Morphological adaptation of the bone graft and fused bodies after non-instrumented anterior interbody fusion of the lower cervical spine

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ABSTRACT

Purpose. To assess the remodelling process of the bone graft and fused bodies after non-instrumented anterior interbody fusion with autogenous iliac graft in patients with spondylosis, infections, fractures, or disorders of the cervical spine.

Methods. 68 patients aged 18 to 58 years who underwent non-plated anterior lower cervical interbody fusion with an iliac graft were retrospectively studied. Diagnoses of the patients were degenerative disc diseases (n=32), disc herniation (n=15), fractures (n=13), and tuberculosis (n=8). The Robinson and Smith technique was used to treat degenerative disc diseases and protruded disc, and the Bailey and Badgley procedure for fractures or tuberculosis of the cervical spine. 34, 25, and 9 patients underwent one-, 2-, and 3-segment fusions, respectively. 18 of the 25 patients underwent two-segment fusion with a single large bone block, and 7 with 2 separate bone blocks for each segment. Four of the 9 patients underwent three-segment fusion with a single large bone block, and 5 used separate grafts for each segment independently. Plain and stress radiography was primarily used to assess the fusion. Computed tomography and magnetic resonance imaging were also used in some patients. Some anterior graft extrusion (amounting to less than 10% of corresponding anteroposterior body width) was used to observe the remodelling during graft-take and thereafter. Postoperative cervical traction for 2 to 4 weeks, then cervical collar immobilisation for 4 to 12 weeks were strictly followed according to the numbers of fused segments. A halo vest was applied in 4 patients with fracture undergoing 3-segment fusion as they could not tolerate the prolonged bed rest or rigid cervical brace.

Results. The mean time for the graft to fuse was 8.6 (range, 7–14) weeks in patients who underwent each
segment fusion with independent free grafts, and 10 and 14 weeks in those who underwent 2- and 3-segment single large graft fusion, respectively. The final loss of disc height and joint angle were negligible, regardless of the extent of fusion. Bony absorption of the anteriorly protruded part of the graft began at postoperative week 10 (range, 6–28), which coincided with the time of graft-take and initiation of remodelling.

**Conclusion.** The earliest sign of bony absorption of the anteriorly protruded part of the graft indicated the initiation of the graft-take and the graft remodelling. The inwaisting sign of the surgically fused block of vertebral bodies was a morphological adaptation. Despite the altered biomechanics of the spine in the fused area, the inwaisting sign indicated maintenance of normal function at the parafusion motion segments.

**Key words** bone remodeling; cervical vertebrae; spinal fusion; transplants

**INTRODUCTION**

Among studies on the radiological measurements of spines, only one reported on developmental vertebral morphology in quadrupedal animals, healthy humans, and patients with severe tuberculous kyphosis. In quadrupedal animals, vertebral height is taller than the width, whereas in adults with severe tuberculous kyphosis since childhood, vertebrae near the gibbus area are taller than their width (as in quadrupeds). Inwaisting of the vertebral bodies in humans starts to develop at the age of 2 years. In ankylosing spondylitis, vertebral bodies are squared without inwaisting, because of the lack of vertebral motion.

Several methods (using clinical parameters and various types of imaging) have been used to assess bone union after anterior cervical fusion without a plate. However, there is no report on graft behaviour and morphological adaptation of the surgically fused vertebral body mass resulting from the altered biomechanics. Unless radiographs are taken every week, it is difficult to define the exact time for fusion by plain radiography alone. For more accurate assessment, computed tomography and magnetic resonance imaging are used, in conjunction with serial plain radiographs (including stress views).

We aimed to assess the morphological adaptation of the bone grafts and the fused vertebral bodies after non-instrumented anterior cervical fusion, using plain radiography at regular intervals.

