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Does Additional Bone Grafting of Atlantoaxial Joint Increase Bone Fusion Rate of Iliac Crest Autograft in Posterior Occipitocervical Fusion? Retrospective, Controlled Study with 2-Year Follow-up

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OBJECTIVE: **We sought to explore whether additional bone grafting of the atlantoaxial joint increases the bone fusion rate of iliac crest autograft in posterior occipitocervical fusion surgery.**

METHODS: **From January 2012 to January 2016, a total of 78 patients who had basilar invagination with occipitalization of the atlas came to our tertiary spine center. Except for those lost to follow-up (10 cases) or who had a follow-up time <2 years (20 cases), there were 48 patients retrospectively included in this study. In the control group, a piece of autogenous iliac corticocancellous bone was placed between the occipital and C2 vertebral lamina for fusion. In the hybrid fusion group, besides posterior occipitocervical autograft, some granular bone harvested from the iliac crest was packed into the bilateral atlantoaxial joint. X-ray imaging and cervical computed tomography (CT) were performed during follow-up.**

RESULTS: **The operations were completed successfully in all patients without intraoperative complications. Only 21 (87.5%) patients in the control group had confirmed posterior bony fusion on CT, while 24 (100%) patients in the hybrid fusion group had confirmed posterior bony fusion. There were postoperative implant-related complications in 2 patients. Both cases belonged to the control group (8.3%). Three patients (12.5%) complained of transient numbness in the posterior occipital region: 2 patients in the hybrid group and 1 patient in the control group. The mean duration to posterior occipitocervical fusion was 5.5 months in the hybrid fusion group versus 6.1 months in the control group ($P = 0.757$). Of note, in the hybrid fusion group, the process of atlantoaxial joint fusion was faster than that of posterior occipitocervical fusion (5.1 months vs. 5.5 months, $P = 0.823$).**

CONCLUSIONS: **Additional bone grafting of the atlantoaxial joint could increase the bone fusion rate of iliac crest autograft in posterior occipitocervical fusion.**

INTRODUCTION

Traumas, rheumatic diseases, infections, tumors, or other congenital diseases are common causes of atlantoaxial dislocation and/or basilar invagination secondary to instability of the upper cervical spine. Posterior occipitocervical fusion is considered an effective method to correct the instability of the upper cervical spine under such conditions. In addition to the ideal reduction and decompression, reliable bone graft fusion directly affects the postoperative outcome. In a previous study,[1] the rate of occipitocervical fusion ranged from 89%–100% and the failure rate of nonunion after occipitocervical fusion was as high as 7%. However, the number of cases in these studies was small and lacked sufficient persuasiveness. Although numerous studies have shown that the rate of bone graft fusion and fixation with internal fixation is higher,[2] some patients still experience unsatisfactory bone graft healing and postoperative complications cannot be ignored, especially the formation of pseudarthrosis and postoperative nonunion.[3-5] Compared with

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- Atlantoaxial arthrodesis
- Atlantoaxial joints
- Basilar invagination
- Bone graft
- Occipitocervical fusion
- Posterior approach

