Local harvest bone graft volume measured by 3 dimensional reconstructed CT in posterior lumbar interbody fusion

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Local harvest bone graft volume measured by 3 dimensional reconstructed CT in posterior lumbar interbody fusion

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Finally, I am enormously grateful to my patients.

<TABLE OF CONTENTS>

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Local harvest bone graft volume measured by 3 dimensional reconstructed CT in posterior lumbar interbody fusion

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Posterior lumbar interbody fusion (PLIF) has been widely performed to treat the various degenerative lumbar spinal diseases. Although the autogenous iliac bone graft remained the golden standard, many complications have been reported in many literatures. The autogenous local bone obtained at decompression site would be also good bone graft source with less complications. Recently, the instrumented posterolateral lumbar fusion (PLF) and PLIF with local bone graft alone reported excellent fusion rate. In previous studies, the number of patients was small and the amount of decompression and the reported local bone graft volume varied considerably in different surgeons. The purpose of this study is to evaluate the local bone graft volume during decompression and the volume of bone graft recipient site, disc space with 3D-reconstructed CT, and simulation program. Twenty male and twenty female patients between 21 to 40 years old, 41 to 60 years old, and 61 to 80 years old were enrolled in this study, respectively. The average local bone graft volume in one, two, and three level-decompression is 13.2 cc, 22.9 cc, and 29.8 cc, respectively. The average disc space volume at L3-L4, L4-L5, and L5-S1 is 9.9 cc, 10.1 cc, and 9.7 cc. Bone loss during decompression and preparation and

impaction into disc space could decrease volume of bone graft. The use of interbody cages which occupied disc space has been frequent, the actual needed bone graft volume would be decreased. The thorough disc preparation was impossible. Because local bone graft had less cancellous portion than autogenous iliac bone, impaction would not be expected too much. Bone packing dorsal to interbody cage or around nerve root was seldom done. The amount of local bone graft without any bone substitutes was sufficient to fill disc spaces in 1- and 2-level PLIF. As local bone graft volume could not be 2 times or 3 times as disc space volume due to overlapped area of decompression, the amount of local bone graft was not enough in 3-level PLIF. This study presented the evidence that the amount of local bone graft was sufficient without expensive bone substitutes in 1- and 2-level PLIF.

Key words : local bone graft, posterior lumbar interbody fusion, 3 dimensional CT

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Ⅰ. Introduction

Posterior lumbar interbody fusion (PLIF) has been widely used to treat the various lumbar spinal diseases.[1-13] PLIF has been introduced for the management of ruptured lumbar intervertebral discs since mid-1940' by Cloward RB.[1,2] At that time, autogenous iliac bone plugs were inserted into the disc space following discectomy to obtain spinal fusion.[1,2] Even though the spinal instruments and surgical techniques have been evolved, appropriate bone graft materials play an important role to achieve good clinical outcomes.[3-18]

Although the autogenous iliac bone graft remained the golden standard, many complications such as donor site morbidity, longer operation time and increased estimated blood loss have been reported in many literatures.[14-20] The autogenous local bone obtained at decompression site would be also good bone graft source with less complications.[3-15] Recently, the instrumented posterolateral lumbar fusion (PLF) and PLIF with local bone graft alone reported fusion rate in single level was more than 93 %.[3-8] However, the number of patients was small and the amount of decompression and the reported local bone graft volume varied considerably.[3-13]

Several studies regarding bone graft volume measured by 3D-reconstructed preoperative CT in oromaxillary surgery showed there was no significant difference between bone graft volume measured in operative field and measured using 3D-reconstructed CT preoperativley.[21-23] Furthermore, 3D-reconstructed CT and simulation program enabled more exact preoperative planning, evaluation and feasibility test in spine surgery.[24,25]

The purpose of this study is to evaluate the local bone graft volume during decompression and the volume of bone graft recipient site, disc space with 3D-reconstructed CT, and simulation program.

Ⅱ. Materials and methods

This study was approved by institutional review board.