**MATERIALS AND METHODS**

68 patients aged 18 to 58 years who underwent non-plate anterior lower cervical interbody fusion with an iliac graft were retrospectively studied. 32 were diagnosed as having degenerative disc diseases. The remainder had disc herniations (n=15), fractures (n=13), and tuberculosis (n=8). Two different types of iliac graft anterior interbody fusion were carried out: the Robinson and Smith technique for degenerative disc diseases and herniated discs, and the Baily and Badgley procedure for fractured or tuberculosis cervical spines. One-segment fusion was performed in 34 patients, 2-segment in 25, and 3-segment in 9. Four of the 9 patients who underwent 3-segment fusion fractured their cervical spines. During insertion of the iliac graft into the excised disk space, in most cases the round smooth cortical edge of the iliac cortex was placed posteriorly and the rough cancellous edge was placed anteriorly, because it was anticipated that the slightly extruded cancellous bone edge would be more easily remodelled than the cortical edge. Some anterior graft extrusion, less than 10% of the anteroposterior vertebral body width, was utilised to observe remodelling of the extruded portion during graft-take. When graft stability in one-segment fusion was confirmed, patients were instructed to mobilise in bed with a cervical brace for 2 weeks. In 2- and 3-segment fusions, regardless of the graft stability, cervical traction in bed for 2 to 4 weeks and then a rigid 4 pillar cervical brace were prescribed for additional 4 to 12 weeks. Many fractures were applied to 4 fracture patients with 3-segment fusion, who could not tolerate the prolonged bed rest or rigid cervical brace.

Blinded assessment was performed by 2 observers to minimise observer bias. Each patient’s graft position, graft height, joint angle, spinous process distance, fusion time, adaptive changes of bone graft and fused vertebral bodies (corporal inwaisting) were measured on serial radiographs, taken every 2 weeks up to 6 weeks, subsequently every week up to 14 weeks, and then once every month. The graft height was measured using a Mitsutoyo precision gauge, and the joint angle using Cobb’s method. Fusion was defined by the maintenance of the initial graft position and graft height, smoothening or thinning of the anterior surface of the graft, no halo in the upper and lower graft beds, gradual disappearance of the contact lines of the graft-graft beds, no graft motion on flexion-extension lateral views at and after postoperative week 8, and Cobb’s angle change. Remodelling processes of the bone graft and the fused vertebral bodies were the primary outcome measures; fusion
rate was not the focus of this study.

**Definition of inwaisting of the fused vertebrae**

A line is drawn along the upper and lower anterior margins of the fused vertebrae on lateral radiographs. The anterior border of the iliac graft and both anterior end-plate margins of the fused vertebral segment were located on or outside the line at the time of fusion. The anteriorly protruded border of the graft and the fused convex vertebral segment gradually being absorbed after graft-take and becoming located inside the concave line, was taken to suggest ongoing of the inwaisting process of the fused vertebra. The inwaisting process is self-limiting and it stops when the fused vertebra is completely vascularised and remodelled.

**RESULTS**

Among the 25 patients with 2-segment fusion, 18 were fused with one bone block and 7 with separate bone blocks, which matched the corresponding disc height of each segment. In 4 of the 9 cases involving 3-segment fusion, a large graft was used. Separate grafts for each segment were used independently in the other 5 cases.

Spontaneous bony absorption of the anteriorly protruded graft and the thinning of the anteriorly placed iliac graft cortex began from postoperative week 6 to 11. In cases of segment fusion (each with independent grafts regardless of the numbers of fusion segments), the mean fusion time was 8.6 (range, 7–14) weeks. In 2- and 3-segment fusion with a single large grafts, the mean times to fusion were 10 and 14 weeks, respectively.

In patients with one-segment fusion, the mean loss of disc height during graft-take was 1.4 mm, and the mean changes of the joint angle (kyphosis) measured by Cobb’s method was 1.2° (in successful fusion). In patients with 2- and 3-segment fusion involving a single large graft, restoration of normal cervical lordosis was less than that with segments fused with separate grafts. The mean changes in joint angle during graft-take were 1.8° in 2-segment and 2.8° in 3-segment fusions.

The earliest evidence of vertebral inwaisting in the fused vertebral bodies was observed at a mean of postoperative week 10 (range, 6–28). This observation coincided with the onset of fusion, as indicated by no further changes in disc height, interspinous process distance, and joint angle. In patients with 2-segment fusion with a large graft, the total collapse of the latter was less than that ensuing in individuals having segment fusion with 2 free independent grafts. Moreover, the corporal inwaisting sign was observed earlier in the former procedure.

