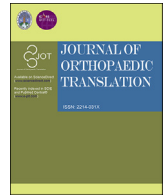


Contents lists available at ScienceDirect

Journal of Orthopaedic Translation

journal homepage: www.journals.elsevier.com/journal-of-orthopaedic-translation

Original Article

The clinical use of the enriched bone marrow obtained by selective cell retention technology in treating adolescent idiopathic scoliosis

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ARTICLE INFO

Keywords:

Adolescent idiopathic scoliosis
Allograft bone
Selective cell retention technology

ABSTRACT

Purpose: This retrospective study aimed to evaluate the curative effect of allografts in combination with bone marrow enrichment realised by selective cell retention (SCR) technology in treating adolescent idiopathic scoliosis (AIS).

Methods: From July 2014 to September 2016, 18 consecutive patients with AIS were treated by posterior fusion and pedicle screw instrumentation. Bone marrow aspirates were obtained and enriched by SCR technology to fabricate bone grafts in combination with allogeneic bones, which were implanted for spinal fusion. Postoperatively, the patients were observed for a minimum of 18 months, with a mean follow-up period of 48 months. The results were assessed both clinically and radiographically. All adverse events and complications were recorded.

Results: A total of 9 male and 9 female patients were included, with an average age of 15.6 years (range, 12–20). The average preoperative Cobb angle was 56° (range, 47°–85°). The average number of levels fused was 11 (range, 9–13). SCR could be accomplished intraoperatively, only consuming approximately 20 min. The enriching multiples of measured cellular elements were approximately 2.3–4.2. At final follow-up, the average Cobb angle correction was 83% (range, 61–96%). There was no obvious loss in correction with an average loss of 1.1° (2%). The visual analogue scale score and the Oswestry Disability Index score at final follow-up were significantly ameliorated than those preoperatively. The Scoliosis Research Society 30 questionnaire revealed remarkable improvement in the domains “pain”, “self-image/appearance”, and “satisfaction with management”. There was neither pseudarthrosis nor severe complication.

Conclusion: The use of SCR technology could be considered as an effective method for promoting spinal fusion in treating AIS. We proposed a safe, simple, and rapid approach to obtain effective bone grafts for spinal fusion.

The translational potential of this article: Enriched bone marrow obtained by selective cell retention technology has the potential to promote spinal fusion for the treatment of adolescent idiopathic scoliosis.

Introduction

Adolescent idiopathic scoliosis (AIS) is an agnogenic and postnatal three-dimensional spinal deformity among teenagers, with an overall incidence in the population of 1–3%, and more than 0.02% of patients need surgical treatment [1]. Currently, the widely recognised approach

is the combination of instrumentation and fusion of 10 or more vertebrae to achieve and sustain forceful deformity correction [2]. However, the chief complication, pseudarthrosis, caused by fusion failure, is still an annoying problem due to the possible loss of correction and even break of rods and nails [3]. For spinal fusion, autologous bone grafting has been considered the gold standard [4]. However, some drawbacks

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<https://doi.org/10.1016/j.jot.2020.02.005>

Received 6 September 2019; Received in revised form 6 February 2020; Accepted 10 February 2020

Available online 5 March 2020

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are inevitable such as donor site pain, postoperative wound infection, vascular injury, and so on [5,6]. Intraoperatively, harvesting bones from the vertebral laminae and spinous processes is another way for autologous grafting to avoid donor site morbidity. However, the volume of implanted bones is usually insufficient for patients with Lenke type 1–3 AIS, in consideration of the long segment fusion and no additional resection of ribs. Based on the advantages of extensive source and convenience, allogeneic bones have been considered as a suitable alternative and widely used [7]. Nevertheless, their osteoinductivity is relatively low owing to the necessary processing steps, such as deesterification and deproteinisation, which are aimed to decrease the antigenicity [8]. It has been reported that a longer time is required for allogeneic bone grafting to achieve spinal fusion as compared with autologous grafting [9]. Hence, spinal fusion with the utilisation of allografts may be improved by incorporating osteogenic progenitors and osteoinductive factors.

