Quantification of callus by Dual Energy Tomosynthesis during distraction histogenesis.

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Learning objectives

Generally, the Extension area during the process of callus formation in limb lengthening surgery in the orthopedics field is assessed visually by plain radiography. General purpose radiography captured by Computed radiography (CR) cannot serve this purpose using pixel values due to issues with the CR's image processing function. This is one of factors making it difficult to decide the optimal time of removal of the external fixation device during limb lengthening surgery. However, it is sometimes used as a supplementary diagnostic method to DEXA and Acoustic emission.

Here we describe our attempt to visualize quantified image pixel values of callus using Dual Energy Tomosynthesis that was newly installed in an x-ray fluorescent system.
Background

Limb lengthening surgery methods is applied in case of bone defect or bone deformation due to congenital disease or trauma of after bone re-section due to malignant tumor or osteomyelitis. The principle of this method is to apply continual tensile stress to increase the amount of tissue through distraction histogenesis. This method exploits the body’s mechanism for healing broken bone. As a bone fracture heals, volume to create bone tissue.

During limb lengthening surgery methods, the joint between artificially re-sectioned bone surfaces is gradually pulled apart to form callus and is then fixed at the optimal length. This creates bone tissue at joint site, resulting in extension of bone. The fixator holding the extension site can be used to apply bending or twisting to lengthen the bone. It can therefore straighten bone that are deformed due to an accident or malformation. In practice, the procedure involves adjusting the fixator by about 1mm/day. Therefore, the x-ray images for limb lengthening surgery must be able to visualize the callus formation process.

Fig.1 on page 4 shows the progression of callus formation at the extension site in the tibia. And then, the extension area during the process of callus formation in limb lengthening surgery in the orthopedics field is assessed visually by plain radiography. General purpose radiography captured by Computed radiography (CR) cannot serve this purpose using pixel values due to issues with the CR’s image processing function. This is one of factors making it difficult to decide the optimal time of removal of the external fixation device during limb lengthening surgery. However, it is sometimes used as a supplementary diagnostic method to DEXA and Acoustic emission. But, if they have value as a pixel value of the x-ray images for callus is correlated with bone strength, will be able to understand more precisely the formation of callus. Here we describe our attempt to visualize quantified image pixel values of callus using Dual Energy Tomosynthesis that was newly installed in an x-ray fluorescent system.
**Fig. 0:** During limb lengthening surgery methods, the joint between artificially resectioned bone surfaces is gradually pulled apart to form callus and is then fixed at the optimal length. Fig shows the progression of callus formation at the extension site in the tibia. 1) Cut the shorter bone surgically 2) Extend that portion by fixing device 3) Callus will form between the bone.

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Imaging findings OR Procedure details

1. We measured callus during limb lengthening surgery methods using Dual energy x-ray absorptiometry (DEXA) as compared to the results of Acoustic emission, which is a method that measures the strength of bone and is applied to measure the strength of callus after bone fracture. We measured the bone density of 3 patients who were subjected to limb lengthening surgery methods biweekly for a period of 1 year to 1.5 years. The X-ray energy used for DEXA was 42keV for effective energy and 80keV. Fig.1 on page 8 and Fig.2 on page 8 shows the bone density values as measured by DEXA indicated increasing values in parallel with callus formation.

Fig.3 on page 9 shows bone density values as measured by DEXA indicated increasing values in parallel with callus formation. The correlation factor of the strength value of callus measured by DEXA and Acoustic emission was 0.918, meaning that it is possible to estimate the strength of callus by this method. Furthermore, when the density of callus was less than 50% of that of ordinary bone, a high correlation of 0.988 was noted between them.