There were minimal shape differences of the fused vertebral body masses after complete remodelling, in spite of the differences in their sagittal alignment. In patients with 3-segment fusion, the fused block spine resembled a long bone with metaphyseal flaring due to the inwaisting process.

**CASE SERIES**

**Case 1**

A 52-year-old man developed incomplete spastic Pott’s paraplegia 2 months earlier. Preoperative anteroposterior and lateral radiographs showed a destructive tuberculous lesion at C5–C6. Radiographs taken immediately after surgery revealed an anteriorly protruded iliac bone graft placed between C5–C6 with regained disc height. Radiographs taken 2 years and 6 months after surgery showed a single solidly fused inwaisted C5–C6 block body mass (Fig. 1).

**Case 2**

A 20-year-old man underwent anterior interbody fu-
sion with a huge iliac graft for a C5 burst fracture; a tricortical iliac graft with thick cortex was used to achieve C4–C6 fusion. There was no graft slip or crumbling. Gradual thinning of the thick cortical bone of the iliac graft is seen with gradual inwaisting of the mid part of the fused block C4–C6.

Case 3

A 32-year-old man sustained a burst fracture of C5 with dislocation and was initially treated by skull traction and subsequent anterior interbody fusion of C4–C6. From postoperative week 8, gradual absorption of the anteriorly protruded graft and subsequent inwaisting were observed, indicating solidified incorporation of the graft to the beds (Fig. 3).

Case 4

A 49-year-old man with C5–C7 spondylosis had a 2-segment decompression and fusion with a separate bone graft, and was followed up for 5 years. Gradual inwaisting was visible from postoperative week 6 together with stabilisation of the fused segments. At postoperative week 12, the anteriorly protruded bone graft was completely absorbed without crumbling and/or changes of joint angle. The cervical sagittal curve was well maintained and no adjacent joint problem was seen on the 5-year follow-up radiographs (Fig. 4).

Case 5

A 29-year-old man gradually developed a spastic quadripareisis due to neurofibromatosis. Tumour excision through an extensive laminectomy from C2–C5 was carried out. Postoperatively, gradual swan-neck deformity developed with worsening of neck and shoulder pain. Eight months after laminectomy, anterior fusion with some correction of the kyphotic...
deformity of each segment separately (from C2 to C5) was performed with an iliac graft. The patient was kept in bed under head-halter traction for 6 weeks, and allowed to sit up with a rigid cervical brace for the next 8 weeks. The long bone appearance of the fused block C2–C5 mass with inwaisting sign became evident one year and 3 months later. The functional result was excellent and there was no neurological deficit (Fig. 5).

DISCUSSION

Following the advent of 3 different types of non-instrumented anterior cervical fusion constructs for the management of various spinal diseases, many investigators have studied the patterns and rates of vertebral body fusion. However, no study dealt with the morphological adaptation of the graft and the fused lower cervical vertebral bodies, secondary to the altered biomechanics.

We have tried to explain the remodelling process of the fused bodies in terms of adaptive biological laws. The architecture of bone is determined by intrinsic and extrinsic factors. Intrinsic factors are hereditary and the most fundamental model of bone architecture. Heredity determines the shape, size, and location of bones. Biomechanics also plays an important role during the postnatal period, although Steindler insists that mechanical power modifies only to a limited extent.

Plain radiographs taken at 4 to 6 weeks intervals have been widely used for clinical assessment and/or evaluation of the time and state of fusion after non-instrumented anterior cervical interbody fusion. However, long intervals may result in inaccuracy in assessing the fusion time. To confirm corporal fusion, others have reported chronological changes of graft size and joint angle together with change of graft position and shape on radiographs. To assess the fusion time more accurately, in our series, plain anteroposterior and neutral lateral radiographs were taken more frequently. Initially at 2-week intervals up to 6 weeks, then plain neutral, flexion, and extension lateral radiographs were taken once every week up to 14 weeks, and then once every month.

It is important to confirm graft incorporation to
the graft bed in the assessment of the fusion consolidation process. Whenever the bone graft is not positioned stably into its graft bed, it may fail to incorporate and therefore gradually disappear. When the graft is stably seated into the graft beds, it becomes a mechanically functioning part of the host bone. There are 4 overlapping healing phases: the regional accelerating phenomenon (trauma of the grafting procedure to the host beds), incorporation, replacement, and modelling. These processes usually take longer in larger grafts.