With the rapid development of tissue engineering and regenerative medicine, much attention has been paid to promote spinal fusion using osteogenic progenitors [10–12]. The bone marrow is a natural source of osteogenesis-related progenitor cells [e.g., mesenchymal stem cells (MSCs), hematopoietic stem cells, and monocytes] and growth factors. However, the proportions of these pro-osteogenic components are quite low. For example, MSCs only occupy approximately 0.001–0.01% of nucleated cells in the bone marrow [13]. To increase the concentration of MSCs, *in vitro* expansion is usually adopted, although certain drawbacks such as a long culture period, high cost, and strict condition are noted [14]. Selective cell retention (SCR) technology is a promising method based on the concept that the bioactive components within the bone marrow (i.e., stem cells and bioactive factors) can be enriched via the appropriate porous structure and surface adhesion property of scaffolds [15]. The major principle of SCR lies in physical interception, which can be reinforced by changing the pore size and microstructure of scaffolds via physical methods. There have been certain chemical or interdisciplinary approaches of ensuring the efficacy of SCR, such as surface modification, which is able to improve cell adhesion via charge attraction or cell–cell/cell–extracellular matrix interactions [16–18]. When the bone marrow passes through the scaffolds at an optimised and controlled velocity, the bioactive components within the bone marrow are selectively retained on the scaffolds to fabricate biografts in a short time period (about 20 min), which allows intraoperative application. Previously, researchers have reported that the decalcified bone matrix (DBM) modified by SCR results in superior spinal fusion to DBM alone and DBM plus marrow in an animal model [19]. However, the clinical efficacy of allografts armed with SCR needs further validation.

In this study, bone marrow aspirates were enriched onto allogeneic bones intraoperatively using a manual enrichment device, bone growth promoter (FUWOSI, Chongqing, China), which was designed based on the principle of SCR. The postenriched bone grafts were used to perform posterior spinal fusion for patients with AIS. The therapeutic effects of the postenriched bone grafts were then assessed.

Materials and methods

Patients

From July 2014 to September 2016, 18 patients who were diagnosed with AIS and underwent surgery were enrolled. This retrospective study was approved by the Medical Ethics Committee of Southwest Hospital. The inclusion criteria were as follows: diagnosis of AIS with curves as classified Lenke type 1–3 [20]; serious deformity leading to unsatisfied appearance; with a Cobb angle > 45° but fine spinal flexibility; and age between 10 and 20 years, regardless of gender. The exclusion criteria included the following: spinal stiffness with a razor back requiring rib excision and those with other systemic diseases or mental illness. A written consent was obtained from each patient before participation.

Surgical procedure

All patients underwent posterior correction via a multisegmented titanium pedicle screw and rod system (Kanghui, Jiangsu, China). All surgeries were performed by the same surgeons, as well as by the same anesthetist, in accordance with standard techniques. Through a standard posterior midline surgical incision, the spine was exposed using a combination of blunt subperiosteal dissection and electrocautery. After imperative facetectomy and removal of soft tissues, pedicle screws were inserted into the determined vertebrae. With the help of concave rods, curve correction was achieved with rod rotation, concave distraction, convex compression, and, if necessary, *in situ* translational correction and direct apical vertebral body derotation. After that, the spinous processes were resected, and outer cortices of bilateral laminae were decorticated to prepare the grafting bed. Bone grafts prepared as mentioned in the following section were then implanted. Postoperatively, the patients were braced for approximately three months.

Preparation of bone grafts

Bone grafts were prepared after curve correction intraoperatively. To reduce the pore size of scaffolds, the allogeneic bones (BIOGENE, Dasting Bio-Tech Co., Ltd, China) were cut into small blocks; then, the cancellous bone particles were mixed with cortical bone powder, at a proportion ratio of 1:1 (Figure 1). As revealed by the scanning electron microscope, the mixed material had a smaller pore size than cancellous bones (Figure 2). Then, the bone marrow aspirate was obtained from the iliac crest or screw trajectory and injected into the subuliform cup of the enrichment device, in which the mixed allogeneic bones were filled in advance. When the handle of the device was pressed to the bottom and released, an enrichment cycle could be automatically accomplished under the negative pressure provided by the constant force spring. After that, the bone marrow effluent was sucked back into the recirculatory cylinder, and the handle was returned to the initial position, waiting for the next cycle. The construction of bone grafts lasted for 4 cycles, consuming about 20 min in total. The whole process of enrichment was showed in Figure 3.

Evaluation of the enrichment efficiency

The enrichment efficiency was evaluated as per the method described previously [16]. Owing to the difficulty in identifying MSCs in the bone marrow, the enriching rate of MSCs was assessed via mimicking the concentration of MSCs *in vitro*. To analysis cell enrichment, the antibodies including CD34-PE and CD45-Per CP (BD, USA) were used. By flow cytometry (FACSCalibur, BD, NJ, USA), a certain volume of the bone marrow (inflow volume, V1) and the cell concentration (M1) were recorded. After enrichment for 4 cycles, the volume of the effluent was recorded as V2, and the cell concentration was measured (M2). The cell concentration (C) and enriching multiple (E) were calculated as follows: $C = (M1 \times V1 - M2 \times V2) / (V1 - V2)$ and $E = C / M1$, respectively.