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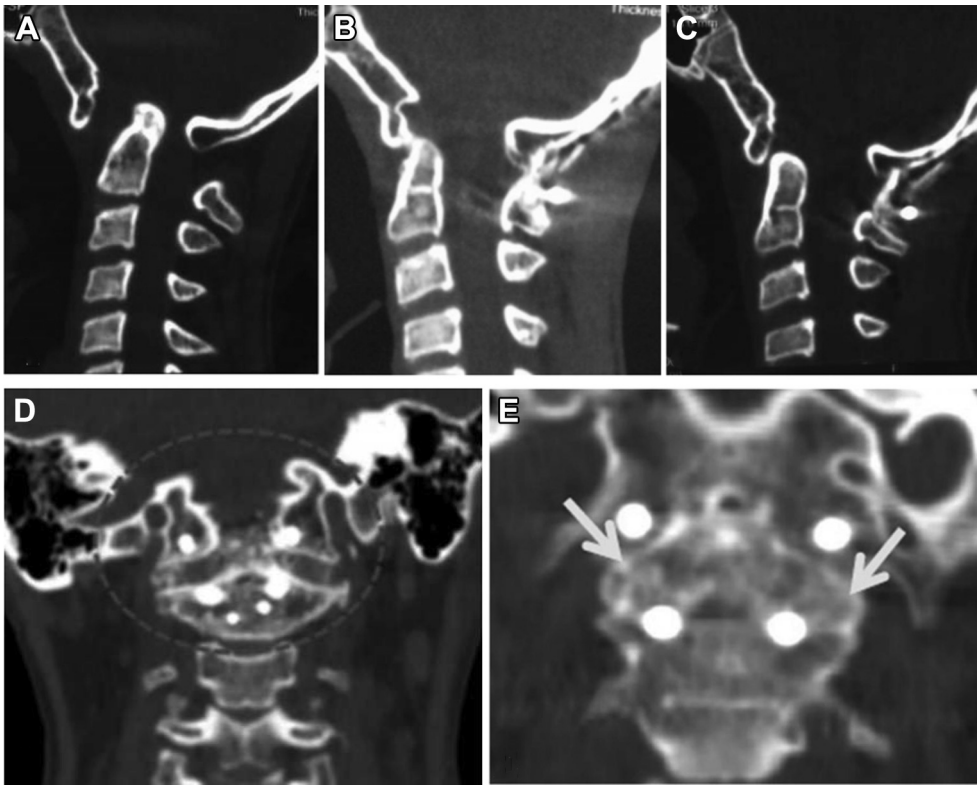

Figure 1. Computed tomography (CT) reconstruction revealed basilar invagination with occipitalization of the atlas, in which the atlantoaxial joint was dislocated (**A**). Occipitocervical alignment was satisfactorily restored at CT reconstruction 1 month postoperatively. Bone graft was visible between the harnpan and C2 vertebral lamina (**B**). The bone graft between harnpan and C2 vertebral lamina was fused at the follow-up of 5 months postoperatively (**C**). The bone graft at the bilateral atlantoaxial joint was visible at CT coronal reconstruction 1 month postoperatively (**D**), which was fused (*white arrow*) at 5 months' follow-up postoperatively (**E**).

allogeneic bone graft, autologous bone grafting demonstrated advantages and safety in bone graft fusion.[6] In our previous study, we performed autologous bone grafting of atlantoaxial joints for occipitocervical fusion and observed satisfactory bony fusion rate. Given the conflicting findings of previous studies, this study aimed to explore whether additional bone grafting of the atlantoaxial joint increases the bone fusion rate of iliac crest autograft in posterior occipitocervical fusion surgery.

MATERIALS AND METHODS

From January 2012 to January 2016, a total of 78 patients who had basilar invagination with occipitalization of the atlas in a tertiary spine center were enrolled (Figures 1, A and 2 left). Except for patients lost to follow-up (10 cases) or whose follow-up time was <2 years (20 cases), there were 48 patients (men = 30, women = 18, average age 53.2 ± 11.7, range 16–68 years) retrospectively included in this study. The 48 cases were divided into the control group (24 cases) and the hybrid group (24 cases) depending on the operation method. There were no differences in the age and gender of patients between these 2 groups ($P = 0.351$, $P = 0.168$). Both groups were treated with screw internal fixation and autogenous iliac bone grafting via a posterior approach. In the control group, only a piece of the autogenous corticocancellous iliac bone was placed between the occipital and C2 vertebral lamina for fusion. In the hybrid fusion group, in addition to posterior occipitocervical autograft, some granular bone harvested from the iliac crest was packed into the bilateral atlantoaxial joint. Patient inclusion criteria were as follows: basilar invagination combined with occipitalization of the atlas and the anatomic abnormality at the occipitocervical region corrected with skull traction under general anesthesia. For the exclusion criteria, vascular malformation was detected by computed tomography angiography, in which the major vessel was located at the dorsal part of the atlantoaxial joint impeding the exposure of the atlantoaxial joint space; there was a high riding vertebral artery at the axis; and basilar invagination could not be corrected with the skull traction under general anesthesia.