In the current series, there were no significant differences in the patterns and rates of fusion between the 2 different fusion constructs; graft collapse and/or sinking before establishment of fusion were minimal, particularly in patients with fracture and tuberculosis. Stable graft positioning and initial postoperative bed rest, followed by subsequent external cervical immobilisation with a brace guaranteed the fusion in an anatomical position without crumbling. This ensued regardless of the extent of fusion segment and differences in the grafting technique. Absorption of the anteriorly protruded part of the graft began at a mean of postoperative week 9, indicating early graft incorporation into the graft beds that ultimately leads to successful fusion. No sign of absorption of the anterior border of the graft was evident at postoperative week 8 to 10, suggesting that the graft had not yet taken.

It is reported that graft bone remodelling takes place in early and late stages. Remodelling starts at the time of graft-take (in the early stage), and the real internal structural remodelling of the fused vertebrae and graft bone as a block vertebra starts when the graft bone is fully incorporated and vascularised with its vertebral bed in the late stage. However, absorption of the extruded anterior rough cancellous border or cortical thinning of the iliac graft suggests that the graft-take starts as early as post-graft week 6 to 15.

The stabilising signs of the fused segment, the appearance of graft remodelling and the fused bodies all indicate the onset of fusion and absorption of bony spurs.

Time of fusion used to be assessed collectively by the relation of the graft bed to the graft, the graft position and the changes of disc height and joint angle. In the present study, attention was not paid to changes of the graft shape (cortical thickness change and/or absorption of the anteriorly extruded portion of the stably positioned, uncrumbled graft). Nor did the study address anterior and posterior bony spurs of the fused segment, and any morphological changes of the fused bodies.

Assuming that the fused block of vertebrae is rectangular at the time of fusion, the middle part of the block becomes gradually narrower than its upper and lower portions, due to a remodelling process. This phenomenon is known as ‘inwaisting’. As a result of global lamellar bone remodelling by drifts, the anteriorly protruded portion of the graft begins to be absorbed gradually soon after graft-take. The absorption of the anterior graft surface (graft cortex thinning phenomenon) is the earliest sign of vertebral inwaisting affecting the fused vertebral bodies. The ‘inwaisting phenomenon’ indicates that the graft has taken and is incorporated solidly into its graft bed. Thus, multiple fused vertebral bodies begin to serve as a single body, which gradually shows the morphological changes due to the locally altered biomechanics. This process is explained by Wolff’s law and by Heuter-Volkmann’s and Frost’s flexure drift laws. For example, gradual loss of motion at each segment of the spinal column in ankylosing spondylitis develops the squaring of the vertebral bodies, which is explained by the flexure drift law. According to Moon and Kim, vertebral body inwaisting is known to develop after the age of 2 years in humans (coincident with the act of standing). This is consistent with Frost’s flexure drift law applied to normal functional unit motion.

Adult patients with severe tuberculous kyphosis since childhood display taller vertebral bodies with narrow width because of altered biomechanics, there being less axial load and less lateral motion at the unaffected upper and lower spines of the kyphotic area. In these areas, the vertebral inwaisting is rarely seen.

More accurate assessment of the fusion time could be attained by more frequent radiological examinations of the graft bone and changes in graft beds, interspinous process distance, and the angle of the fused motion segment. Additionally the absorption process of the anteriorly protruded part of the graft, changes of the cortical thickness of the grafted bone and/or gradual absorption of the bony spurs at the fusion site may be more accurate and earlier indicators of the time to fusion. In patients with multi-level anterior interbody fusion, the fused bodies gradually show long bone appearance with the inwaisting sign, regardless of the type of fusion. The different morphologies of the fused vertebral bodies reflect the altered biomechanics in the fused cervical spine, which functions as single vertebral body through gradual adaptive changes.

CONCLUSION

Postoperative maintenance of the graft height, graft
beds, and joint angle, coupled with gradual absorption of the anteriorly protruded graft margin and bony spurs are the most important indicators of the earliest phase of bony fusion. The vertebral inwaisting of the surgically fused anterior cervical column indicates maintenance of the normal function at the parafusion motion segments, which ensues despite altered biomechanics after surgery.

REFERENCES