.40, 28.7)	0.201
EQ-5D-5L	0.83	0.13	0.71	0.26	0.13	(0.09, 0.34)	0.231	0.12	(-0.09, 0.34)	0.253
Surgery time 4-5 hour	N=8		N=15							
EQ-VAS	74.0	22.5	67.6	21.6	6.43	(-15.7, 28.6)	0.549	-1.00	(-21.4, 17.4)	0.918
Majeed	74.2	18.3	75.3	18.3	-1.12	(-19.7, 17.5)	0.901	-7.41	(-24.4, 9.33)	0.387
EQ-5D-5L	0.67	0.23	0.58	0.51	0.09	(-0.37, 0.56)	0.680	-0.11	(-0.49, 0.33)	0.606
Surgery time >=6 hour	N=11		N=17							
EQ-VAS	69.4	19.8	64.6	22.0	4.80	(-12.3, 21.9)	0.569	4.29	(-6.06, 14.6)	0.399
Majeed Pelvic Score	70.8	15.8	58.6	26.4	12.2	(-6.74, 31.1)	0.190	11.6	(-1.20, 24.5)	0.065
EQ-5D-5L utility	0.66	0.19	0.35	0.61	0.30	(-0.11, 0.72)	0.136	0.29	(0.00, 0.59)	0.043*

Table 5. Incidence of complication between 32 cases of patients with 3D printing and 64 cases of patients with traditional approaches

	Complication no.	Person-years	Rate, per 100 person-years	HR (95% CI)	p-value
Traditional	15	110.73	13.55	1.00 (reference)	
3D Printing	2	35.13	5.69	0.40 (0.09-1.77)	0.226