



## Original article

# Effectiveness of closed reduction and percutaneous fixation of isolated sacral fractures. Functional outcomes and sagittal alignment after 3.6 years in 20 patients



Sébastien Ruatti\*, Mehdi Boudissa, Gael Kerschbaumer, Michel Milaire, Jérôme Tonetti

CHU Grenoble, avenue Maquis du Grésivaudan, 38700 La Tronche, France

## ARTICLE INFO

## Article history:

Received 17 July 2018

Accepted 1<sup>st</sup> February 2019

## Keywords:

Sacrum

Sagittal alignment

Pelvic ring

Percutaneous

## ABSTRACT

**Background:** Displaced U- or H-shaped sacral fractures (Roy-Camille Grade II or III) are treated at our institution by early transcondylar traction and manual countertraction, hyperlordosis induced by a pad positioned under the lumbo-sacral junction, and percutaneous ilio-sacral screw fixation. The objective of this study was to evaluate the outcome of this technique used in a level 1 trauma centre.

**Hypothesis** Our early reduction technique provides anatomical reduction of U- or H-shaped sacral fractures by correcting the sagittal malalignment due to the intra-sacral kyphosis, thereby obviating the need for decompression laminectomy and improving neurological outcomes.

**Material and methods:** We retrospectively evaluated 20 patients treated for U- or H-shaped sacral fractures using our original reduction technique followed by percutaneous fixation only. Mean follow-up was 42.4 months. Mean displacement of the S1 posterior wall was measured on computed tomography scans obtained before and after surgery. Pelvic incidence (PI) and measured lumbar lordosis (LLm) were evaluated on standard radiographs before surgery and on stereoradiographs after surgery. Expected lumbar lordosis (LLe) was computed as  $LLe = PI + 9^\circ$ . A 25% or greater difference between LLe and LLm defined lumbo-pelvic mismatch. At last follow-up, functional outcomes were assessed based on the Majeed score and the Iowa Pelvic Score (IPS), and a neurological examination was performed.

**Results:** Mean S1 posterior wall displacement in the sagittal and axial planes was 64% and 64.8%, respectively, before surgery versus 5.6% and 15.2%, respectively, after surgery. At last follow-up, LLm was 63.5° and the LLe-LLm difference was 11.2%; only 3 (15%) patients had lumbo-pelvic mismatch at last follow-up. The mean Majeed score and IPS values were 86.6 and 79, respectively, and lumbo-pelvic mismatch correlated significantly with a worse functional outcome defined as a Majeed score below 75 ( $p = 0.0087$ ). At last follow-up, the neurological dysfunctions were improved in 90% of patients, and 70% of patients had achieved a full neurological recovery.

**Discussion/Conclusion:** Given these encouraging findings, we advocate early reduction and percutaneous fixation of U- or H-shaped sacral fractures. Although technically demanding, this method restores the normal pelvic parameters and improves neurological function.

**Level of evidence:** IV, retrospective observational study.

© 2019 Published by Elsevier Masson SAS.

## 1. Introduction

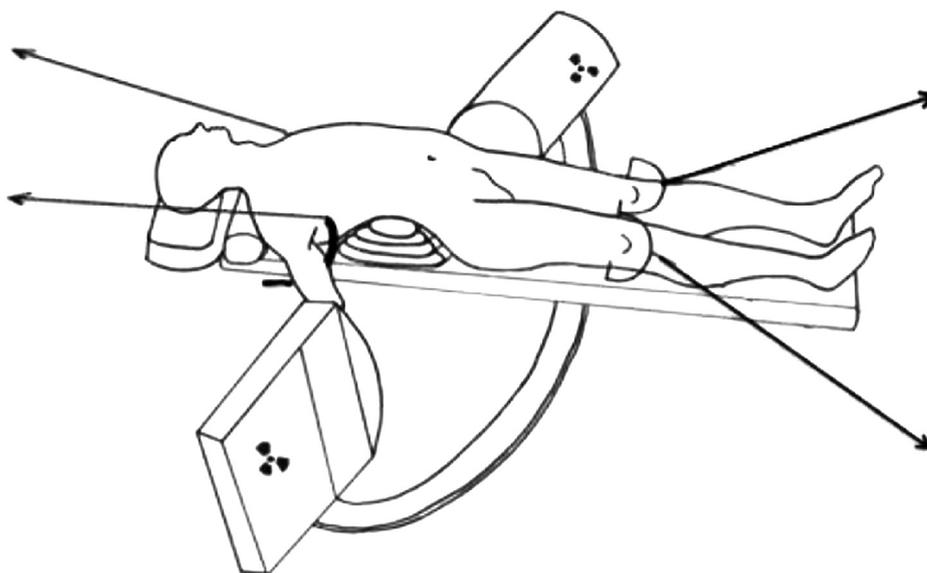
Although 15% to 45% of posterior pelvic ring fractures involve the sacrum [1,2], only 2% to 5% are isolated U- or H-shaped sacral fractures [3,4]. Work reported by Roy-Camille since 1985 has clarified the pathophysiological mechanisms responsible for U- or H-shaped sacral fractures, which typically occur when the patient lands after a fall from a considerable height (e.g., in attempted sui-