1. Inclusion and exclusion criteria

From July 2014 to June 2015, consecutive 313 patients who performed lumbar spine CT because of spinal disease were evaluated. Exclusion criteria included 1) skeletally immature patient under twenty, 2) previous history of spine surgery, infection and fracture, and 3) congenital anomaly. Among these patients, 20 male and 20 female patients between 21 to 40 years old, 41 to 60 years old, and 61 to 80 years old were enrolled, respectively.

2. 3D Reconstruction and simulation program

The axial images of 1-mm thickness CT scan (Philips IDT 16^{TM}, Philips Medical System, Best, Netherlands) were exported and converted to DICOM (Digital Imaging and Communication in Medicine) file. The 3D image was reconstructed by 3D simulation software (V Works^{TM}, Cybermed Inc., Reston, VA, USA) (Figure 1.). The volume of interested area were measured by summation of marked interested area on 1-mm thickness axial image.

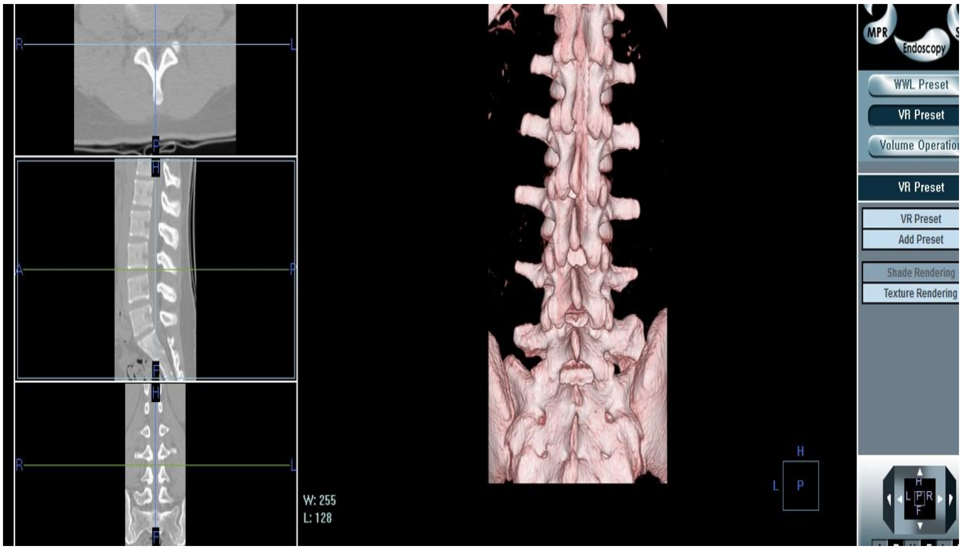

Figure 1. The 3D image of L-spine CT was reconstructed by 3D simulation software (V Works^{TM}, Cybermed Inc., Reston, USA).

3. Local bone graft volume

The virtual decompression surgery was done on 3D reconstructed image. The bilateral partial laminectomy and medial 1/3 facetectomy were virtually undertaken to preserve biomechanical stability by saving lateral half of facet joints and associated pars interarticularis (Figure 2.). The volume of part of cephalad and caudal spinous processes, laminae, facet joints and osteophytes were measured. The local bone graft volume obtained by decompression at the level of L3-L4, L4-L5, L5-S1, L3-L4-L5, L4-L5-S1 and L3-L4-L5-S1 was calculated, respectively.