Surgical Methods

All 48 operations were performed by the same senior surgeon. After general anesthesia of the tracheal intubation, the patient was placed in the prone position, whose neck was placed in neutral position. Skull traction with weights progressively

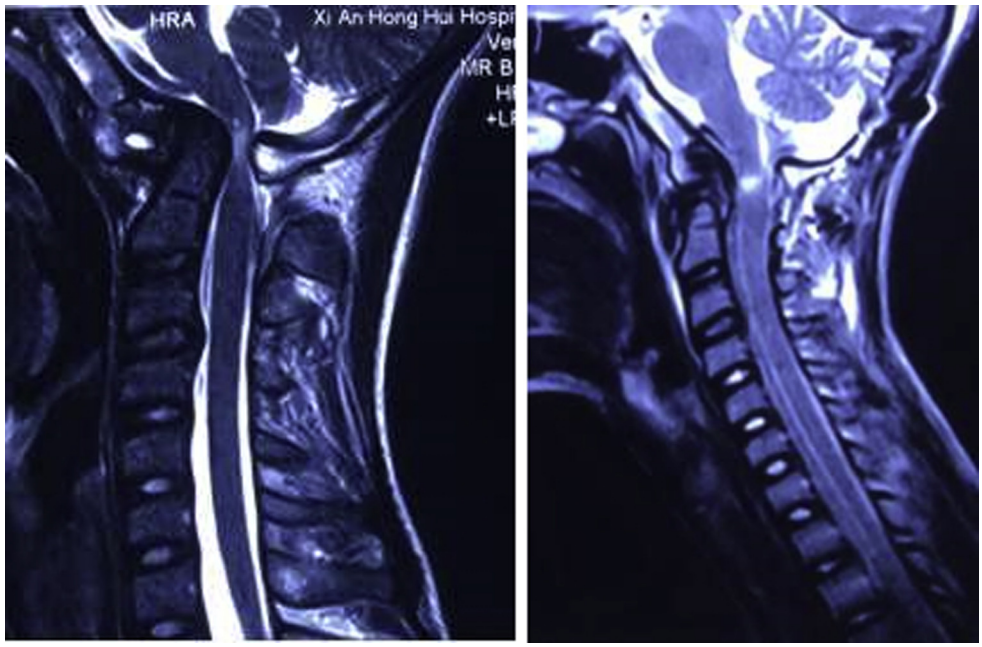

Figure 2. Magnetic resonance imaging (MRI) revealed the spinal canal was severely narrow with obvious intramedullary high signal (left). Circumferential compression of the spinal cord was relieved with the reduction of basilar invagination at the MRI 3 months postoperatively (right).

increased to <1/6 of the body weight (≈6–10 kg) was performed before the incision. When satisfactory reduction was observed during fluoroscopy, a conventional posterior midline skin incision was made to expose the occipitocervical region, which includes the foramen magnum, arch of the atlas, and C2 lamina. During operation, delicate operation and caution were observed to detect possible anatomic variation in the C2 nerve root or vertebral artery. According to the technique we have described in our previous study,[7] we first isolated and pulled the C2 nerve complex and surrounding epidural venous plexus using a retractor upward to the atlas to expose the atlantoaxial joints. To protect the nerve root and facilitate hemostasis, a small piece of a gelatin sponge was placed between the C2 nerve root and retractor. Note that the C2 nerve root was released at