Postoperative evaluation and follow-up

Considering that frequent radiation exposure to computed tomography (CT) was harmful to adolescents, radiological evaluation was mainly dependent on standing full-length anteroposterior and lateral X-rays. CT was performed only when pseudarthrosis was suspected in case of either of the following situations: loss of correction > 10°; back pain; or internal fixation failure. The radiographs were scheduled at discharge, 3 months, 6 months, 12 months, 24 months, and every 12 months thereafter. Successful spinal fusion was determined on the basis of the complaint, examination, and radiography. The back pain was judged using the visual analogue scale (VAS). The Oswestry Disability Index (ODI) was used to assess pain-related disability [21]. The Scoliosis Research Society 30 questionnaire (SRS-30) was used to evaluate the health-related quality of life (HRQoL) [22].

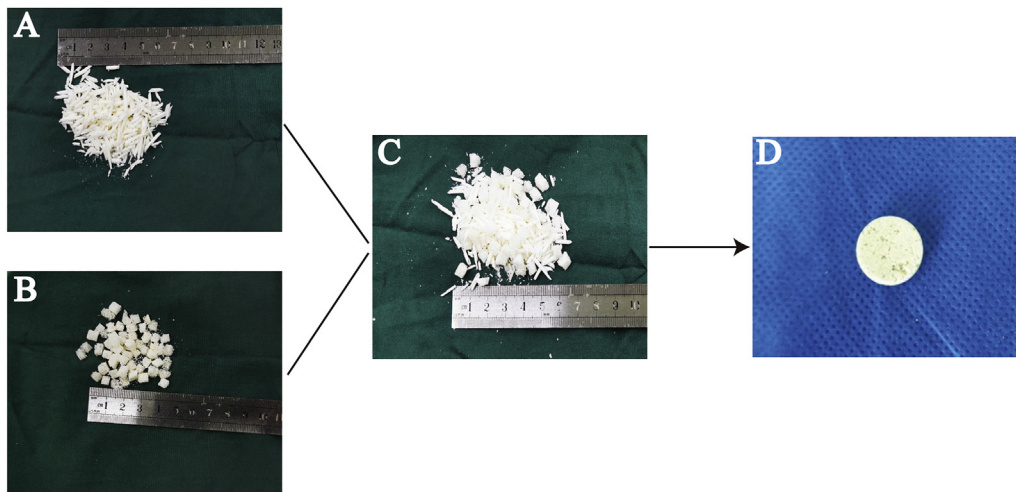


Figure 1. The images of the allogeneic bones used in surgery. (A) Cortical bone powder; (B) cancellous bone particles; (C) a mixture of cortical bone powder and cancellous bone particles; (D) bone cake.

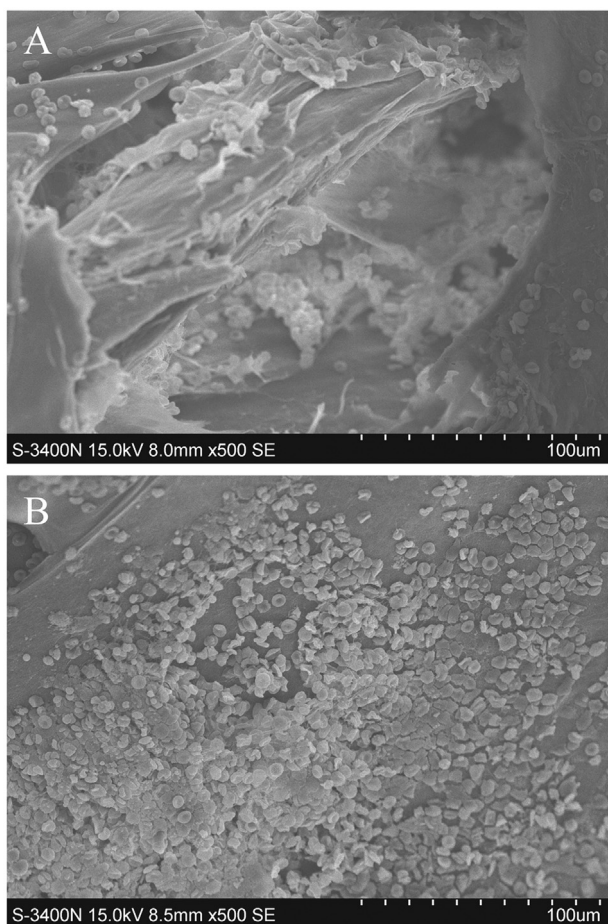


Figure 2. Morphological observation under the scanning electron microscope. (A) A few cells were adhered to the surface of cancellous bone particles after enrichment; (B) a large number of cells were adhered to the cancellous bone particles/cortical bone powder composite after enrichment.