cide by defenestration) with the lumbar spine in marked lordosis and the hips extended [5]. Roy-Camille et al. established the first classification for these fractures, distinguishing three grades, and Strange-Vognsen and Lebech subsequently added a grade 4 defined as a burst fracture of the S1 body [6].

Compared to non-operative treatment, lumbo-pelvic or trans-sacral surgical fixation has not been consistently effective [7–12]. However, lumbo-pelvic mismatch due to a displaced fracture may be responsible for chronic low back pain [13]. Furthermore, recent meta-analyses indicate that surgical treatment provides benefits by restoring normal pelvic parameters [12,13]. Open surgery has been associated with poor wound healing and infections [14–17].

\* Corresponding author.

E-mail address: [sruatti@chu-grenoble.fr](mailto:sruatti@chu-grenoble.fr) (S. Ruatti).



**Fig. 1.** Early reduction technique: installation of the patient in the operating room. Note the pad under the low back and the fluoroscope positioned to provide lateral views for assessing the quality of the reduction.

Percutaneous ilio-sacral screw fixation as described by Rouit et al. in 1996 decreases the morbidity of sacral fracture surgery [18,19].

Since 2011, we treat displaced U- and H-shaped sacral fractures (Roy-Camille Grades II and III) using early reduction by strong trans-condylar traction (15% of body weight) combined with strong manual counter-traction. We then place a roll of sheets under the lumbo-sacral junction to achieve full reduction by inducing hyperlordosis. Finally, ilio-sacral screws are inserted percutaneously to ensure fixation [20] (Fig. 1).

The objective of this study was to evaluate the outcome of this early reduction and fixation technique used in a level 1 trauma centre. Our working hypothesis was that this technique provides anatomical reduction of U- or H-shaped sacral fractures by correcting the sagittal malalignment due to intra-sacral kyphosis, thereby obviating the need for decompression laminectomy and improving neurological outcomes.

## Material and method

We retrospectively included 20 patients, 10 males and 10 females, managed at our centre between September 2007 and July 2016. Mean age at the time of surgery was  $36.5 \pm 11.1$  years (range, 17–69 years). All patients consented to the collection of their data for research purposes. Thus, functional outcome data were available for all 20 patients.

### 1.1. Inclusion criteria

We included patients who were managed during the study period for a U- or H-shaped (Roy-Camille grade II or III) sacral fracture and were still alive at last follow-up.

### 1.2. Surgical technique

The surgical procedures were performed by five surgeons who had extensive experience with the surgical management of pelvic ring disruption. Two-dimensional fluoroscopy was used for all procedures. Reduction within 24 hours followed by definitive percutaneous fixation was performed as described previously by our group [20] (Fig. 1).

Our technique involves setting up bilateral transcondylar traction in the operating room within 24 hours after the injury. The

patient is supine on the table, which is inclined in the Trendelenburg position. After sedation and neuromuscular blockade, the surgeon applies strong explosive traction to both transcondylar traction stirrups, while two assistants apply manual counter-traction to the armpits. The occurrence, during this manoeuvre, of a cracking sound indicating sacral fracture reduction is the most favourable scenario. The reduction is maintained by applying 15% of the patient's body weight to each traction pin. It is then possible to wait for the optimal time to perform internal fixation, in accordance with the principles of damage control. Thus, unstable patients can be admitted to the intensive care unit with the traction devices in place until their condition improves. Definitive fixation is then performed.

For definitive fixation, the patient is supine on a radiolucent surgical table with both transcondylar traction devices in place. A large hard cylinder made of rolled sheets is placed under the lumbo-sacral junction to increase the lordotic curve, thereby achieving full reduction of the intra-sacral kyphosis. Lateral fluoroscopy is performed to check the quality of the reduction. In our opinion, one of the best criteria of good-quality reduction is restored alignment of the anterior sacral cortex.

