

At the 42nd Annual Meeting of the Japanese Society for Spine Surgery and Related Research (25 to 27 April 2013), Dr. Shuichiro Ohno of the Spine Center, Seirei Hamamatsu General Hospital, made an academic presentation entitled "How Tomosynthesis Changes the Evaluation of PLIF Bone Union." The contents of his presentation are introduced below.



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How Tomosynthesis Changes the Evaluation of PLIF Bone Union

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1. Purpose

Tomosynthesis is a new radiography technique that takes tomographic images with only one-tenth the exposure dose of CT. It is said to permit rapid radiographic imaging of patients in various postures and dramatically cut metal artifacts. We performed bone union evaluation after posterior lumbar interbody fusion (PLIF) using tomosynthesis and investigated the utility of this technique by comparing it to existing evaluation techniques using radiography and CT.

2. Materials and Methods

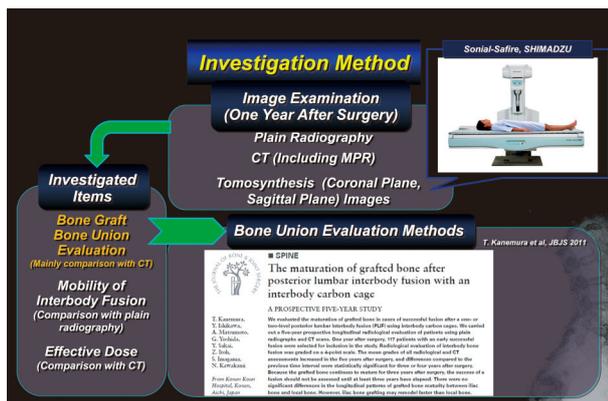
Targets were 16 cases of lumbar spinal canal stenosis surgery accompanying lumbar spine instability that permitted diagnostic imaging after one year. The PLIF procedures were performed between April and October 2011. Of these cases, nine were female and seven were male. The average age at surgery was 62.5 years. A total of 18 interbody fusions were performed (one interbody fusion in 14 cases and two interbody fusions in two cases). The investigation involved radiography, CT, and tomosynthesis one year after surgery. The items evaluated were bone union of the grafted bone, mobility of the interbody fusion, and effective X-ray dose. The grade points method reported by Kanemura et al.¹⁾ was used to evaluate bone union.

This method of bone union evaluation involves three evaluation parameters, which are each classified from grade 0 to grade 3 and a point score applied. SPSS Ver. 19 was used for statistical studies. The Student-T test and the Wilcoxon signed rank test achieved a significant difference of $p < 0.05$.

Bone Union Evaluation Methods				
	Plain Radiography	CT and Tomosynthesis Images		
Parameter	Grade 0 (0 points)	Grade 1 (1 point)	Grade 2 (2 points)	Grade 3 (3 points)
Cross sign formation (Plain radiography, frontal image)	No continuity with endplates, no cross sign	Some continuity with endplates, no cross sign	Partial, but not complete cross sign	Almost complete cross sign
Continuity with upper and lower vertebral body endplates (Plain radiography lateral image, CT sagittal image)	No continuity with endplates	Less than 50% continuity with endplates	50% or higher continuity with endplates	Almost complete continuity with endplates
Bone formation around cage (Plain radiography lateral image, CT sagittal image)	No bone formation or extension	Bone formation but does not reach vertebral body leading edge or trailing edge	Bone formation/extension reaches vertebral body leading edge or trailing edge	Bone formation/extension reaches vertebral body leading edge or trailing edge

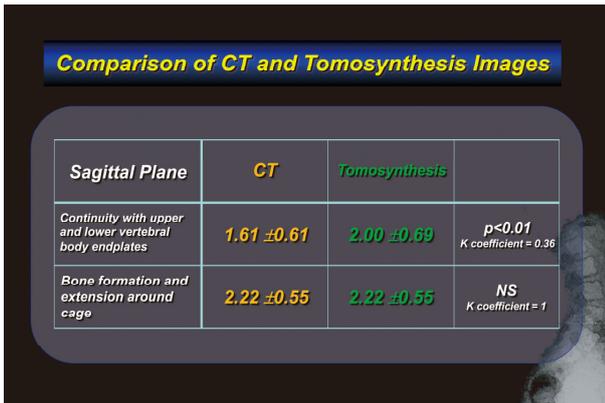
3. Results

Results of conventional bone union evaluation using radiography were an average 1.22 points for cross sign formation in the frontal images, average 1.61 points for continuity with the upper and lower vertebral body endplates in lateral images, and average 2.22 points for bone formation around the cage. In the CT sagittal plane images, the continuity with the upper and lower vertebral body endplates was an average 1.61 points and bone formation around the cage was an average 2.22 points.

