Acta Orthop. Belg., 2014, **80**, 515-521

ORIGINAL STUDY

Anatomical assessment of iliac crest graft size for anterior spondylodesis

D. Kubosch, A. Vacariu, S. Milz, K. Izadpanah, N.P. Südkamp, P.C. Strohm

From Department of Orthopedic and Trauma Surgery, Albert-Ludwigs-University of Freiburg Medical Center, Germany

Standard procedure for monosegmental anterior spondylodesis often combines anterior stabilization with autologous iliac crest graft. Recent publications defined a minimum size of the graft as a technical specification for this procedure. The cross sectional area of the graft to be transplanted should be at least 23.9% of the cross sectional area of the vertebral bodies to be fused.

We investigated whether the required minimum size of autologous graft, as identified both experimentally and clinically, is compatible with the anatomical conditions in central european patients.

Computed tomography scans (n = 348) of polytraumatized patients were obtained in the course of initial diagnosis. The scans were evaluated for vertebral body size and the possible size of autologous bone graft in the region of the anterior superior iliac crest. The evaluation of 348 CT scans demonstrated that 95% of the quantified iliac crest grafts would achieve the size recommended for anterior spinal fusion between T10 and T12. In 90% of all cases the planned iliac crest graft exceeded the size limit of 23,9% between concerning the endplates T10 and L2. In 85% the planned iliac crest graft exceeded the size limit of 23,9% between T10 and L3.

The recommendation to take this value into account for monosegmental anterior spondylodesis should gain in importance in clinical practice.

Keywords : spinal fusion ; autologous bone graft ; spondylodesis ; graft failure.

INTRODUCTION

Diseases of the spinal column are highly relevant to society today. A total number of 200,000 spinal fusions with bone grafting are performed annually in the USA alone (*29*). This high number of spine interventions underlines the recommendation that surgery should be preferred over a non-surgical procedure in the management of spinal instability, especially because the outcome after surgery is significantly better than after a non-surgical procedure (*8*).

A method commonly applied to stabilize the spine is monosegmental, anterior spondylodesis of the spinal column. The desired fusion of motion segments can be achieved by insertion of autologous, allogenic or xenogenic bone graft between the

■ D. Kubosch.
■ A. Vacariu.
■ K. Izadpanah.
■ N.P. Südkamp.
■ P.C. Strohm.
Department of Orthopedic and Trauma Surgery, Albert-Ludwigs-University of Freiburg Medical Center, Germany.
■ S. Milz.
Department of Anatomy, Ludwig-Maximilians-University of Munich, Germany.
Correspondence : Dr med David C. Kubosch, Department of Orthopedic and Trauma Surgery, Albert-Ludwigs-University of Freiburg, Medical Center, Hugstetterstr. 55, 79106 Freiburg im Breisgau, Germany.
E-mail : david-christopher.kubosch@uniklinik-freiburg.de

No benefits or funds were received in support of this study. The authors report no conflict of interests.

vertebral bodies to be fused. Other materials and systems, for example, titanium or PEEK cages have gradually gained in importance and have already entered clinical practice. Nevertheless, monosegmental spondylodesis with autologous, tricortical iliac crest graft currently remains a frequently used clinical standard in many hospitals (*15,21,24*).

Despite the positive properties of autologous material in terms of osteogenesis, osteoinduction and osteoconduction, the number of patients reporting to the clinic after radiologically successful anterior spondylodesis to complain of persistent symptoms in the affected region of the spine is not negligible. Depending on the patient collective under investigation this number can amount to 33% of all surgically treated patients (*12*). Partial healing, lysis or graft fractures are some of the possible explanations for these persisting symptoms (*5*).