Fixation was with bilateral percutaneous cannulated 7.3-mm titanium screws in all 20 patients. The total number of screws was 4 (2 on each side) in 6 patients, 3 (2 on one side and 1 on the other) in 3 patients, and 2 (one on each side) in 11 patients. Selection of the number of screws was based chiefly on the size of the space between the first sacral foramen and the upper S1 endplate and on the surgeon's perceptions. Another criterion was bone quality as estimated by the surgeon, with poorer quality leading to the use of a larger number of screws.

### 1.3. Post-operative care

Weight bearing was started 15 to 45 days after surgery, depending on surgeon preference and bone quality.

### 1.4. Radiological classification

Radiological classification of the sacral fractures was based on the work by Roy-Camille et al. and Strange-Vognsen and Lebech [5,6]. Before and after surgery, a lateral radiograph of the pelvis and sacrum was obtained. Pelvic incidence (PI) was measured on the pre-operative view. Computed tomography (CT) in the sagittal

**Table 1**  
Main patient data and neurological status at last follow-up.

Patient #	Type of injury	Age, years	Pre-op. neurological status	Neurological status at last FU	PrePI, <sup>o</sup>	PostPI, <sup>o</sup>	LLm, <sup>o</sup>	LLe, <sup>o</sup>	[LLm-LLe] (% LLe)	FU (months)
Patient 1	2-m fall while skiing	32	Left S1 dysaesthesia	Left S1 dysaesthesia	60	41	51.2	50	2.4	55
Patient 2	3-m fall	37	Cauda equina syndrome	0	66	43	58	52	11.5	61
Patient 3	Snowboard	40	0	0	64.3	55	65.1	64	12.7	52
Patient 4	Motorcycle	17	Bilateral S1 dysaesthesia + S2 to S5 anaesthesia	Bilateral S1 dysaesthesia	56.7	54	64.2	63	1.85	57
Patient 5	Paragliding	39	Cauda equina syndrome + complete loss of right lumbo-sacral trunk function + foot dorsiflexor palsy 1/5	Foot dorsiflexor palsy 3/5 + partial loss of right lumbo-sacral trunk function	65	52	64.5	61	5.7	121
Patient 6	Fall from horseback	40	0	0	68.6	50	62	59	5	51
Patient 7	Paragliding	53	Complete loss of left lumbo-sacral trunk function	0	62.7	53	62.2	62	0.37	51
Patient 8	7-m fall	23	0	0	57.7	52	65	61	6.5	49
Patient 9	1-m fall	61	0	0	61	50	70.2	59	19	45
Patient 10	3-m fall while skiing	22	Partial cauda equina syndrome	0	58	45	64.8	54	20	44
Patient 11	Paragliding	27	0	0	64.2	45	68.4	54	26.7	34
Patient 12	Traffic accident	21	Cauda equina syndrome	0	61	42	64.4	51	26.3	32
Patient 13	9-m fall	28	0	0	57	52	62.1	61	19	32
Patient 14	5-m fall	23	0	0	63	53	69	62	11.3	31
Patient 15	Traffic accident	23	0	0	61	51	64.3	60	7.2	53
Patient 16	Traffic accident	69	0	0	70	56	70.4	65	16	28
Patient 17	12-m fall	40	Left S1 dysaesthesia	0	61.7	42	66.8	51	30.95	18
Patient 18	3-m fall	44	0	0	62	48	64.1	57	12.5	15
Patient 19	Fall from horseback	34	Bilateral S1 paraesthesia	0	53.5	50	61.4	59	4	14
Patient 20	Speedriding	57	Left S1 dysaesthesia	0	55	51	53	52	1.9	5

FU: follow-up; PrePI: pre-operative pelvic incidence; PostPI: post-operative pelvic incidence; LLm: measured lumbar lordosis; LLe: expected lumbar lordosis.

and axial planes was also performed before and after surgery and used to classify the fracture according to Roy-Camille, as well as to measure the posterior displacement of the posterior S1 wall.

Fracture healing was assessed on standard antero-posterior and lateral radiographs obtained routinely 6 months after surgery. At last follow-up, low-dose biplanar stereoradiographs (EOS<sup>®</sup>, EOS Imaging SA, Paris, France) were obtained to assess sagittal alignment by measuring PI and lumbar lordosis (LL), thus allowing an evaluation of the first part of our working hypothesis. The imaging studies were read by the authors and by an independent experienced radiologist.

Post-operatively, the PI and measured LL (LLm) were determined on lateral EOS<sup>®</sup> views. The expected LL (LLe) was computed as follows:  $LLe = IP + 9^\circ$ . The LLe and LLm were then compared. A greater than 25% difference defined lumbo-pelvic mismatch [13].