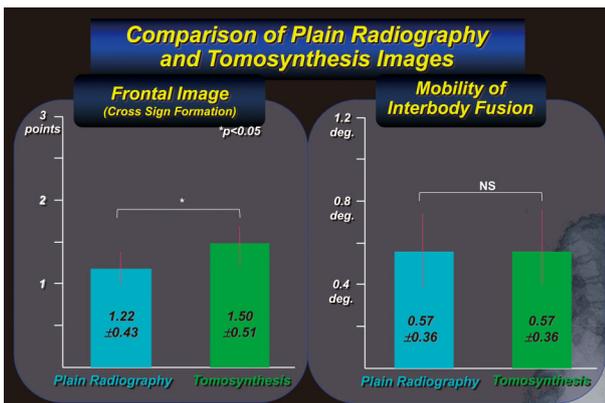


Plain Radiography	CT
Frontal Image (Cross Sign Formation) 1.22 ± 0.43 points Grade 0: 0 cases Grade 1: 14 cases Grade 2: 4 cases Grade 3: 0 cases	Sagittal Image (Continuity with Upper and Lower Vertebral Body Endplates) 1.61 ± 0.61 points Grade 0: 0 cases Grade 1: 8 cases Grade 2: 9 cases Grade 3: 1 case
Lateral Image (Continuity with Upper and Lower Vertebral Body Endplates) 1.61 ± 0.61 points Grade 0: 0 cases Grade 1: 8 cases Grade 2: 9 cases Grade 3: 1 case	Sagittal Image (Bone Formation Around Cage) 2.22 ± 0.55 points Grade 0: 0 cases Grade 1: 1 case Grade 2: 12 cases Grade 3: 5 cases
Lateral Image (Bone Formation Around Cage) 2.22 ± 0.55 points Grade 0: 0 cases Grade 1: 1 case Grade 2: 12 cases Grade 3: 5 cases	

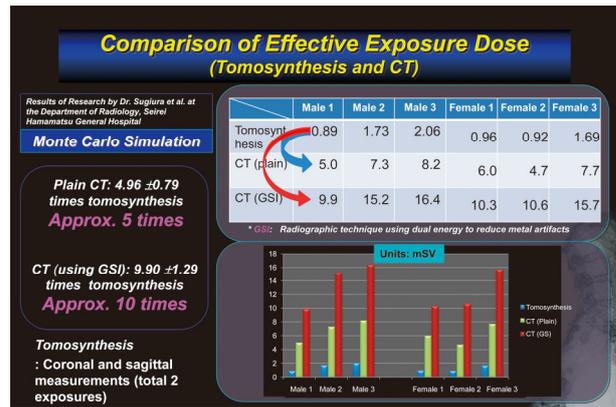
Comparison of CT and tomosynthesis revealed an average 1.61 points for the continuity with the upper and lower vertebral body endplates by CT and an average 2 points by tomosynthesis. A statistically significant difference is confirmed between the two. The kappa coefficient of 0.36 indicates a poor match. However, an average 2.22 points was achieved for bone formation and extension around the cage for both groups. No statistically significant difference was confirmed between the two and the kappa coefficient was 1.



Comparison of radiography and tomosynthesis revealed an average 1.22 points by radiography and average 1.5 points by tomosynthesis for the cross sign formation parameter in the frontal images. A statistically significant difference is confirmed between the two. However, an average 0.57° was achieved for mobility of the interbody fusion for both groups, and no statistically significant difference was confirmed.