Numerous guidelines and recommendations for harvesting and implantation of the graft can be found in the literature. For example, if a graft is implanted in so-called “graft inlay technique“ it is especially important to adhere to the “tongue-in-groove principle“, i.e. to ensure optimal form-fit between the graft and the graft bed (*1,13*). In addition, it is also important that harvested and transplanted graft should extend beyond the median sagittal plane of the vertebral body (*13*). More recently a minimum cross sectional area of the graft to be transplanted was defined. This value is related to the surface areas of the endplates of the vertebrae to be fused (*16*). Compliance with these recommendations should culminate in optimal incorporation of the graft and, simultaneously, minimize the risk of partial incorporation, lysis or graft fracture. The recommendation is of a purely technical nature and should be followed by the surgeon at the pre-operative planning stage of any intervention for spinal fusion. The recommendation concerning the defined minimum cross sectional area of the graft to be harvested does however depend on the available anatomical bone stock of the individual patient, a factor on which the surgeon has no influence.

This study therefore aimed to answer the question whether the minimum size of autologous graft as determined by retrospective animal and clinical investigation can be endorsed with regard to individual iliac bone stock and thus find acceptance as a valuable recommendation for clinical practice.

MATERIAL AND METHODS

A total of 348 64-MDCTs (Multi Detector Computed Tomography, Somatom Sensation, Siemens, Erlangen

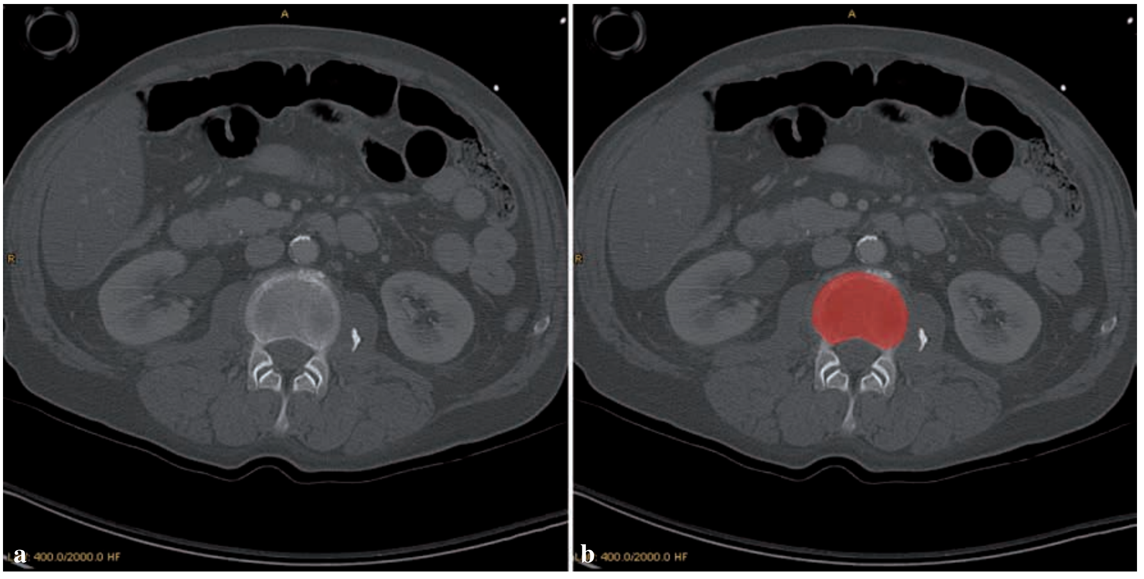

Fig. 1a-b. — Axial layer of a spinal section with and without marked L3 endplate

Germany) of hospital patients were analyzed retrospectively. The CT scans were obtained in the period from August 2008 to August 2009 as part of the routine radiological diagnostics of polytraumatized patients. Average patient age was 45 years (min. 18 years, max. 92 years). CT is currently the standard procedure for evaluation and analysis of bone structures (*18,19,22,23,30*). The exclusion criteria for this study were fractures of the iliac crest and the thoracolumbar junction (Th10-L3) and previous surgeries or injuries to the thoracolumbar junction or the pelvis.

For the purpose of analysis the surface areas of the endplates of the intervertebral space were calculated from the axial layers of the CT scan. The measurements extended from T10 (inferior endplate) to L3 (superior endplate). This distance was chosen because more than 2/3[rds] of all spine fractures seen in clinical practice are located within this range (*27*). Morphometric quantification of cross sectional area was performed with a radiology software package (IMPAX EE R20 V, Agfa Healthcare, Belgium) (Fig. 1a-b).