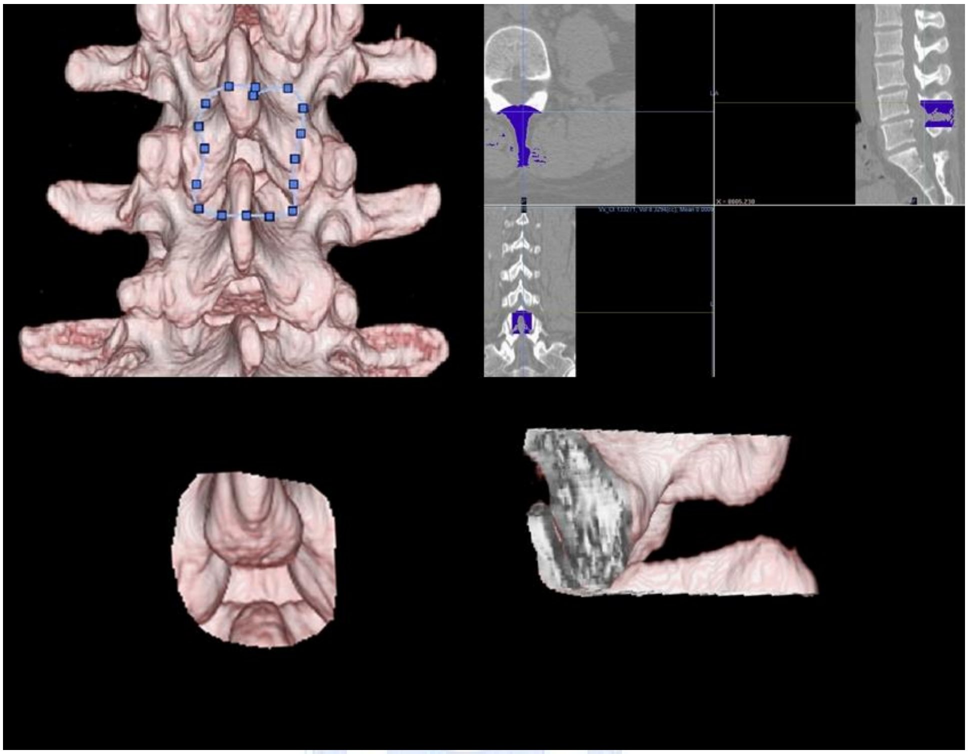

Figure 2. A 62-year-old female patient underwent virtual decompression of L3-L4 level on 3D reconstructed image. The local bone graft volume obtained at L3-L4 was 9.9 cc.

4. Disc space volume

The volume between inferior endplate of cephalad vertebral body and superior endplate of caudal endplate was measured on 3D reconstructed image (Figure 3.). The disc space volume at L3-L4, L4-5 and L5-S1 was measured, respectively.