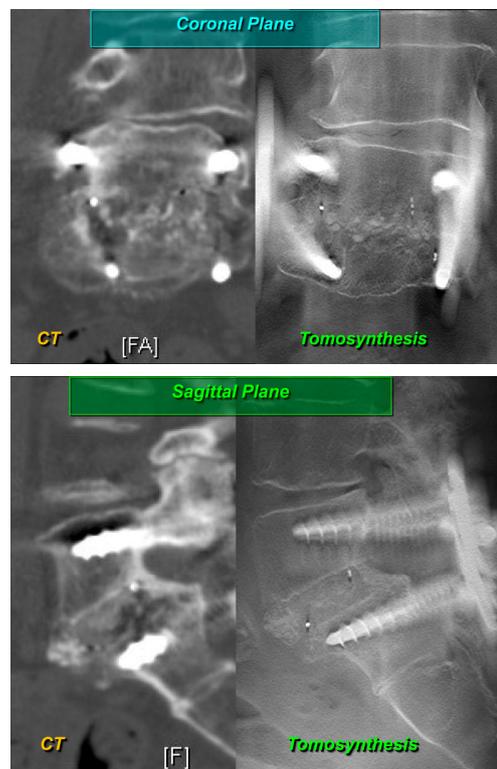


Research by Sugiura et al. at the Department of Radiology at this hospital used Monte Carlo simulation to compare the effective dose between tomosynthesis and CT. Results indicate that plain CT requires approximately five times the X-ray dose of tomosynthesis. CT under conditions that reduce metal artifacts results in ten times the exposure dose.

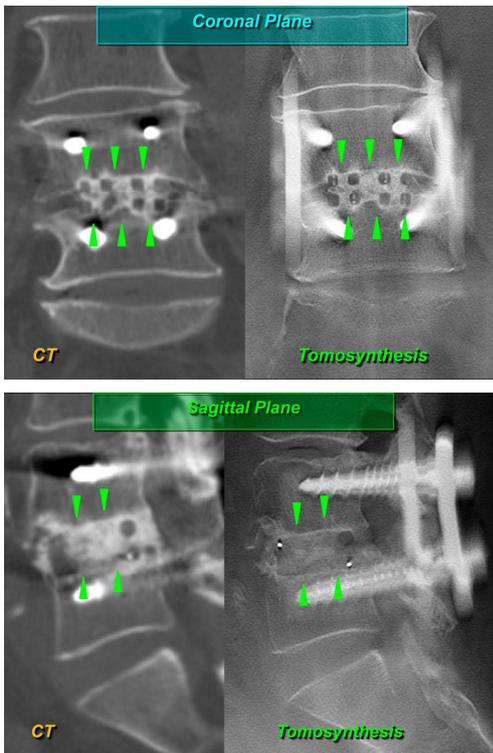


4. Typical Cases

Case 1 is a 78-year-old female with PLIF of L5/S1. Case 2 is a 78-year-old female with PLIF of L4/L5. It is apparent that tomosynthesis produces less artifacts of the screws and metal markers in the cage than CT. It also achieves superior image quality, clearly revealing the boundaries between the vertebral body endplate, cage, and grafted bone. The continuity with the vertebral body endplates and properties within the grafted bone can be clearly observed.



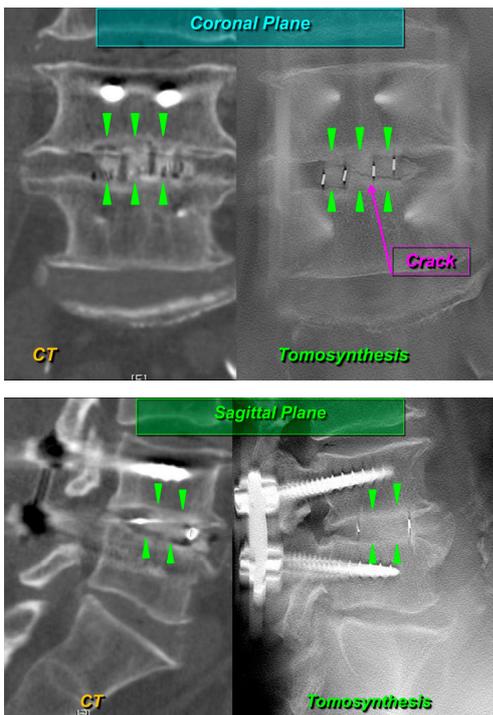
Case 1



Case 2

Case 3 is an 83-year-old male with PLIF of L4/L5. In this case, too, tomosynthesis produces less artifacts of the screws and metal markers in the cage than CT.

It also achieves superior image quality, such that the continuity of the grafted bone and vertebral body endplates can be clearly observed. Even fine cracks are visible in the grafted bone within or between cages.