The anterior superior iliac crest on the right side was measured at a defined position to determine possible graft size. Even if bone graft harvesting is mostly performed on the left superior iliac crest, we measured the superior iliac crest on the right side, since there are no significant differences between the size of the right and the left iliac crest (*4*). To this end the specific layer in which the anterior superior iliac crest was located was selected from the axial layers of the pelvis since the iliac crest represents the typical site of clinical graft harvesting and has been identified through research as the optimal autologous donor site (*7*). A line was then drawn from the superior anterior iliac spine parallel to the iliac crest extending 30 mm in a posterior direction. At the end of this reference line and at right angles to it a line was drawn from the internal to the external wall of the iliac crest. The area within this outline was then calculated by application of the area measurement tool of the radiology software (Fig. 2a-b). The graft defined in this way corresponds to the so-called Bailey-Badgley tall wedge as described in 1973 by White *et al.* (*2*).

Analysis of the results was performed with SPSS for Windows (Version 18.0). The variable under investigation was the ratio of graft to vertebral body cross sectional area.

RESULTS

The evaluation of 348 CT scans demonstrated that 95% of the quantified iliac crest grafts would achieve the minimum size recommended for anterior spinal fusion between T10 and T12, i.e. they occupy at least 23.9% of the area of the vertebral bodies to be fused (Table I and II).

In 90% of all cases the planned iliac crest graft exceeded the size limit of 23,9% between concerning the endplates T10 and L2. In 85% of all cases the planned iliac crest graft exceeded the

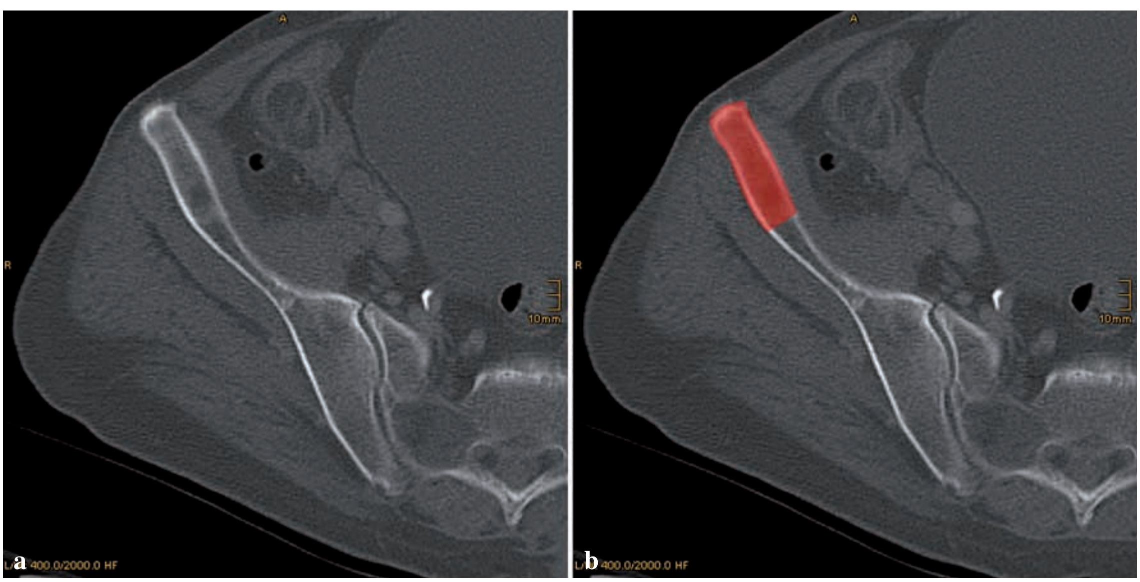

Fig. 2a-b. — Axial layer of the pelvis with and without coloration of the graft to be harvested size limit of 23,9% between T10 and L3 (Table I and II).

The average values including the descriptive statistics for each vertebra for T10 and L3 are given in table III.

In the performed subgroup analysis between male and female, no significant differences were found.