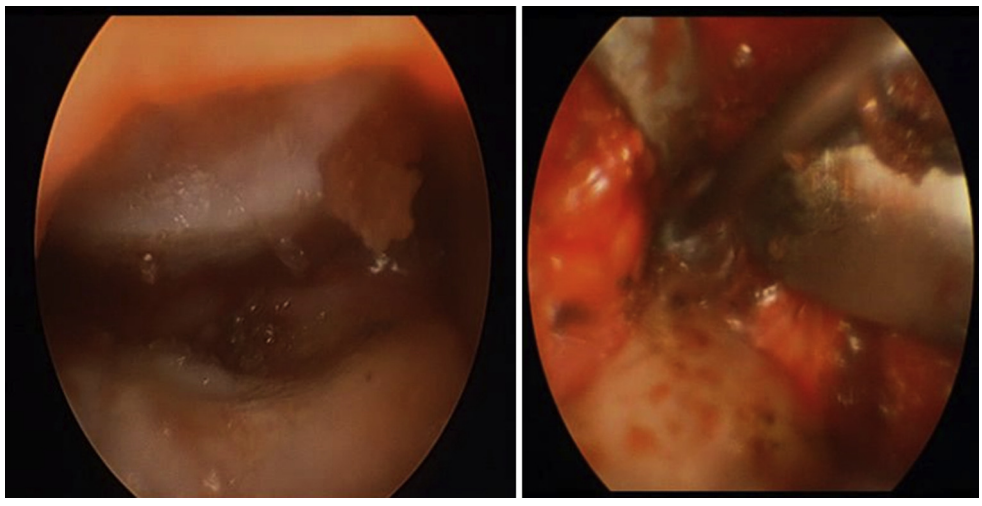

Figure 3. Cartilages of atlantoaxial joints were visible under endoscopy (left), which was widely destroyed by a high-speed microburr (right).

least 30 seconds after retraction for 5 minutes to decrease postoperative C2 nerve root irritation. When the atlantoaxial joints were exposed (Figure 3, left), the posterior part of the joint capsule could be incised and a probe could be inserted into the joint space to verify the trajectory of the joint space and facilitate placement of the bone graft into the atlantoaxial joint. When considering that all patients had basilar invagination with occipitalization of the atlas, the pedicle medullary cavity is dysplastic. It is really risky to perform the C1 fixation. Thus in our cases series, the occipitocervical fixation was completed at the occipital and C2 except C1. According to the technique of C2 pedicle screw placement described by Harms and Melcher,[8] bilateral C2 pedicle screws (titanium alloy screws, Fule, Beijing, China) were placed under fluoroscopy guidance. Next, the prepared bended rods and screws (Fule) were implanted to immobilize the harnpan and C2 for occipitocervical fusion. When anatomic reduction was confirmed by fluoroscopy, the joint cartilage was widely destroyed by a high-speed microburr (see Figure 3, right) and the cancellous bone particles harvested from the posterior superior iliac crest were trimmed into granular bones of about 2 mm and then punched into the bilateral atlantoaxial joint space along the previously defined trajectory only in the hybrid fusion group. The decortication of the harnpan and C2 vertebral lamina was performed by a high-speed burr. Incisions were thoroughly irrigated, and a piece of autogenous iliac corticocancellous bone with a dovetail shape was placed to cover the space in both groups, which were appropriately fixed by pressure and covered by a gelatin sponge. No additional implantations or adjuncts (demineralized bone matrix or bone morphogenetic protein) were applied in our patients. After meticulous hemostasis, a drainage tube was placed and the incision was closed.

Postoperative Management and Follow-up

Intraoperative complications including rupture of the vertebral artery and spinal cord injury were recorded. In addition, postoperative complications, such as infection, numbness in the posterior occipital region, failure of the internal fixation, nonunion, and pseudoarthrosis, were also recorded. Patients were recommended to engage in off-bed activities 2 days after surgery and to wear a collar for 2 weeks. Cervical computed tomography and magnetic resonance imaging (MRI) were performed during follow-up (see Figure 1, B–E and 2, right). The follow-up time and situation of bone graft fusion were recorded simultaneously. The fusion criteria of bone graft was in accordance with the Eck fusion classification standard.[9] The bony defect was entirely connected by the bone bridge with satisfactory remodeling. Two senior spine surgeons who did not participate in the surgery were selected as the evaluators. The result of bone graft fusion was evaluated according to the results of discussion between the 2 groups.

Statistical Analysis

Independent sample Student's t-tests were used to compare the parameters between the 2 groups. $P < 0.05$ was considered statistically significant. Statistical analyses were conducted using SPSS version 19 (IBM Corp., Armonk, New York, USA).