### 1.5. Functional assessment

In each patient, pain intensity was evaluated using a visual analogue scale (VAS). The Majeed score and Iowa Pelvic Score (IPS) were used as measures of subjective outcomes. The patients were evaluated 6 weeks then 3, 6, and 12 months after surgery. We evaluated whether a poor functional outcome, defined for this study as a Majeed score below 75 at last follow-up, was associated with lumbo-pelvic mismatch, using Fisher's test. Neurological findings before surgery and at last follow-up were compared to assess the second part of our working hypothesis.

## 2. Results

### 2.1. Mechanisms of injury

The sacral fracture was due to a paragliding accident in 3 patients; a horseback riding fall in 2 patients; a 3-meter fall from a scaffolding in 1 patient; voluntary defenestration with a fall of 3 to 12 meters in 5 patients; a speedriding accident in 1 patient; a motorcycle accident in 1 patient; traffic accidents in 3 patients; falls of 2 and 3 meters, respectively, during Alpine skiing in 2 patients; a 3-meter fall while snowboarding in 1 patient, and a fall from a height in 1 patient (Table 1).

### 2.2. Radiographic evaluation

All 20 fractures were Grade 2 in the Roy-Camille classification modified by Strange-Vognsen. The fracture was U-shaped in 10 patients, H-shaped in 9 patients, and Y-shaped in 1 patient.

Mean PI measured on the pre-operative lateral radiographs of the sacrum (prePI) was  $61.42^\circ$  (range,  $53.5^\circ$ – $70^\circ$ ). Mean posterior displacement of the S1 posterior wall on pre-operative CT views was 64% in the sagittal plane and 64.8% in the axial plane. Corresponding values on the CT scan obtained immediately after surgery were 5.6% and 15.2%, respectively (Figs. 2–5).

After the mean follow-up of 42.4 months (range, 12–121 months), pelvic parameters and parameters reflecting sagittal alignment were measured on the EOS images by an independent experienced radiologist. Mean post-operative PI (postPI) was  $49.25^\circ$  (range,  $41^\circ$ – $56^\circ$ ). Mean LLm between the upper L1 endplate and the lower L5 endplate was  $57.8^\circ$  (range,  $51.2^\circ$ – $70.4^\circ$ ). Mean LLe (computed as  $PI + 9^\circ$ ) was  $63.5^\circ$  (range,  $50^\circ$ – $65^\circ$ ), yielding a mean LLe-LLm difference of 11.2%. At last follow-up, only 3 (15%) patients had lumbo-pelvic mismatch defined as an LLe-LLm difference of 25% or more, as described by Boyoud-Garnier et al. [13] (Table 1).



**Fig. 2.** Pre-operative computed tomography, sagittal view: posterior displacement of the S1 posterior wall and intra-sacral kyphosis.

### 2.3. Complications

With our closed reduction and strictly percutaneous fixation method, wound healing was uneventful and no infections developed. Impingement of an ilio-sacral screw on the ipsilateral S1 root occurred in 2 patients, both of whom achieved a full neurological recovery when the screw was removed 6 months after surgery.

### 2.4. Functional outcomes

All 20 patients were re-evaluated, after a mean of 42.4 months (range, 12–121 months). Fixation was performed immediately after reduction in 19 patients. The unstable condition of the remaining patient required an 8-day period of care before fixation.

Mean time from injury to surgery was 1.4 days (range, 0–8 days). Weight bearing was started 15 to 45 days after surgery depending on bone quality and fracture complexity; mean time to weight bearing was 37 days.