Data analysis

Data were reported as mean \pm standard deviation and analyzed using SPSS 20.0 software (IBM Corp., Armonk, New York, USA). The paired *t*

test was used to compare the Cobb angle of the main thoracic curve, thoracic kyphosis, lumbar lordosis, VAS, ODI, and SRS-30 scores. The statistical significance was set at $p < 0.05$.

Results

General data

A total of 18 patients were eligible including 9 female and 9 male patients, with an average age of 15.6 years (range, 12–20 years) at the time of surgery. By July 2019, the mean follow-up period was 48 months (range, 18–60 months). The numbers of cases with Lenke type 1, 2, and 3 curves were 10, 5, and 3, respectively. They had an average of 11.2 levels (range, 9–13 levels) fused and received implantation of a mean of 40.4 cm³ (range, 32.4–46.8 cm³) allogeneic bones. The mean surgery time, estimated intraoperative blood loss, and length of hospital stay were 231 min (range, 180–289 min), 650 mL (range, 300–1300 mL), and 10 d (range, 6–17 d), respectively (Table 1).

Enriching rate of the cells

Flow cytometry (Supplementary Fig. 1) provided quantitative values for calculating the enriching parameters. The result was detailed in Table 2. The concentration of all measured cellular elements, including karyocytes, monocytes, hematopoietic stem cells, and MSCs, was elevated approximately 2.3- to 4.2-fold after enrichment.

Radiographic assessment

The average preoperative Cobb angle of the main curvature was 56° (range, 47–85°). The correction angle measured postoperatively and at the final follow-up was 10° (range, 2–28°) and 11° (range, 3–30°), respectively. This indicated a 83% correction from before operation to after operation and a 2% loss of correction at the follow-up. No loss of correction more than 10° was found at the final visit. The Cobb angles regarding thoracic kyphosis (T5–T12) and lumbar lordosis (L1–S1) were recorded in the sagittal plane. The result showed an increased thoracic kyphosis and lumbar lordosis after surgery. For all cases, new bone formation was found on plain X-rays at 3 months postoperatively, and spinal fusion was achieved at the last follow-up. Representative radiographs of a typical case were shown in Figure 4. Another patient complaining a slight back pain was subjected to CT, as revealed in Figure 5. The radiographic data were detailed in Table 3.

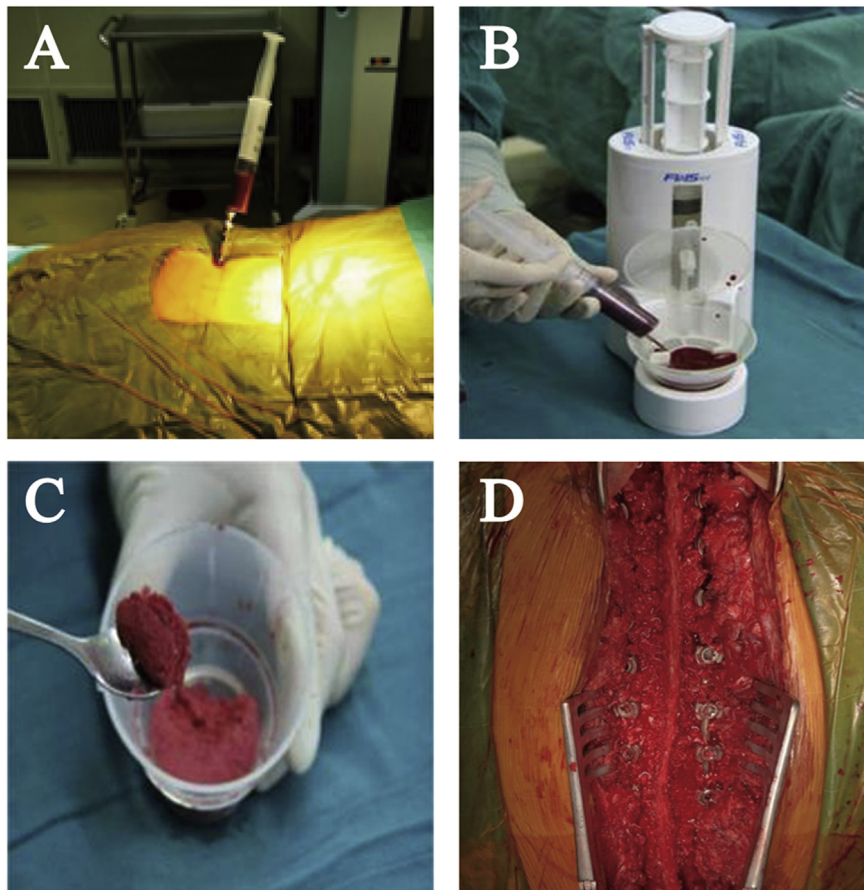


Figure 3. The brief process of bone marrow enrichment. (A) The bone marrow aspirate was obtained via insertion of a single-hole needle into the posterior iliac crest; (B) the bone marrow aspirate was injected into the subuliform cup of the enrichment device, in which the mixed allogeneic bones were filled in advance; (C) after 4 cycles of SCR, bone grafts were fabricated intraoperatively; (D) bone grafting. SCR = selective cell retention.