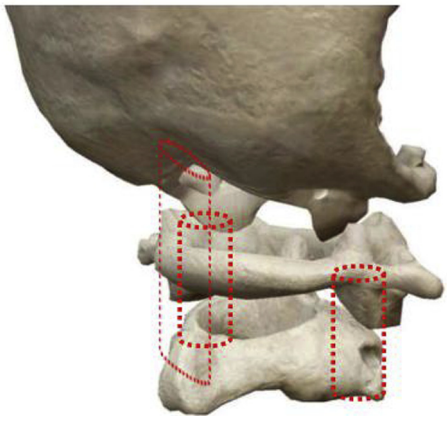

Figure 4. "Three-column structures" in the occipitocervical region consisted of the posterior bone graft between the harnpan and C2 vertebral lamina and bilateral atlantoaxial joint.

RESULTS

Operations were completed successfully in all patients without intraoperative complications, such as vertebral artery or spinal cord injury. Among 3 patients with nonunion, 2 had implantation-related complications including 1 case of screw loosening and 1 case of broken rod, which belonged to the control group (8.3%). They received a revision surgery and obtained a satisfactory fusion after 9 months. The patient of nonunion without internal failure refused the revision surgery. At the follow-up of 2 years postoperatively, he was satisfied with the treatment effect and lost the further follow-up. Three patients (12.5%) complained of transient numbness in the posterior occipital region, 2 patients in the hybrid group and 1 patient in the control group. The symptom was attributed to the C2 nerve root irritation, which was gradually relieved after the oral administration of mecobalamine and celecoxib. No wound infection was observed during follow-up. Compared with the blood loss of 210 ± 35 mL in the control group, the blood loss in the hybrid group was 325 ± 55 mL, with a statistically significant difference ($P = 0.038$). The operation time in the control group was 155 ± 33 minutes, and that in the hybrid group was 182 ± 41 minutes, in which a statistically significant difference was found ($P = 0.045$). On follow-up, 24 patients (100%) in the hybrid group achieved bone fusion in the occipitalcervical bone graft, but it was only 87.5% (21 patients) in the control group. The mean time of fusion in the control group was 6.1 months, and that in the hybrid group was 5.5 months. There was no statistically significant difference between the 2 groups ($P = 0.757$). In addition, in the hybrid group, the fusion time of the atlantoaxial joint was 5.1 months, which was faster than that in the posterior occipitocervical region (5.5 months); no statistically significant difference was found ($P = 0.823$).

DISCUSSION

In the occipitocervical fusion, internal fixation is conducive to restore the stability of the upper cervical region immediately after

the operation and bone graft fusion is considered to provide long-term maintenance of stability. As the pioneer, Cone[10] first reported the occipitocervical fusion surgery in 1937, in which the autogenous iliac bone graft was fixed with wire bundling. However, this method could increase the iatrogenic injury to the spinal cord. Abumi et al[11] mentioned that iliac bone graft with fixation by wire bundling could induce damage to the spinal cord and vertebral artery and paraspinal venous plexus, and it is likely to cause lamina fracture in older patients with osteoporosis. Most importantly, the wire bundling technique is limited against rotation and horizontal force. Patients were required to wear a brace for a long time. Even so, the nonfusion rate is as high as 3%–25%. Although numerous authors modified the fixation techniques to compress the bone graft to increase the bony fusion rate, all studies were limited by the small number of cases, unsatisfactory fusion rate, or increasing the economic burden due to additional placement of implant.[1]

Adequate bone grafting material, thorough preparation of the bone graft bed, and firm fixation are bases for successful bone grafting.[12] We speculate the reasons why the occipitocervical fusion rate was higher in the hybrid group than in the control group based on the following aspects: Autologous bone has been proven to have good histocompatibility and show osteogenic (osteoblasts and mesenchymal stem cells promote new bone formation), osteoinductive (bone morphogenetic protein recruitment and induction of osteoblast activity), and osteoconductive (providing a bone cell growth scaffold structure) properties.[13] Compared with allogeneic bone graft, autogenous bone graft has better bony fusion and infection rate in animal experiments or human studies.[14] Moreover, allogeneic bone graft has a higher incidence of immune rejection and inflammatory reactions, which reduced vascularization and impeded the process of bone fusion.[15] Niu et al[16] performed a prospective controlled study of 43 cases of lumbar spine fusion. After 24.6 months of follow-up, autologous iliac bone graft was found to have a higher fusion rate than artificial bone ($P < 0.05$). These indicate that autologous bone graft has excellent osteoinductive and osteoconductive properties and is safer and faster than allogeneic bone fusion. Our previous study has found that allograft is not reliable for posterior atlantoaxial fusion even with the rigid internal fixation, and autograft remains the first choice.[17]