2. To determine the exposure factor of Dual energy exposure mode, the pixel value of the images obtained with DEXA method and an x-ray fluorescent system (SONIALVISION SAFIRE, Shimadzu,) were compared using a phantom for bone densitometry (Type-UHA, Kyoto Kagaku). Dual energy exposure technique was performed at 60kV, 70kV, 80kV and 100kV, 120kV, with a 0.1mm Cu filter. As for the results shown in Fig.4 on page 10, the correlation factor of bone density and pixel value of bone densitometry evaluation phantom to determine the exposure factor was 0.9866 at 60kv and 120kV, 0.9742 at 60kV and 100kV, 0.9477 at 70kV and 120kV, 0.9650 at 70kV and 100kv, 0.9512 at 80kV and 120kV. The combination of 60kV and 120kV showed the best correlation coefficient. The fact that the combination of exposure kV factor at 60kV and 120kV showed the closest relationship between pixel value and bone density on images obtained by Dual Energy exposure technique makes it possible to quantify bone strength.

3. Images obtained with the Dual Energy system and Dual energy Tomosynthesis system of 33 patients 55cases subjected to limb lengthening surgery methods were compared. The tomography angle was 30 degrees, and image reconstruction slice thickness ++. Then, color mapping image processing of the callus elongated areas on the images, and quantification of the images was performed. It was possible to evaluate the strength of the callus observed visually with radiographs using dual energy Tomosynthesis. These results indicate that Dual Energy Tomosynthesis images can help to confirm the diagnosis in the process of callus formation during limb lengthening surgery.
Below are some representative some cases in which the Dual Energy system and Dual energy Tomosynthesis system were applied.

Fig.5 on page 11 shows a case of limb lengthening by the Ilizarov method. Fig.5 -1) is an image by CR system, 2) is an image obtained with the Dual Energy system, and 3) is an image for which color mapping was applied to the Dual Energy system.

On the image in Fig.5-3), calcification (shown by the arrow) can be clearly identified in the elongated portion after limb lengthening surgery by the Ilizarov method.

Fig.6 on page 12 shows images from the same patient as in Fig.5. The images were obtained serially by the Dual Energy system.

Fig.7 on page 12 shows images to which color mapping was adapted for the Dual Energy system. From Fig.7, it is seen that callus begins to form from the ends of the cut bone at the limb lengthening surgery, and forms progressively toward the center. And then, in the image subjected to color mapping processing this process can be observed clearly.

Fig.8 on page 13, Fig.9 on page 14 show the Dual Energy Tomosynthesis system image and image subjected to the color mapping processing (2010/04/14). Fig.10 on page 14, Fig.11 on page 15 show images taken of the same patient at 2010/11/10 using the Dual Energy Tomosynthesis system.

These images make it possible to determine the condition of the interior of the elongated portion by limb lengthening surgery methods, which is difficult to determine on Dual Energy system images. And these are useful in the determination of bone strength.

From Fig.12 to Fig.15 show images from other cases to which the Dual Energy system and Dual Energy Tomosynthesis system were applied. Fig.12 on page 15 and Fig.13 on page 16 show images obtained with the Dual Energy system.

Fig.14 on page 16 and Fig.15 on page 17 show images obtained by the Dual Energy Tomosynthesis system (2010/11/17). Fig.13 shows that callus begins to form from the cut end of the bone in the limb lengthening surgery. The callus then forms progressively toward the center. In addition, in the images that were obtained on 11/17 and 12/7, formation of callus from the side opposite to the external fixation device is seen. Also, in the image in Fig.15 it is noted that a portion of callus lacks sufficient strength in the elongated portion.