Clinical outcome

Compared with the VAS scores preoperatively, the scores were significantly improved at the final follow-up, although one patient had a slight back pain. In addition, the ODI score at final follow-up showed a remarkable decline. HRQoL assessment revealed a visibly increased

“total score” compared with the preoperative status. This result was mainly attributed to significant improvement of the domains “pain”, “self-image/appearance”, and “satisfaction with management”. Other domains, including “function/activity” and “mental health”, were neither ameliorated nor deteriorated. The clinical data were displayed in [Table 4](#).

Table 1
Patient data and perioperative parameters.

Patient	Age	Gender	Lenke type	Levels fused	Allograft bone volume (cm ³)	Surgery time (min)	Intraoperative blood loss (mL)	Hospital stay (d)	Complication	Fusion	Follow-up (months)
1	18	F	1B	T2-L1	43.2	269	500	11	None	Good	60
2	15	M	1A	T2-L2	46.8	252	700	10	None	Good	60
3	15	M	3B	T3-L1	39.6	235	600	17	None	Good	60
4	12	F	1A	T2-L1	43.2	205	600	9	None	Good	58
5	17	F	1A	T3-L1	39.6	227	1000	6	None	Good	58
6	20	M	1A	T2-T11	36	236	600	9	None	Good	54
7	13	F	2A	T2-L1	43.2	229	600	10	None	Good	54
8	15	M	2A	T2-L1	43.2	264	1300	7	None	Good	53
9	15	F	2A	T2-L2	46.8	223	600	9	None	Good	52
10	17	F	1A	T4-L1	36	180	700	10	None	Good	48
11	14	F	2B	T2-T12	39.6	266	600	12	None	Good	48
12	16	F	1A	T2-T11	36	217	500	11	None	Good	47
13	14	M	3B	T2-L1	43.2	239	1000	8	None	Good	47
14	17	F	1A	T2-L1	32.4	235	800	10	None	Good	42
15	16	M	2C	T2-T12	39.6	192	500	14	Poor incision healing	Good	36
16	17	M	1B	T3-T12	36	195	300	13	None	Good	36
17	13	M	1A	T5-L3	39.6	289	500	13	None	Good	36
18	16	M	3C	T3-L4	43.2	212	300	9	None	Good	18

F = female; M = male.

Table 2
Analysis of cell enrichment.

Cellular elements	Bone marrow aspirate (/mL)	Bone marrow concentrate (/mL)	Fold increase
Karyocytes	$18.3 \pm 1.7 \times 10^6$	$41.3 \pm 8.4 \times 10^6$	2.3 ± 0.4
Monocytes	$1.2 \pm 0.1 \times 10^6$	$3.7 \pm 0.9 \times 10^6$	3.0 ± 0.6
HSCs	$0.5 \pm 0.1 \times 10^6$	$1.6 \pm 0.8 \times 10^6$	2.9 ± 1.1
MSCs	0.04×10^6	$0.17 \pm 0.03 \times 10^6$	4.2 ± 0.8

HSC = hematopoietic stem cell; MSC = mesenchymal stem cell.

Complications

One patient had a poor wound healing owing to *Staphylococcus aureus* infection and was completely cured with sensitive antibiotics and a superficial debridement and suturing. There was no revision surgery for any reason. Other potential adverse events, such as tumourigenesis or immunosuppression, were not observed with the use of bone marrow enrichment.

Discussion

For decades, spinal fusion has been a common practice to treat various spinal diseases including severe deformity such as AIS. An ideal bone graft for fusion should simultaneously possess excellent osteoconductivity, osteoinductivity, and osteogenicity. One prime example is autologous bones, which still represent the gold standard for bone fusion. However, the unavoidable complications associated with bone harvesting have encouraged the development of alternatives. Currently, various bone substitutes, such as hydroxyapatite, calcium phosphate, or sulfate and freeze-dried allogeneic bones, have shown satisfactory osteoconductivity by supporting bone ingrowth. With the aim to develop novel effective bone grafts to meet the large clinical demand, empowering these substitutes with osteoinductivity and osteogenicity via different approaches, such as surface modification, cell seeding, and bioactive factor incorporation, has currently become a research hotspot.