DISCUSSION

The current literature contains numerous publications on anterior spondylodesis and the outcome in relation to specific types of implants (*17,28,31*). The advantages and disadvantages of tricortical iliac crest grafts and their biomechanical properties have also been discussed extensively (*3,26*). Nevertheless, despite the widespread application of alternative materials such as titanium and PEEK cages in daily clinical routine, autologous tricortical iliac crest grafts in many publications are recommended as the standard for monosegmental vertebral body fusion (*13,21,24*).

One disadvantage of monosegmental vertebral body fusion by means of autologous tricortical iliac crest graft can be a very high graft failure rate. Incorporation rates for bone grafts after vertebral body fusion as reported in the literature range from 65 to 100% (*5,6,11,13-15*), which implies a failure rate up to 35%. Furthermore, the data on graft fracture rates have to be viewed critically since the incidence of graft fractures evading easy detection is probably distinctly higher than has so far been diagnosed by clinical methods (*30*). On the other hand, it should be noted that the reported spondylodeses and published outcomes were all performed without reference to the recommendations of a size limit of autologous iliac crest graft as described by Kubosch *et al.* (*16,17*).

Another disadvantage is the widely discussed and published issue of donor site morbidity related to harvesting tricortical iliac crest graft. It is a problem,

Table I. — Percentage area of superior endplate (SEP) that would be covered by a potential autologous graft (P1). Percentile distribution for vertebra T10 to L3. Note the grey marked fields which do not exceed the 23,9% limit

Percentile	%P1/SEP_T10	%P1/SEP_T11	%P1/SEP_T12	%P1/SEP_L1	%P1/SEP_L2	%P1/SEP_L3
5.00	33.40	28.83	26.07	24.27	22.59	21.58
10.00	36.36	32.20	28.58	26.27	24.84	23.73
15.00	38.41	34.27	30.10	27.95	26.54	25.29
20.00	40.45	35.29	31.45	29.09	27.67	26.28
25.00	41.66	37.13	32.98	30.25	28.75	27.60
30.00	43.57	38.15	34.23	31.67	29.95	28.51
35.00	45.24	39.80	35.19	32.71	30.68	29.39
40.00	46.48	41.09	36.24	33.78	31.80	30.04
45.00	48.36	42.50	37.44	34.56	32.67	31.19
50.00	50.20	43.43	38.73	35.60	33.63	32.20
55.00	52.14	45.32	40.08	36.63	34.58	33.03
60.00	53.61	46.77	41.11	38.02	35.46	33.86
65.00	54.79	48.88	42.82	39.24	36.30	34.82
70.00	57.03	49.95	44.08	40.47	37.90	36.41
75.00	59.14	51.40	45.48	41.63	39.43	37.33
80.00	61.14	53.61	47.11	43.45	41.25	38.56
85.00	63.88	55.30	49.54	45.42	42.42	40.57
90.00	67.90	58.78	52.73	47.74	44.19	42.35
95.00	73.50	64.53	57.10	51.38	47.16	45.82

Table II. — Percentage area of inferior endplate (IEP) that would be covered by a potential autologous graft (P1). Percentile distribution for vertebra T10 to L3. Note the grey marked fields which do not exceed the 23,9% limit

Percentile	%P1/IEP_T10	%P1/IEP_T11	%P1/IEP_T12	%P1/IEP_L1	%P1/IEP_L2	%P1/IEP_L3
5.00	29.50	26.10	24.70	22.95	21.84	20.91
10.00	31.67	28.63	27.06	25.16	24.11	23.09
15.00	33.53	30.64	28.69	26.32	25.63	24.43
20.00	35.07	32.06	30.14	28.02	26.90	25.74
25.00	36.66	33.19	31.35	29.11	27.65	26.88
30.00	37.81	34.31	32.29	29.90	28.37	27.60
35.00	39.22	35.77	33.29	30.94	29.22	28.20
40.00	40.80	36.66	34.09	31.63	30.01	28.85
45.00	41.77	37.90	35.28	32.40	30.93	29.84
50.00	43.54	39.22	36.51	33.56	32.26	30.88
55.00	44.83	40.26	37.70	34.67	33.29	32.02
60.00	46.69	41.72	38.76	35.98	34.20	32.84
65.00	48.11	42.98	40.11	37.16	35.08	33.96
70.00	49.29	44.37	41.56	38.32	36.39	35.07
75.00	51.31	45.56	42.69	39.25	37.64	36.40
80.00	53.31	47.38	44.01	41.15	38.57	37.36
85.00	55.55	49.75	46.96	43.09	40.81	38.59
90.00	57.83	52.73	50.14	44.93	42.52	40.15
95.00	63.17	57.10	52.34	47.82	44.78	43.39