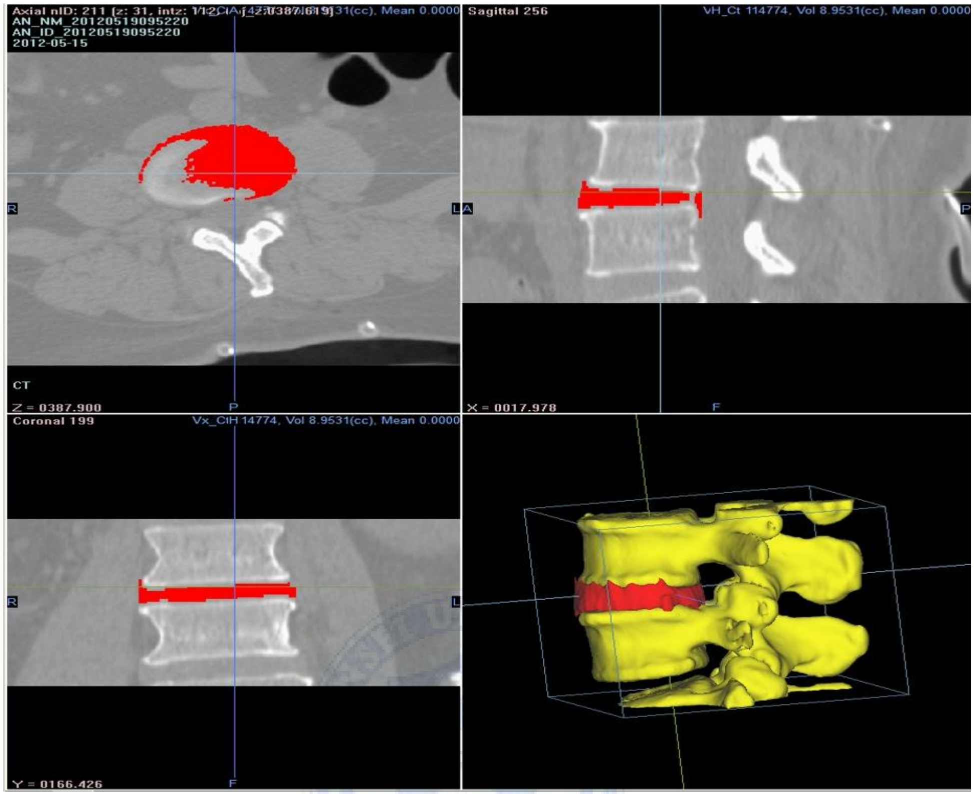

Figure 3. A disc space of 43-year-old female was shown on 3D reconstructed image. The disc space volume of L4-L5 was 8.95 cc, approximately.

Ⅲ. Results

1. Demographic data

The average height, weight and body mass index of enrolled patients were shown in Table 1.

Table 1. Demographic data

	Male	Female	Average
21~40 Years old	n=20	n=20	n=40
Height(㎝)	174.8	158.4	166.6
Weight(㎏)	69.7	55.1	62.4
Body Mass Index(kg/㎡)	25.9	21.5	23.7
41~60 Years old	n=20	n=20	n=40
Height(㎝)	171.1	152.7	161.9
Weight(㎏)	78.4	60.8	69.6
Body Mass Index(kg/㎡)	27.1	23.1	25.1
61~80 Years old	n=20	n=20	n=40
Height(㎝)	168.8	150.2	159.5
Weight(㎏)	61.7	56.3	59
Body Mass Index(kg/㎡)	24.3	22.7	23.5
Total	n=60	n=60	n=120
Height(㎝)	171.6	153.8	162.7
Weight(㎏)	69.9	57.4	62.2
Body Mass Index(kg/㎡)	25.8	22.4	24.1

2. *Local bone graft volume*

The average local bone graft volume of male and female patients obtained at L3-L4, L4-L5, L5-S1 (one level) decompression is 13.7 cc, 14.9 cc, 13.4 cc and 12.7 cc, 12.9 cc, 11.9 cc, respectively. The average local bone graft volume of male and female patients obtained at L3-L4-L5, L4-L5-S1 (two level) decompression is 25.8 cc, 24.0 cc and 21.6 cc, 20.3 cc, respectively. The average local bone graft volume of male and female patients at L3-L4-L5-S1 (three level) decompression is 30.7 cc and 28.9 cc, respectively. The average local bone graft volume in one, two, and three level-decompression is 13.2 cc, 22.9 cc, and 29.8 cc, respectively (Table 2).

Table 2. The average local bone graft volume

	Male	Female	Average
21~40 Years old	n=20	n=20	n=40
L3-L4	13.9 cc	12.1 cc	13.0 cc
L4-L5	14.1 cc	11.9 cc	13.0 cc
L5-S1	12.8 cc	11.2 cc	12.0 cc
L3-L4-L5	24.5 cc	21.4 cc	22.9 cc
L4-L5-S1	22.3 cc	19.9 cc	21.2 cc
L3-L4-L5-S1	29.8 cc	28.7 cc	29.2 cc
41~60 Years old	n=20	n=20	n=40
L3-L4	13.5 cc	13.6 cc	13.5 cc
L4-L5	15.3 cc	12.9 cc	14.1 cc
L5-S1	14.7 cc	12.7 cc	13.7 cc
L3-L4-L5	26.7 cc	21.3 cc	24.0 cc
L4-L5-S1	25.9 cc	20.9 cc	23.4 cc
L3-L4-L5-S1	30.8 cc	28.1 cc	29.4 cc
61~80 Years old	n=20	n=20	n=40
L3-L4	13.7 cc	12.5 cc	13.1 cc
L4-L5	15.2 cc	13.8 cc	14.5 cc
L5-S1	12.6 cc	11.8 cc	12.2 cc
L3-L4-L5	26.1 cc	22.1 cc	24.1 cc
L4-L5-S1	23.9 cc	20.1 cc	22.0 cc
L3-L4-L5-S1	31.5 cc	29.9 cc	30.7 cc
Total	n=60	n=60	n=120
L3-L4	13.7 cc	12.7 cc	13.2 cc
L4-L5	14.9 cc	12.9 cc	13.9 cc
L5-S1	13.4 cc	11.9 cc	12.6 cc
L3-L4-L5	25.8 cc	21.6 cc	23.7 cc
L4-L5-S1	24.0 cc	20.3 cc	22.1 cc
L3-L4-L5-S1	30.7 cc	28.9 cc	29.8 cc