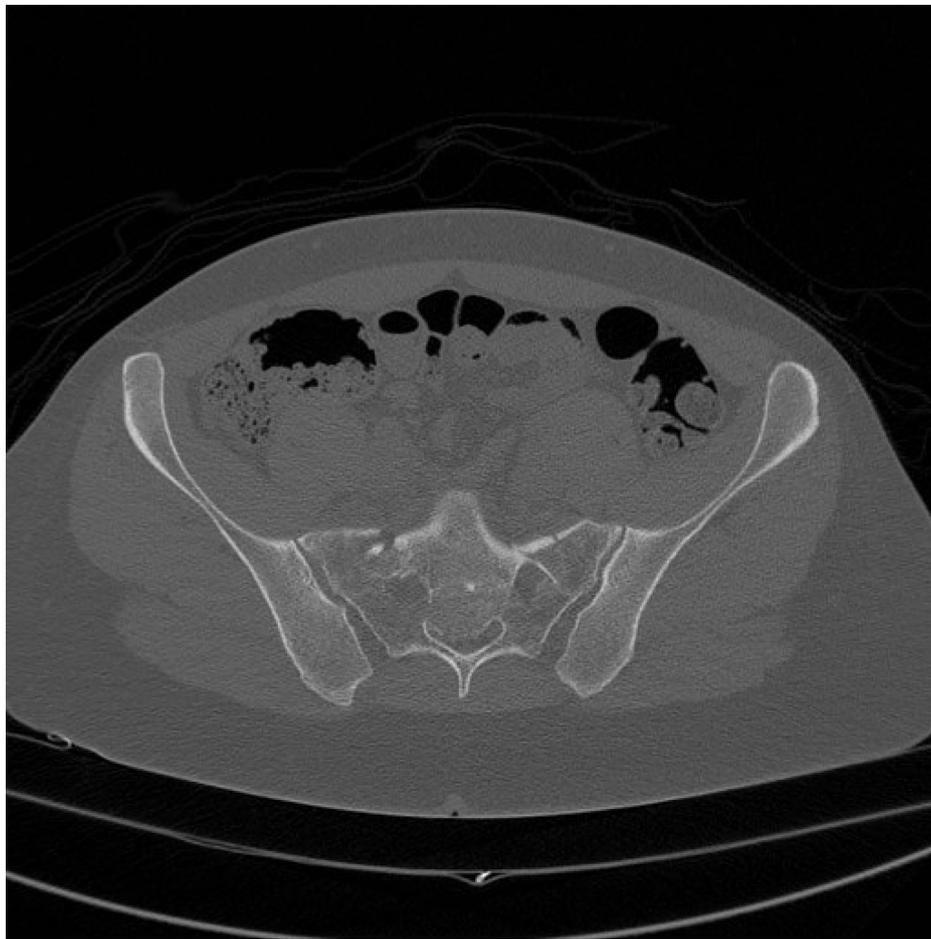
The subjective outcome was excellent in 10 patients, very good in 9 patients, and good in 1 patient. The mean VAS pain score was 0.87/10. The Majeed score was 86.6 and the IPS was 79.

To assess whether anatomical reduction was associated with good functional outcomes, we compared LLe and LLm [13]. LPM correlated significantly with a Majeed score below 75 (Fisher's test,  $p = 0.0087$ ; covariance, 0.58).

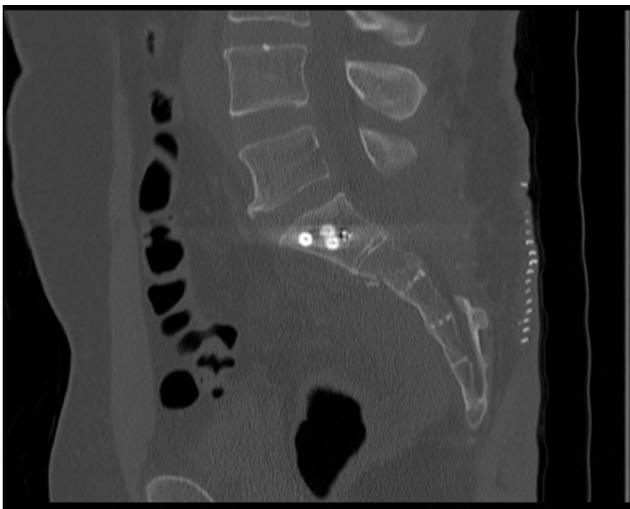
At last follow-up, 19 (94%) patients had returned to their previous occupation.

### 2.5. Neurological status

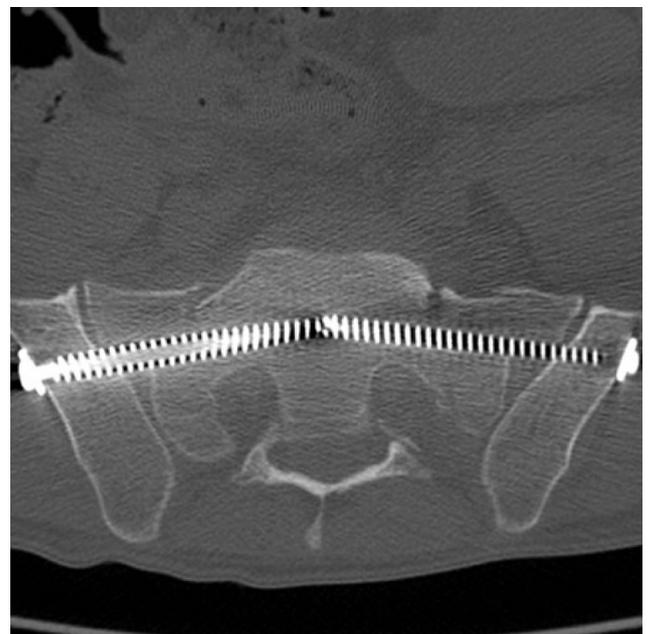
Before surgery, 8 patients reported unilateral paraesthesia in an S1 distribution; 3 had cauda equina syndrome, including 1



**Fig. 3.** Pre-operative computed tomography, axial view: posterior displacement of the S1 posterior wall and intra-sacral kyphosis.