The bone marrow is rich in pro-osteogenic components, such as MSCs, which can differentiate into osteoblasts. Bone marrow aspirates have been used to promote osteogenesis, whether as an adjuvant to bone substitutes with osteoconductivity or via direct injection. However, simple usage of the bone marrow, whether soaking or injection, is insufficient owing to the low ratio of osteogenic progenitors therein. To improve the efficacy of the bone marrow in spinal fusion, it is very critical to find ways to increase the content of osteogenic components. Using a cell separator (COBE 2991TM Cell Processor, GAMBRO BCT., Inc.), Gan et al. [23] harvested the postenriched bone marrow with the alkaline phosphatase level increased 4.3 times. The good spinal fusion rate was 95.1%, with a mean follow-up of 34.5 months. Despite the favourable result, this approach required relatively higher volume of the bone marrow, intricate instrument, and another preparation room. SCR technology is another promising method, by which osteogenesis-related progenitors can be selectively retained within polyporous bioscaffolds to prepare bone grafts intraoperatively. With the help of the Collect DBM System (DePuy Spine, NJ, USA), Lee and Goodman [24] successfully fabricated bone grafts using SCR technology and demonstrated that the number of osteoprogenitor cells was increased 3–4 times. Three patients with secondary osteonecrosis of the femoral condyle received grafting and achieved excellent results with no complication during the two-year follow-up. Fitzgibbons et al. [25] found that the osteoprogenitor cells in the bone marrow could be concentrated by use of the selective retention system. The concentrated bone marrow, in combination with allografts, led to promoted osteoconductivity, osteoinductivity, and osteogenesis, with limited morbidity for most patients with foot and ankle arthrodesis. Nevertheless, there is no clinical report on SCR technology for spinal fusion in treating scoliosis.

In this study, bone marrow aspirates were enriched and incorporated into the allogeneic bones intraoperatively to construct bone grafts for

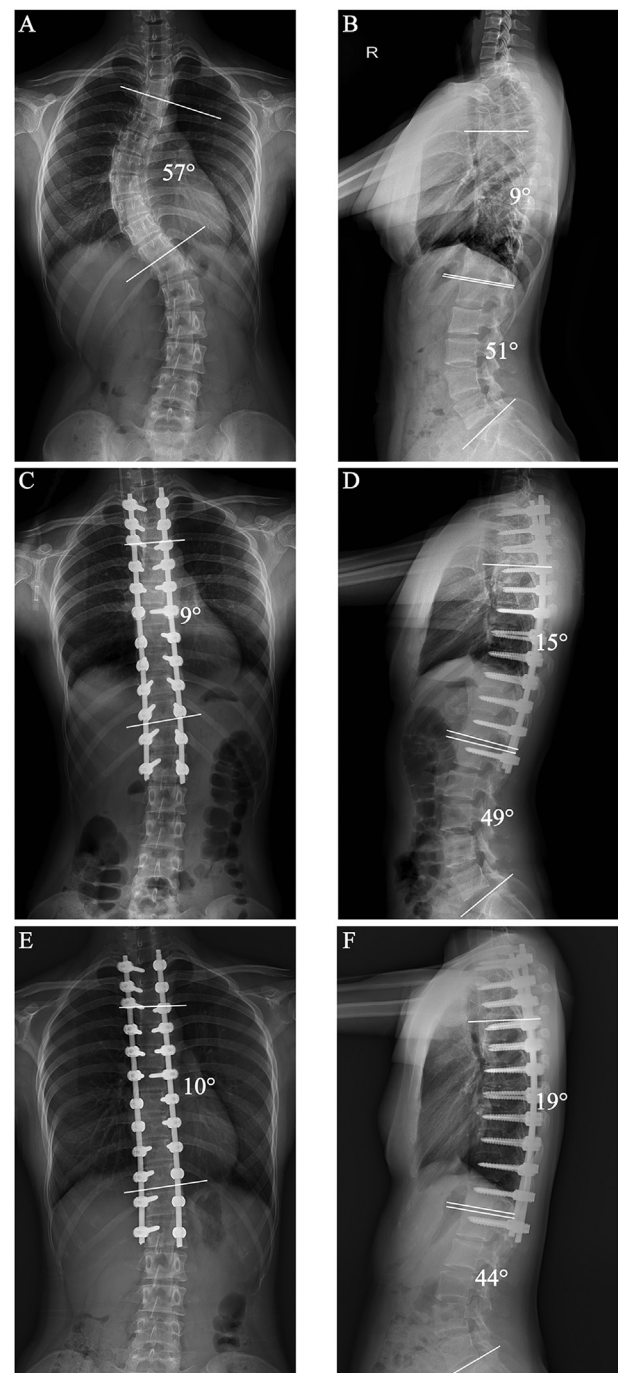


Figure 4. The standing posteroanterior and lateral radiographs of an 18-year-old female patient with Lenke 1B adolescent idiopathic scoliosis. (A and B) Preoperatively, a main thoracic curve of 57° from T4 to T11 was noted; (C and D) at 3 days postoperatively, the main thoracic curve was corrected to 9°, and thoracic kyphosis was well restored; (E and F) at 5 years postoperatively, no significant correction loss was observed, all fixation segments were well fused, and no crack was noted.