3. Disc space volume

The average disc space volume of male and female patients at L3-L4, L4-L5, L5-S1 is 10.2 cc, 10.6 cc, 10.1 cc and 9.7 cc, 9.7 cc, 9.3 cc, respectively (Table 3). The average disc space volume at L3-L4, L4-L5, and L5-S1 is 9.9 cc, 10.1 cc, and 9.7 cc.

Table 3. The average disc space volume

	Male	Female	Average
21~40 Years old	n=20	n=20	n=40
L3-L4	11.2 cc	10.9 cc	11.0 cc
L4-L5	11.5 cc	10.8 cc	11.1 cc
L5-S1	11.6 cc	10.2 cc	10.9 cc
41~60 Years old	n=20	n=20	n=40
L3-4	10.2 cc	9.4 cc	9.8 cc
L4-5	10.3 cc	9.4 cc	9.8 cc
L5-S1	9.8 cc	9.1 cc	9.4 cc
61~80 Years old	n=20	n=20	n=40
L3-L4	9.2 cc	8.8 cc	9.0 cc
L4-L5	9.9 cc	9.0 cc	9.4 cc
L5-S1	8.9 cc	8.7 cc	8.8 cc
Total	n=60	n=60	n=120
L3-L4	10.2 cc	9.7 cc	9.9 cc
L4-L5	10.6 cc	9.7 cc	10.1 cc
L5-S1	10.1 cc	9.3 cc	9.7 cc

IV. Discussion

The bone graft materials in spinal fusion include autograft, allograft, synthetic bone graft substitute, collagen-based matrices, demineralized bone matrix, bone morphogenic proteins (BMP) and autogenous growth factors. Even though autogenous bone graft has some advantage such as excellent fusion rate and no concern of disease transmission, autogenous iliac bone graft results in donor site morbidity and longer operation time.[3-13] An autogenous local bone obtained by decompression would be good source of bone graft material.[3-17] It is associated with shorter operation time and less morbidity compared to autogenous iliac bone graft.[14-20] Disadvantages of local bone graft include limited volume, bone loss during preparation, less composition of cancellous portion, cumbersome procedure of cleansing off soft tissue, and increased infection risk.[14-18] These problems have led to developing the bone graft substitute.[26-33] The heterotopic ossification, osteolysis, seroma, infection, arachnoiditis, increased neurologic deficits, retrograde ejaculation, and cancer have been reported as complications of BMP.[26-33] Unfortunately, industry-sponsored articles had possibility of underreporting adverse events of bone graft substitute and emphasizing complications of autograft simultaneously.[27,29-33] Some of industry-sponsored trials about serious adverse events or poor outcomes of bone graft substitute would not be published.[27,29,32] First and foremost, the high cost of bone substitute should be an enormous economic burden to patients and their family.

Some authors reported that local bone in one-level PLIF showed almost identical fusion rate with autogenous iliac bone graft.[4,8] Other studies showed fusion rate with local bone in one- and two-level PLF was similar to autogenous iliac bone graft.[3,5,11] However, previous studies have shortcomings. 1) The number of patients was so small. 2) Age and gender were not matched. 3) The amount of decompression and bone loss was so different due to surgeon's techniques. 4) The volume of local bone was varied widely according to authors.