which the surgeon can only minimize by taking adequate care when performing the procedure. There are additional recommendations with regard to the suitability of instruments for harvesting these grafts that focus on preventing other associated risks such as biomechanical weakening of the graft (*10*).

In our opinion, the advantages of autologous tricortical iliac crest graft clearly outweigh the disadvantages. Specifically, autologous graft indubitable prevails over any form of titanium or PEEK cage or xenogenic material in terms of osteogenesis, osteoinduction and osteoconduction.

It therefore is necessary to focus on the positive properties of this material and to attempt to minimize known risks by optimizing surgical technique. The aim of this study therefore was to clarify whether the anatomical conditions in the adult population permit a graft harvesting procedure which follows the recommended size ratio between iliac crest graft and cross sectional areas of the adjacent endplates of the vertebral bodies to be fused in patients in clinical practice. The results derived from our retrospective data analysis indicate that the recommendation can be confirmed virtually without reservation for the lower thoracic spine. Some flexibility is unavoidable at the mid lumbar spine. This is due to the shape and width of the lumbar vertebral bodies, which increase from cranial to caudal in human individuals (*20,25*). Accordingly, the size ratio between the endplates and the iliac crest graft changes so that adherence to the recommended minimum size cannot be achieved in every individual patient.

For the lower lumbar spine the anterior superior iliac spine could be a less suitable harvesting site for autologous iliac crest graft intended for monosegmental spondylodesis because bone mass at that location is limited and cannot provide the recommended size of graft for fusion of a motion segment. In these cases, the use of alternative materials such as titanium or PEEK cages should be considered. Another alternative is to harvest two iliac crest grafts that can be inserted between the vertebrae to

Table III. — Average values of endplate coverage for vertebra T10 to L3. Superior (SEP) and inferior (IEP) endplate values are separately presented

	%P1/SEP_T10	%P1/SEP_T11	%P1/SEP_T12	%P1/SEP_L1	%P1/SEP_L2	%P1/SEP_L3
Mean SEP	51.15	44.87	39.77	36.45	34.26	32.68
Median	50.20	43.43	38.73	35.60	33.63	32.20
Standard deviation	12.04	10.50	9.48	8.18	7.44	7.18

	%P1/IEP_T10	%P1/IEP_T11	%P1/IEP_T12	%P1/IEP_L1	%P1/IEP_L2	%P1/IEP_L3
Mean IEP	44.43	40.01	37.40	34.49	32.72	31.50
Median	43.54	39.22	36.51	33.56	32.26	30.88
Standard deviation	10.46	9.23	8.52	7.55	6.95	6.69

be fused, whereby risk assessment is clearly important here. Xenogenic grafts cannot be recommended since the data in the published literature indicates that their properties are inadequate for monosegmental spondylodesis (*9*).

Our results confirm that the ratio recommended in the literature between endplate area of the motion segment to be fused and the autologous tricortical iliac crest graft cross sectional area is appropriate for application in daily clinical routine. The anatomical structures in the majority of patients in the present study would permit graft harvesting with an adequate cross sectional area for fusion of the motion segments at the thoracolumbar junction.

In our opinion, taking these reference values into account will reduce the risk of potential complications related to anterior spondylodesis by selection of an adequately sized graft alone without recourse to additional techniques or instrumentation. However, there is a very small group of patients who would not present with suitable graft material at one iliac crest, especially for the treatment of the lower lumbar region. Detailed research is required to determine whether alternative treatment methods should be preferred in these individuals.