**Fig. 4.** Post-operative outcome as assessed by computed tomography, sagittal view: correction of the posterior displacement of the S1 posterior wall, thanks to the reduction and fixation by ilio-sacral screws.



**Fig. 5.** Post-operative outcome as assessed by computed tomography, axial view: correction of the posterior displacement of the S1 posterior wall, thanks to the reduction and fixation by ilio-sacral screws.

with complete loss of lumbo-sacral trunk function; 1 had loss of lumbo-sacral trunk function due to compression for 2 hours by the ipsilateral innominate bone; and 1 had bilateral S1 nerve root pain. In the remaining 7 patients, the neurological evaluation was normal at admission.

At last follow-up, the initial neurological symptoms had improved at least partially in 90% of patients and had resolved fully in 70% of patients. [Table 1](#) provides details on neurological status.

## 2.6. Concomitant lesions

Additional skeletal injuries were present in 4 patients: 1 patient had a tibial and fibular fracture, 2 patients had a fracture involving both obturator rings, and 1 had pubic symphysis disjunction with haemorrhagic shock.

## 3. Discussion

For the treatment of isolated sacral fractures, some authors have expressed a preference for non-operative methods, which can be used at centres that do not have experience with the surgical treatment of sacral fractures. Optimal non-operative treatment is a better option than a hazardous surgical procedure performed by an inexperienced team [20–22], notably when multiple injuries are present, as is often the case in patients with sacral fractures. Nevertheless, reduction and open fixation is advocated by most authors [14–16,23–31]. However, the extensive approaches required for open fixation are associated with wound healing complications and surgical-site infections, which occurred in a mean of 16% of patients in studies by Helgeson et al. and Schildhauer et al. [23,24].

In 1993, Pohlemann et al. drew attention to the risk of infection after open surgery for sacral fractures, as well as to the considerable experience required by the complexity of the fixation constructs [32]. Percutaneous ilio-sacral screw fixation techniques were therefore developed to decrease the risk of complications. They spare the haematoma at the pelvic fracture site and limit intra- and post-operative bleeding [18,19]. The technique described here requires only percutaneous fixation, and the initial reduction can be performed early, at patient admission. Greater fracture-site mobility facilitates reduction, which is therefore most effective when performed early after the injury. In our experience, reduction produces less predictable outcomes when performed after more than 72 hours. In this study, the mean time from injury to reduction (with immediate fixation in 19/20 patients) of only 1.4 days reflects the commitment of our anaesthesiology and surgery teams to the prompt management of sacral fractures. Final fixation can be performed either during the same stage or after patient preparation and stabilisation according to the damage-control principle. The considerable force used during reduction, combined with the mechanical effect of the roll placed under the low back to induce hyperlordosis, is effective in correcting the posterior tilting of S1 while simultaneously restoring sagittal alignment [33]. Irifune et al. [33] recently reported that using hyperlordosis under fluoroscopic control for reduction, without trans-osseous traction, was sufficient to restore normal pelvic parameters, notably by eliminating the intra-sacral kyphosis induced by the fracture. We believe that strong traction as described previously [20] improves reduction quality via ligamentotaxis while avoiding the application of force to the anterior sacral hinge created by the fracture. Furthermore, impacting the two anterior sacral cortices into each other contributes to stabilise the reduction, as a complement to the percutaneous fixation.

Of our 20 patients, only 3 (15%) had LPM as defined by Boyoud-Garnier et al. [13]. The subjective outcomes were extremely satisfactory overall (excellent,  $n=10$ ; very good,  $n=9$ ; and good,  $n=1$ ), and 19 (94%) patients returned to their previous occupation. LPM correlated significantly with a poor functional outcome (Majeed score  $<75$ ) ( $p=0.0087$ ; covariance, 0.58), supporting the need for restoring the normal pelvic parameters. We therefore agree with Hart et al. that pelvic parameter restoration predicts the quality of the functional recovery [12]. Boyoud-Garnier et al. also reported a strong correlation between chronic low back pain and

abnormal pelvic parameters [13]. None of our patients had evidence of secondary displacement or loss of reduction at last follow-up. Consequently, LPM, when present, was entirely ascribable to insufficient initial reduction.