3D reconstruction image and simulation programs presented noninvasive, repetitive and accurate preoperative plan or measurement.[21-25] In our study, we measured disc space volume composed of disc and adjacent endplate cartilages. In fact, the true volume needed for PLIF considering disc space preparation was not disc volume itself but disc space volume. Our study showed that the average disc space volume at L3-4, L4-5 and L5-S1 level was 9.9 cc, 10.1 cc, 9.7 cc, respectively. One of previous cadaveric studies revealed that disc volume at L3-4 and L4-5 level was 12.46 cc and 12.27 cc and other results showed also larger volume than ours.[34-36] We used 1-mm thickness CT and large number of age- and gender-matched population with lumbar spinal diseases, representing degenerative lumbar spine (narrow disc space). As previous cadaveric studies were based on 3~5mm CT or MRI by Cavalieri method, the accuracy was questionable and the number of cadaver was so small with wide range of standard deviation.[34-36]

To our knowledge, the minimum volume of bone graft in PLIF has not decided yet in clinical studies. Biomechanical study of Closkey et al demonstrated bone graft area covering more than 30% or more which was able to carry a load greater than 600 *N* in PLIF was recommended.[37] Carragee et al reported mean volume of local bone obtained by decompression in PLF was 25 cc (12-36 cc) in 25 patients.[10] Inage et al also reported mean volume in 1-level , 2-level, and 3-level PLF was 14.0 cc, 24.0 cc, and 31.0 cc, respectively. [3] They concluded local bone graft provided good clinical outcomes in 1- and 2-level PLF and poor results were expected because of insufficient amount of local bone in for 3-level PLF.[3] Their results of prospective study with a 2-year follow-up are very similar to our simulation study. Our results showed the average local bone graft volume in one, two, and three level-decompression was 13.2 cc, 22.9 cc, and 29.8 cc, respectively. As 2- or 3-level PLIF performed, disc space volume must be 2 times or 3 times. However, local bone graft volume could not be 2 times or 3 times as disc space volume due to overlapped area of decompression.

Even though 3D CT and simulation program using 1-mm thickness CT has been known reliable and validated, the real volume could be different from preoperative measurement.[21-25] 1) As peripheral disc remnant and disc material adjacent to anterior longitudinal ligament could not be removed thoroughly, actual needed volume of bone graft should be decreased. 2) In patients with severe foraminal stenosis, more facet decompression should be needed which produced more volume of local bone. 3) If smaller Kerrison rongeur or burr was used during decompression, more local bone loss was anticipated. 4) Bone loss during preparation of local bone and impaction of local bone packed into disc space could be possible. Because local bone has more cortical portion than autogenous iliac bone, impaction of local bone would not be expected too much. 5) If narrow disc space was distracted, more bone graft must be needed. 6) Bone packing dorsal to interbody cage or around nerve root was seldom done (Figure

4.). The volume of commercially manufactured unilateral interbody cage ranged from 1.3 cc to 3.6 cc. The internal volume of unilateral interbody cage ranged from 0.32 cc to 1.19 cc. 7) If two unilateral interbody cages used, the need for bone graft was increasingly decreased. For instance, if two 10 mm X 12 mm X 22 mm-sized cages were used (2.6 cc X 2), internal volume within interbody cage needed 0.5 cc (0.5 cc X 2). So, the actual cage-occupying volume within disc space was 4.2 cc. Even allowing for all angles of measurement errors, bone loss and impaction, the local bone graft volume with interbody cage was sufficient in 1- and 2-level PLIF.

Figure 4. This diagram showed entire disc space could not be prepared and filled with interbody cage and local bone graft.