In the hybrid group, we additionally packed some granular cancellous bone into the bilateral atlantoaxial joint space. According to relevant literatures,[16,18,19] cancellous bone contained more osteoinductive factors than cortical bone and cell activity was better because osteoprogenitor cells formed more blood vessels to promote bone conduction and osteogenesis. Wolff's law has elaborated that bony graft could be easily fused and reconstructed with stress stimulation.[20] When patients were kept in a sitting or upright position, the mechanical force could generate stress on the bilateral atlantoaxial joint and posterior bone graft. Moreover, the bony bridge distance in the atlantoaxial joint fusion was shortened compared with that in the posterior occipitocervical fusion. Theoretically, when considering stress stimulation and bony bridge distance, atlantoaxial joint fusion was more likely to fuse than posterior occipitocervical fusion. We believed that there are "3 column structures" in the occipitocervical fusion (**Figure 4**), which consisted of the posterior bone graft between the harnpan and C2 vertebral lamina and bilateral atlantoaxial joint. When the bone graft was placed in these 3 structures, instant support of the bone graft and bony fusion process in the bilateral atlantoaxial joint could be improved for local stability and promote fusion of the posterior bone graft.

This conjecture is also consistent with our conclusion. The fusion rate of the posterior bone graft was 100% in the hybrid group, which was higher than that in the control group (87.5%). Although the difference is not significant, the average bone graft healing time of the atlantoaxial joint (5.1 months) was faster than that in the posterior occipitocervical region (5.5 months). Interestingly, in the hybrid group, besides the satisfactory fusion rate in the posterior occipitocervical region, all bone grafts in the bilateral atlantoaxial joint were fused. Whether only bone grafting in the atlantoaxial joint is sufficient for occipitocervical fusion in these cases could be explored in further study.

Limitation

Because the study is a nonrandomized, retrospective study, the reliability of the conclusion could be limited. Assuming it was nonrandom, there is a concern for selection bias given that all operations were performed by a single surgeon. A slightly high rate of loss of follow-up was another limitation. Although the number of patients is small, considering that the incidence of the disease itself was low and the cases that meet the inclusion criteria are relatively low, our patient sample is the largest to date. To compare the speed of these 2 groups, the follow-up interval was 1 month until the bone graft was fused. However, as the study is retrospective, some patients had inconsistent follow-up intervals. For additional bone graft at the atlantoaxial joint, it undoubtedly increased the surgical duration and blood loss, while surgical duration and blood loss were controlled with established surgical technique. During the process of packing bone graft into the atlantoaxial joint, medial or lateral bone graft migration could induce spinal cord or vertebral artery injury. However, the bilateral joint capsule was kept during the exposure of the joint space, which, together with the bilateral narrow joint space, could limit the bone graft migration. Moreover, when the cartilage was thoroughly removed, the bone graft could only play the role of bridging the joint space without abundant bone graft. C2 nerve root irritation is another postoperative complication. Three patients complained of transient numbness in the posterior occipital region, which belonged to the early 3 cases and was relieved after conservative management. We speculate that it was only related to the overretraction during the pedicle placement and the exposure of atlantoaxial joint. The following cases were not encountered. We speculated that we released the C2 nerve root at least 30 seconds after retraction for 5 minutes during the operation.

CONCLUSION

Additional bone grafting of the atlantoaxial joint could increase the bone fusion rate of the iliac crest autograft for posterior occipitocervical fusion. It is a good choice for occipitocervical fusion for patients with basilar invagination accompanied with occipitalization of the atlas.

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