REFERENCES

1. **Anetzberger H FH, Putz R, Trentz O.** Posttraumatische Defekt- und Infektsanierung, Schädel, Wirbelsäule Becken. Platzer W TO, editor : Georg Thieme Stuttgart New York ; 1997.
2. **Bailey RW, Badgley CE.** Stabilization of the cervical spine by anterior fusion. *J Bone Joint Surg Am* 1960 ; 42-A : 565-94.
3. **Banwart JC, Asher MA, Hassanein RS.** Iliac crest bone graft harvest donor site morbidity. A statistical evaluation. *Spine (Phila Pa 1976)* 1995 ; 20 (9) : 1055-60.
4. **Boulay C, Tardieu C, Benaim C, Hecquet J, Marty C, Prat-Pradal D *et al.*** Three-dimensional study of pelvic asymmetry on anatomical specimens and its clinical perspectives. *Journal of anatomy* 2006 ; 208 (1) : 21-33.
5. **Briem D, Rueger J, Linhart W.** [Osseous integration of autogenous bone grafts following combined dorso-ventral instrumentation of unstable thoracolumbar spine fractures]. *Unfallchirurg* 2003 ; 106 (3) : 195-203.
6. **Buhren V.** [Injuries to the thoracic and lumbar spine]. *Unfallchirurg* 2003 ; 106 (1) : 55-68 ; quiz -9.
7. **Ebraheim NA, Yang H, Lu J, Biyani A, Yeasting RA.** Anterior iliac crest bone graft. Anatomic considerations. *Spine (Phila Pa 1976)* 1997 ; 22 (8) : 847-9.
8. **Fritzell P, Hagg O, Wessberg P, Nordwall A.** 2001 Volvo Award Winner in Clinical Studies : Lumbar fusion versus nonsurgical treatment for chronic low back pain : a multicenter randomized controlled trial from the Swedish Lumbar Spine Study Group. *Spine (Phila Pa 1976)* 2001 ; 26 (23) : 2521-32 ; discussion 32-4.
9. **Jensen SS, Broggini N, Hjorting-Hansen E, Schenk R, Buser D.** Bone healing and graft resorption of autograft, anorganic bovine bone and beta-tricalcium phosphate. A histologic and histomorphometric study in the mandibles of minipigs. *Clin Oral Implants Res* 2006 ; 17 (3) : 237-43.
10. **Jones A, Dougherty P, Sharkey N, Benson D.** Iliac crest bone graft. Osteotome versus saw. *Spine (Phila Pa 1976)* 1993 ; 18 (14) : 2048-52.
11. **Josten C, Katscher S, Gonschorek O.** [Treatment concepts for fractures of the thoracolumbar junction and lumbar spine]. *Orthopade* 2005 ; 34 (10) : 1021-32.