As with any studies, our study has some limitations. 1) Race and diagnosis of our subjects were not considered in this study. 2) There could be observer errors in virtual decompression surgery on 3D reconstruction image. 3) Distraction of narrow disc space was not considered. 4) Minimal measurement errors of local bone graft and disc volume could be possible. 5) The sufficient bone graft volume does not guarantee good clinical outcomes. However, to our best knowledge, this large number of study presented strong evidence that local bone graft was sufficient to fill disc space in 1- and 2-level PLIF. Especially in degenerative lumbar spine at which disc space was narrow and large osteophytes and hypertrophied facet joints were noted. It means disc space volume is smaller and amount of local bone graft volume is larger than young and healthy persons. Further comparative study between real volume in spine surgery and estimated volume with 3D reconstruction image and simulation program is required.

V. Conclusion

In conclusion, this simulation study demonstrated that local bone graft without any bone substitute was sufficient in 1- and 2-level PLIF. If one or two interbody cages were used, local bone graft was large enough to fill disc space thoroughly in 1- and 2-level PLIF.

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ABSTRACT(IN KOREAN)

3차원 재구성 CT를 이용한 요추 추체간 후방유합술에 필요한 국소 골이식양의 측정

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강성식

요추 추체간 후방유합술은 다양한 요추의 퇴행성 질환을 치료하기 위해 시행되어 왔다. 후방 유합술의 골이식에 있어서 가장 좋은 재료는 자가장골이나, 추가로 환자의 장골에서 골을 채취해야 하므로 많은 부작용이 보고되고 있다. 감압술을 시행할 때 발생되는 자가 국소골을 이용하면, 골을 채취할 때 발생하는 부작용을 줄이면서 우수한 골유합을 얻을 수 있다고 알려져 있다. 기존 선행 연구는 환자 수가 작고, 술자마다 감압하는 정도가 달라서 발생되는 국소골의 양의 차이가 많은 실정이다. 이에 저자는 요추 CT를 3차원으로 재구성한 뒤 모사 프로그램을 이용하여, 국소 골이식양과 추간판 공간의 부피를 측정하였다. 20-40대, 40-60대, 60-80대 남녀 각각 20명씩 총 120명을 분석하였다. 1 분절 감압 시 평균 13.2 cc, 2 분절 감압 시는 22.9 cc, 3 분절 감압 시에는 29.8 cc의 국소골이 나올 것으로 예측되었다. 제 3-4 요추의 추간판 공간의 평균 부피는 9.9 cc, 제 4-5 요추는 10.1 cc, 제 5요추-제 1천추는 9.7 cc로 측정되었다. 예측과는 달리 국소골 채취 과정에서 골손실이 발생할 수도 있고, 국소골을 추간판 공간에 채우는 과정에서 압착이 발생하여 부피가 줄어들 수도 있다. 하지만, 근래에는 요추 추체간 후방유합술에서 케이지를 빈번하게 사용하므로

실제로 필요한 골이식양은 디스크 공간 내에서 케이지가 차지하는 공간을 제외하여야 한다. 그리고 추간판을 완전히 제거하는 것은 불가능하고, 국소골은 해면골 성분이 많지 않아 압착이 적게 되는 편이며, 케이지 바깥쪽은 신경이 있으므로 추간판 공간을 가득 채우지는 않기 때문에 다른 골대체제 없이 국소골만으로도 추간판 공간을 충분히 채울 수 있다. 이는 1 분절 또는 2 분절 요추 추체간 후방유합술에만 가능한 데, 그 이유는 2 분절 또는 3 분절 요추 추체간 후방유합술을 시행할 경우, 추간판 공간은 2 배 또는 3 배씩 늘어나는 데 비해, 나오는 국소골의 양은 2 배 또는 3 배가 되지 않기 때문이다. 본 연구를 통해 1,2 분절 요추 추체간 후방유합술을 시행할 경우, 값 비싼 골대체제가 아닌, 갑압술 시행 시 필연적으로 발생되는 국소골만을 이용하더라도 추간판 공간을 채울 수 있는 근거를 마련하는 데 도움이 될 것으로 생각된다.

핵심되는 말 : 국소골 이식, 요추 추체간 유합술, 3차원 CT