spinal fusion in patients with AIS. The postenrichment contents of detected cells were significantly increased, and the concentrated cells could adhere to the inner wall of the porous substrates. This might be mainly attributed to the mixture of allogeneic bone blocks, particles, and powder, which significantly reduced the pore size of scaffolds and reinforced physical interception. Moreover, the preparation process of the allogeneic bones made the scaffold surface rough and certain proteins exposed, which might contribute to SCR by increasing cell adhesion. The postenriched

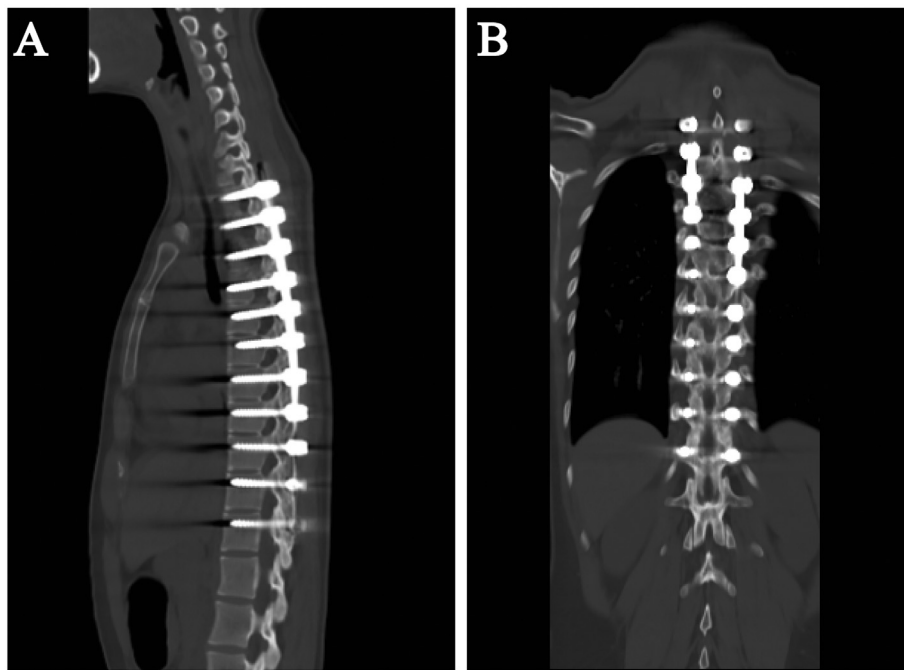


Figure 5. Reconstructed coronal and sagittal CT scans showing solid bilateral fusion with the bridging bone extending in all fixed segments. A. Sagittal CT view. B. Coronal CT view.

Table 3
Preoperative and postoperative radiographic assessment.

Follup-up time points	Cobb angle of the main curve	Thoracic kyphosis	Lumbar lordosis
Before operation	55.9 ± 10.9	18.2 ± 8.9	43.8 ± 9.3
After operation (% correction)	9.9 ± 6.9 (83.0 ± 9.49%)	21.9 ± 6.7	48.3 ± 9.2
Final follow-up (% correction)	10.8 ± 7.3 (81.3 ± 9.80%)	23.1 ± 8.0	48.8 ± 8.3
Correction loss	1.1° (2%)		

composite exhibited satisfactory radiological outcomes in the mean four-year follow-up. As the established criteria for possible pseudarthrosis, all patients were considered to achieve complete fusion at final visit with a favourable maintenance of curve correction. The incidence of

Table 4
Preoperative and postoperative clinical data.

Clinical scores	Before operation	7 days Post-op	6 months Post-op	12 months Post-op	Final follow-up
VAS score	1.1 ± 0.8	3.1 ± 0.9*	0.6 ± 0.5*	0.2 ± 0.4*	0.1 ± 0.2*
ODI score	6.0 ± 2.5	NA	3.3 ± 1.9*	1.7 ± 1.8*	1.1 ± 1.4*
SRS-30					
Pain	4.2 ± 0.5	NA	4.3 ± 0.3*	4.4 ± 0.2*	4.5 ± 0.1*
Appearance	3.3 ± 0.4	NA	4.1 ± 0.3*	4.2 ± 0.1*	4.2 ± 0.2*
Activity	3.9 ± 0.2	NA	3.9 ± 0.2	4.0 ± 0.2	4.0 ± 0.2
Mental	4.2 ± 0.2	NA	4.2 ± 0.2	4.2 ± 0.3	4.2 ± 0.2
Satisfaction	3.4 ± 0.3	NA	4.6 ± 0.1*	4.7 ± 0.2*	4.7 ± 0.2*
Total score	3.9 ± 0.2	NA	4.2 ± 0.2*	4.3 ± 0.2*	4.3 ± 0.1*