12. **Knop C, Blauth M, Buhren V, Arand M, Egbers HJ, Hax PM *et al.*** [Surgical treatment of injuries of the thoracolumbar transition – 3 : Follow-up examination. Results of a prospective multi-center study by the "Spinal" Study Group of the German Society of Trauma Surgery]. *Unfallchirurg* 2001 ; 104 (7) : 583-600.
13. **Kossmann T, Ertel W, Platz A, Trentz O.** [Combined surgery for fractures of the thoraco-lumbar junction using the inlay-span method]. *Orthopade* 1999 ; 28 (5) : 432-40.
14. **Kossmann T, Jacobi D, Trentz O.** The use of a retractor system (SynFrame) for open, minimal invasive reconstruction of the anterior column of the thoracic and lumbar spine. *Eur Spine J* 2001 ; 10 (5) : 396-402.
15. **Kubosch D, Milz S, Lohrmann C, Schwieger K, Konstantinidis L, Sprecher CM *et al.*** Risk of graft fracture after dorso-ventral thoraco-lumbar spondylodesis : is there a correlation with graft size ? *Eur Spine J* 2011 ; 20 (10) : 1644-9.
16. **Kubosch D, Milz S, Sprecher CM, Sudkamp NP, Muller CA, Strohm PC.** Effect of graft size on graft fracture rate after anterior lumbar spinal fusion in a sheep model. *Injury* 2010 ; 41 (7) : 768-71.
17. **Kubosch D, Rohr J, Izadpanah K, Hammer TO, Sudkamp NP, Strohm PC.** [Radiological comparison between two procedures for ventral spondylodesis : Autologous iliac crest bone graft vs bovine bone graft.]. *Unfallchirurg* 2011.
18. **Link TM, Lin JC, Newitt D, Meier N, Waldt S, Majumdar S.** [Computer-assisted structure analysis of trabecular bone in the diagnosis of osteoporosis]. *Der Radiologe* 1998 ; 38 (10) : 853-9.
19. **Link TM, Majumdar S.** Osteoporosis imaging. *Radiologic clinics of North America* 2003 ; 41 (4) : 813-39.
20. **Masharawi Y, Salame K, Mirovsky Y, Peleg S, Dar G, Steinberg N *et al.*** Vertebral body shape variation in the thoracic and lumbar spine : characterization of its asymmetry and wedging. *Clin Anat* 2008 ; 21 (1) : 46-54.
21. **Maus U, Andereya S, Gravius S, Siebert CH, Schippmann T, Ohnsorge JA *et al.*** How to store autologous bone graft perioperatively : an in vitro study. *Arch Orthop Trauma Surg* 2008 ; 128 (9) : 1007-11.
22. **McAfee PC, Boden SD, Brantigan JW, Fraser RD, Kuslich SD, Oxland TR *et al.*** Symposium : a critical discrepancy-a criteria of successful arthrodesis following interbody spinal fusions. *Spine (Phila Pa 1976)* 2001 ; 26 (3) : 320-34.
23. **Moll R, Schindler G, Weckbach A.** [Evaluation of ventral stabilization techniques for thoracolumbar fractures by helical computer tomography]. RoFo : Fortschritte auf dem Gebiete der Rontgenstrahlen und der Nuklearmedizin 2002 ; 174 (7) : 880-6.
24. **Nichols T, Sagi H, Weber T, Guiot B.** An alternative source of autograft bone for spinal fusion : the femur : technical case report. *Neurosurgery* 2008 ; 62 (3 Suppl 1) : E179 ; discussion E.
25. **Panjabi MM, Goel V, Oxland T, Takata K, Duranceau J, Krag M *et al.*** Human lumbar vertebrae. Quantitative three-dimensional anatomy. *Spine (Phila Pa 1976)* 1992 ; 17 (3) : 299-306.
26. Parsch D, Breitwieser T, Breusch SJ. Mechanical stability of structured bone grafts from the anterior iliac crest. *Clin Biomech (Bristol, Avon)* 2008 ; 23 (7) : 955-60.
27. **Reinhold M, Knop C, Beisse R, Audige L, Kandziora F, Pizanis A *et al.*** Operative treatment of 733 patients with acute thoracolumbar spinal injuries : comprehensive results from the second, prospective, Internet-based multicenter study of the Spine Study Group of the German Association of Trauma Surgery. *Eur Spine J* 2010 ; 19 (10) : 1657-76.
28. **Riesner HJ, Matzen KA, Mlinaric M, Wild A.** [Therapeutic efficiency in multisegmental fusions of the lumbar spine]. *Z Orthop Unfall* 2008 ; 146 (4) : 444-51.
29. **Sandhu HS, Grewal HS, Parvataneni H.** Bone grafting for spinal fusion. *The Orthopedic clinics of North America* 1999 ; 30 (4) : 685-98.
30. **Strohm PC, Kubosch D, Bley TA, Sprecher CM, Sudkamp NP, Milz S.** Detection of bone graft failure in lumbar spondylodesis : spatial resolution with high-resolution peripheral quantitative CT. *AJR Am J Roentgenol* 2008 ; 190 (5) : 1255-9.
31. **Williams AL, Gornet MF, Burkus JK.** CT evaluation of lumbar interbody fusion : current concepts. *AJNR American journal of neuroradiology* 2005 ; 26 (8) : 2057-66.