A long similar lines, we found that greater posterior displacement of the posterior S1 wall was associated with the greatest benefits from our reduction technique. In the patients with more than 50% of posterior displacement on the pre-operative sagittal views, mean posterior displacement was only 5.6% after surgery. In the patients with less than 50% of posterior displacement initially, mean post-operative displacement was greater, at 11% ( $p=0.008$ ).

Recent meta-analyses support beneficial effects of laminectomy to release nerve roots subjected to traction or contusion [16,25]. The chances of recovery after nerve root avulsion are low. Yi et al. [16] stated that laminectomy must be performed during the same surgical procedure, before reduction and final fixation, because expelled small bone fragments may threaten the nerve roots trapped in the sacral canal during the reduction and fixation manoeuvres. In our experience, however, effective closed reduction is sufficient to ensure indirect nerve root decompression (Figs. 2–5). This technique eliminates the wound healing complications and infections seen after open surgery [24] while providing very satisfactory outcomes compared to earlier reports, with neurological improvements in 90%, and a full neurological recovery in 70%, of cases. With laminectomy and internal fixation, the rates of full and partial neurological recovery were 16% and 67%, respectively, in a study by George et al. [26], whereas 84% of patients studied by Schildhauer et al. experienced partial or full recovery [24]. Dussa and Soni observed neurological improvements in 40% of patients after open reduction and internal fixation [15]. Finally, all 6 patients with acute urinary retention described by Fountain et al. experienced resolution of the neurological deficit after laminectomy [29].

In our department, sacral laminectomy is reserved for the uncommon scenario of unchanged neurological manifestations after closed reduction and percutaneous fixation and is performed only to remove bone fragments displaced into the S1 foramen or sacral canal. None of the patients included in this study required sacral laminectomy.

The limitations of this study include the retrospective design. The sample size is small, but isolated sacral fractures are uncommon.

## 4. Conclusion

Isolated sacral fractures are serious injuries and must be managed in level 1 trauma centres that have considerable experience with treating spinal and pelvic ring trauma. In our experience, surgery is consistently required if the fracture is displaced. The findings from this study of 20 patients support the reliability of early closed reduction and percutaneous fixation for restoring normal pelvic parameters. Thus, the first part of our working hypothesis is confirmed: our early reduction and percutaneous fixation technique usually provides anatomical reduction, thus correcting the alterations in pelvic parameters related to the intra-sacral kyphosis.

Our technique also improved the neurological status in 90% of cases, confirming the second part of our working hypothesis: anatomical reduction obviates the need for decompression laminectomy. Wound healing complications and infections are considerably less common than after open surgery, allowing early mobilisation and decreasing the morbidity and mortality rates.

## Disclosure of interest

The authors declare that they have no competing interest.

## Funding

None.

## Contribution

SR collected the data and wrote the manuscript.

MB, GK, and MM collected the data and contributed to the manuscript framework.

JT conceived the study and contributed to write the manuscript.

All authors contributed to the surgical procedures in the study patients.