Case 3

5. Discussions

There are very few reports of the utility of tomosynthesis in the field of orthopedics. However, Aoki et al.²⁾ have reported on its utility for scaphoid fractures and nonunions, as well as staging and post-surgical evaluations of Kienbock's disease. Mermuys et al.³⁾ have reported on the utility of tomosynthesis for the definitive diagnosis of suspected scaphoid fractures. Machida et al.⁴⁾ have reported its utility for bone union evaluation after olecranon fracture surgery. Takenaka et al.⁵⁾ have also reported the effectiveness of tomosynthesis for pathology evaluations and callus evaluations before and after distraction osteogenesis for the treatment of limb nonunion and malunion. However, we were unable to find any reports on its utility in spine surgery.

Utility of Tomosynthesis Imaging

- Useful for staging and post-surgical evaluation of scaphoid fractures and Kienbock's disease.* (Aoki et al., 1995)
- Useful for the definitive diagnosis of suspected scaphoid fracture.* (Mermuys K et al., 2008)
- Useful for post-surgical bone union process evaluation after internal fixation surgery for olecranon fractures.* (Machida H et al., 2011)
- Useful for pre- and post-surgical pathology evaluation of distraction osteogenesis (Ilizarov method and osteotomy) for limb reconstruction after nonunion, malunion, or infected nonunion after trauma fracture, in particular callus evaluation.* (Takenaka et al., 2011)

No reports on utility in spine surgery

In comparison with CT, tomosynthesis generally offers radiography in both the upright and decubitus positions, fewer metal artifacts, and while it does not permit 3D reconstructions, it permits oblique image reconstruction up to $\pm 20^\circ$.

Comparison of Tomosynthesis and CT Imaging

	Positioning	Radiography Angle	Metal Artifact	Reconstruction	Number of Images
Tomo synthesis	Standing Supine	Max. 30 deg. with respect to axis	Little	320 degrees reconstruction possible 3D reconstruction not possible	74 per direction
CT	Supine	360 deg. with respect to body axis	Large	Permits required reconstruction Permits 3D reconstruction	1000 to 2000

The results of this research into the utility of tomosynthesis for the evaluation of PLIF bone union indicate that it achieves significantly fewer metal artifacts due to pedicle screws and metal markers in cages than CT. Its superior spatial resolution in tomographic plane, better image contrast, and higher image quality offer better evaluation of bone union of vertebral body endplates to bone grafts inside and outside the cages and provide clearer observations of the bone quality inside the grafted bone than with CT. Using a Monte Carlo simulation to compare the effective dose between tomosynthesis and CT indicates that tomosynthesis can cut the dose by 90%. This indicates that tomosynthesis offers highly safe radiographic image examinations. In the future, tomosynthesis may replace CT as an effective method of radiographic image examination of bone union.

6. Limitations in This Research

The following limitations applied to this research.

1. Few cases and interbody fusions.
2. Evaluations were performed only one year after surgery. In the future, it will be necessary to evaluate long-term data, including periodical evaluations.
3. There is no established evaluation standard for maturation of bone grafts inter and intra cages.
4. Comparative investigations are required of functional radiographic images by CT and tomosynthesis.
5. Comparative investigations are required into measured exposure dose values for CT and tomosynthesis under the radiography conditions actually used.

7. Conclusions

Tomosynthesis achieves significantly and fewer metal artifacts due to pedicle screws and metal markers in cages than CT. It makes image evaluation easier.

In comparison with CT, tomosynthesis requires short imaging times of just 2.5 to 5 seconds and achieves approximately one-tenth the exposure dose. It offers highly safe radiographic image examinations.

In the future, tomosynthesis may replace CT as an effective method of radiographic image examination of bone union.

As evaluations were performed only one year after surgery and involved few cases, it will be necessary to evaluate long-term data in the future, including periodical evaluations.

References

- 1) T. Kanemura, Y. Ishikawa, A. Matsumoto, G. Yoshida, Y. Sakai, Z. Itoh, S. Imagama, N. Kawakami. : The maturation of grafted bone after posterior lumbar interbody fusion with an interbody carbon cage. a prospective five-year study. *J Bone Joint Surg Br*, Vol.93-B, No.12, 1638-1645, 2011.
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Dr. Shuichiro Ohno plans to establish the Ohno Orthopedics & Spine Clinic in Hamamatsu City, Shizuoka, Japan on November 13, 2013. Dr. Ohno will use the SONIALVISION safire system in the new clinic and perform further research into the utility of tomosynthesis in orthopedics.

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