*Statistically significant ($p < 0.05$, vs. preoperative data).
NA = not applicable; ODI = Oswestry disability index; Post-op = postoperatively; SRS-30 = Scoliosis Research Society 30 questionnaire; VAS = visual analogue scale.

pseudarthrosis was similar to that of autologous bone grafting and lower than that of allografting, which was described previously [26,27]. As with deformity correction, although rigid internal fixation ensures initial stability, the maintenance of corrective effect relies on the definite fusion of the fixed segments. Previously, Franzin et al. [26] compared the functional and radiographic results in patients receiving iliac bone grafts or not receiving iliac bone grafts and reported that the correction loss in the group of iliac bone grafts was 5.9% (nearly 3–4°). Knapp et al. [28] performed spinal fusion for AIS with the use of allogeneic bones. The average correction loss was 3.5° (5.9%) at the final visit. In this study, the loss of correction was 2%. Despite the difference in internal fixation and correction approach, this result implied that the introduction of SCR was likely to contribute to bone fusion and the maintenance of corrective effect. Moreover, the Cobb angles of thoracic kyphosis and lumbar lordosis were restored and kept in most cases postoperatively, which was consistent with the results reported previously [29].

The average VAS score at 7 days postoperatively was higher than that before operation, which may be attributed to postoperative wound pain. After that, the VAS score gradually decreased, and only one patient complained a slight back pain at final visit. CT scans of this patient showed good bone fusion in all fixed segments, denying the possible relationship between the residual pain and fusion outcome. In this regard, it was noteworthy that the donor site pain due to bone harvest from the posterior iliac crest was nasty even after more than 4 years [5]. In this study, the average ODI score was significantly reduced, suggesting that pain-related disability was improved by surgery. A consistent result was obtained from SRS-30 outcome assessment, which demonstrated a remarkable increase in overall HRQoL. The domains “function/activity” and “mental health” changed slightly, which might be attributed to the fact that patients without severe scoliosis were engaged.

Based on the analogical microstructure to bones and excellent osteoconductivity, allogeneic bones have been widely used in spinal surgery, although the question regarding their efficacy is frequent in the literature [30]. It is recommended to add osteogenesis-related cells and factors to allogeneic bones to replenish with osteoinductivity and osteogenicity. Vaccaro et al. [31] reported that allogeneic demineralised bone matrix putty combined with iliac autografts had a similar performance to autografts alone in posterolateral spinal fusion. Slosar et al. [32] found that the

addition of recombinant human bone morphogenetic protein-2 (rhBMP-2) to allografts significantly elevated the spinal fusion rate. Taghavi et al. [33] declared that rhBMP-2 and bone marrow aspirates, in combination with allografts, were appropriate alternatives to autologous bone grafts in revision posterolateral fusion (PLF). Consistently, the use of allografts in combination with the enriched bone marrow in this study not only brought benefits to spinal fusion but also avoided the complications caused by autologous bone harvest.

The main limitation of this study was the small number of patients and the absence of a comparative group. In addition, radiographic assessment of spinal fusion was dependent on plain X-rays, which may be inaccurate as possible overestimated solid fusion [34]. Larger sample, multicentre, and prospective comparative trials are required for further identification.

Conclusion

In the present study, we retrospectively investigated the effectiveness of bone marrow enrichment by SCR technology in spinal fusion for patients with AIS. With the help of the device, the whole process encompassing aspiration of the bone marrow, graft preparation, and SCR could be accomplished intraoperatively, only consuming approximately 20 min. SCR increased the number of osteogenesis-related cells by 2–4 times. The radiographic and clinical outcomes were satisfactory. Using this method, there was no need for additional autografts, specific or expensive equipment, strict quality control and safety criteria, and revision operation. Therefore, we proposed a safe, simple, and rapid approach to obtain effective bone grafts for spinal fusion. Considering the huge demand for effective bone substitutes in the clinic, this study may provide us with insights into developing novel strategies to promote spinal fusion.

Conflict of Interest

The authors have no conflicts of interest to disclose in relation to this article.

Acknowledgments

This work was supported by the Foundation of Southwest Hospital (SWH2014 LC06), the Foundation of Chongqing Science and Technology Commission (cstc2015jcyjA10015), and Major Project of Army (AWS17J004).

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jot.2020.02.005>.

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