## References

- [1] Denis F, Davis S, Comfort T. Sacral fractures: an important problem: retrospective analysis of 236 cases. *Clin Orthop* 1988;227:67–81.
- [2] Taguchi T, Kawai S, Kaneko K, et al. Operative management of displaced fractures of the sacrum. *J Orthop Sci* 1999;4:347–52.
- [3] Carl A, Delman A, Engler G. Displaced transverse sacral fractures: a case report, review of the literature, and the CT scan as an aid in management. *Clin Orthop* 1985;194:195–8.
- [4] Phelan ST, Jones DA, Bishay M. Conservative management of transverse fractures of the sacrum with neurological features: a report of four cases. *J Bone Joint Surg Br* 1991;73:969–71.
- [5] Roy-Camille R, Saillant G, Gagna G, et al. Transverse fracture of the upper sacrum. Suicidal jumper's fracture. *Spine (PhilaPa 1976)* 1985;10:838–45.
- [6] Strange-Vognsen HH, Lebech A. An unusual type of fracture in the upper sacrum. *J Orthop Trauma* 1991;5:200–3.
- [7] Wiesel SW, Zeide MS, Terry RL. Longitudinal fractures of the sacrum: case report. *J Trauma* 1979;19:70–1.
- [8] Ferris B, Hutton P. Anteriorly displaced transverse fracture of the sacrum at the level of the sacro-iliac joint. A report of two cases. *J Bone Joint Surg Am* 1983;65:407–940.
- [9] Dogra AS, Karkhanis AR, Asurlekar RV. Fracture sacrum. *J Postgrad Med* 1995;41:47–9.
- [10] Ikada K, Wada E, Kodama N. Traction injury of the lumbosacral spinal nerve roots: report of a case. *Spine* 1991;16:368–71.
- [11] Mouhsine E, Wettstein M, Schizas C, et al. Modified triangular posterior osteosynthesis of unstable sacrum fracture. *Eur Spine J* 2006;15:857–63.
- [12] Hart RA, Badra MI, Madala A. Use of pelvic incidence as a guide to reduction of H-type spino-pelvic dissociation injuries. *J Orthop Trauma* 2007;21:369–74.
- [13] Boyoud-Garnier L, Boudissa M, Ruatti S, et al. Chronic low back pain after lumbosacral fracture due to sagittal and frontal vertebral imbalance. *Orthop Traumatol Surg Res* 2017;103:523–6, <http://dx.doi.org/10.1016/j.otsr.2017.01.013>.
- [14] Robles LA. Transverse sacral fractures. *Spine J* 2009;9:60–9.
- [15] Dussa CU, Soni BM. Influence of type of management of transverse sacral fractures on neurological outcome. A case series and review of literature. *Spinal Cord* 2008;46:590–4.
- [16] Yi C, Hak DJ. Traumatic spinopelvic dissociation or U-shaped sacral fracture: a review of the literature. *Injury* 2012:43402–8.
- [17] Hak DJ, Baran S, Stahel P. Sacral fractures: current strategies in diagnosis and management. *Orthopedics* 2009;32, <http://dx.doi.org/10.3928/01477447-20090818-18>.
- [18] Routh Jr ML, Simonian PT. Closed reduction and percutaneous skeletal fixation of sacral fractures. *Clin Orthop Relat Res* 1996;329:121–8.
- [19] Routh Jr ML, Nork SE, Mills WJ. Percutaneous fixation of pelvic ring disruptions. *Clin Orthop Relat Res* 2000;375:15–29.
- [20] Ruatti S, Kerschbaumer G, Gay E, et al. Technique for reduction and percutaneous fixation of U- and H-shaped sacral fractures. *Orthop Traumatol Surg Res* 2013;99:625–69, <http://dx.doi.org/10.1016/j.otsr.2013.03.025>.
- [21] Schwab F, Lafage V, Patel A, et al. Sagittal plane considerations and the pelvis in the adult patient. *Spine (PhilaPa 1976)* 2009;34:1828–33.
- [22] Kellam JF, McMurtry RY, Paley D, et al. The unstable pelvic fracture. Operative treatment. *Orthop Clin North Am* 1987;18:25–41.
- [23] Helgeson MD, Lehman Jr RA, Cooper P, et al. Retrospective review of lumbosacral dissociations in blast injuries. *Spine (PhilaPa 1976)* 2011;36:E469–75.
- [24] Schildhauer TA, Bellabarba C, Nork SE, et al. Decompression and lumbopelvic fixation for sacral fracture-dislocations with spino-pelvic dissociation. *J Orthop Trauma* 2006;20:447–57.
- [25] Kim MY, Reidy DP, Nolan PC, et al. Transverse sacral fractures: case series and literature review. *Can J Surg* 2001;44:359–63.
- [26] George S, Sapkas, Andreas F, Mavrogenis et al. Transverse sacral fractures with anterior displacement. *Eur Spine J* 2008;17:342–7.
- [27] Gribnau AJ, Van Hensbroek PB, Haverlag R, et al. U-shaped sacral fractures: surgical treatment and quality of life. *Injury* 2009;40:1040–8.
- [28] Vresilovic EJ, Mehta S, Placide R, et al. Traumatic spondylopelvic dissociation. A report of two cases. *J Bone Joint Surg Am* 2005;87:1098–103.
- [29] Fountain SS, Hamilton RD, Jameson RM. Transverse fractures of the sacrum. A report of six cases. *J Bone Joint Surg Am* 1977;59(4):486–9.
- [30] Vaccaro AR, Kim DH, Brodke DS, et al. Diagnosis and management of sacral spine fractures. *Instr Course Lect* 2004;53:375–85.
- [31] König MA, Seidel U, Heini P, et al. Minimal-invasive percutaneous reduction and transsacral screw fixation for U-shaped fractures. *J Spinal Disord Tech* 2013;26:48–54, <http://dx.doi.org/10.1097/BSD.0b013e3182318539>.
- [32] Pohlemann T, Angst M, Schneider E, et al. Fixation of transforaminal sacrum fractures: a biomechanical study. *J Orthop Trauma* 1993;7:107–17.
- [33] Irifune H, Hirayama S, Takahashi N, et al. Closed reduction in a "hyperextended supine position" with percutaneous transsacral-transiliac and iliosacral screw fixation for Denis zone III sacral fractures. *Adv Orthop* 2018:6098510, <http://dx.doi.org/10.1155/2018/6098510> [eCollection 2018].