Images of another patient were obtained by the Dual Energy system shown in Fig.16 on page 18. In this case, AE is measured simultaneously with the examination performed with the Dual Energy System.
The strength of capitulation measurements was 42kg and 82kg when on 2010/07/10, and 2010/08/11, respectively. Similarly, the pixel value of the image for the elongated portion increased from 2915 to 3225. These results are consistent with the clinical findings

4. Visual evaluation was performed for 33 patients 55cases using a 3-grade evaluation scale which was adapted by Dual Energy system and Dual Energy Tomosynthesis system. Evaluation had been done comparing to CR system relatively. Score each item are "Excellent: It is possible to observe follow-up it well." "Equivalent: There is some image that cannot be observed to use follow-up it." "Poor: It is not possible to observe follow-up it". Fig.17 on page 18 shows the result of visual evaluation. These results demonstrate that the state of callus formation can be quantified values, thereby making it possible to evaluate callus strength. We consider that the Dual Energy Tomosynthesis images can help to confirm the diagnosis in the process of callus formation during limb lengthening surgery methods.
Fig. 0: Bone density data for case No.1. In this case, the bone density of healthy part of this patient is 1.32g/cm². The bone density values as measured by DEXA indicated increasing values in parallel with callus formation.

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Fig. 0: Bone density data for case No.1. In this case, the bone density of healthy part of this patient is 0.65g/cm². The bone density values as measured by DEXA indicated increasing values in parallel with callus formation.

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Fig. 0: Study of the correlation factor between by DEXA and Acoustic emission. The correlation factor of the strength value of callus measured by DEXA and Acoustic emission was 0.918, meaning that it is possible to estimate the strength of callus by this method. The correlation factor of the strength value of callus measured by DEXA and Acoustic emission was 0.988, when the density of callus was less than 50% of that of ordinary bone, a high correlation between them.

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Fig. 0: Study of the correlation factor between by DEXA and pixel value of bone densitometry evaluation phantom to determine the exposure factor. The correlation factor of bone density and pixel value of bone densitometry evaluation phantom to determine the exposure factor. The combination of 60kV and 120kV showed the best correlation coefficient.

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Fig. 0: The images obtained with the Dual Energy system and CR system who were subjected to limb lengthening surgery methods were compared. 1) The image obtained with CR image 2) The image obtained with Dual Energy system 3) Color mapping image processing of the callus elongated areas on the images and quantification of the images were performed.

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Fig. 0: The images obtained with the Dual Energy system who were subjected to limb lengthening surgery methods were compared at findings of elapsed days.

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**Fig. 0:** The images obtained with the Dual Energy system who were subjected to limb lengthening surgery methods were compared at findings of elapsed days. Color mapping image processing of the callus elongated areas on the images and quantification of the images were performed.

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**Fig. 0:** The images obtained with the Dual Energy system and Dual Energy Tomosynthesis system who were subjected to limb lengthening surgery methods were compared at findings of same days.
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<table>
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<tr>
<th>Association of using cases</th>
<th>Results of Visual evaluation</th>
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<tr>
<td>Number of patients</td>
<td>Excellent</td>
</tr>
<tr>
<td>Number of examination</td>
<td>33</td>
</tr>
<tr>
<td>Follow-up case</td>
<td>Dual Energy Tomosynthesis</td>
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Fig. 0: Results of the visual evaluation. Evaluation had been done comparing to CR image relatively. Score each item are "Excellent: It is possible to observe follow-up it well." "Equivalent: There is some image that cannot be observed to use follow-up it. " "Poor: It is not possible to observe follow-up it. "

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Conclusion

In this study, we attempted to visualize quantified image pixel values of callus using Dual Energy Tomosynthesis that was newly installed in an x-ray fluorescent system. The following results were obtained: 1) It is possible to estimate the callus strength from the bone density. Furthermore, when the density of callus was less than 50% of that of ordinary bone, a high correlation of 0.988 was noted between them indicating a close relationship and more effective method of estimating callus strength. 2) The combination of 60kV and 120KV exposure technique images of Dual Energy Exposure mode showed a close relationship between an image’s pixel value and bone density. These results demonstrate that by applying a color map to quantify pixel values, the state of callus formation can be visualized as quantified values, thereby making it possible to evaluate callus strength. It is possible to evaluate the strength of the callus observed visually with radiographs using a dual energy Tomosynthesis. We consider that the Dual Energy Tomosynthesis images can help to confirm the diagnosis in the process of callus formation during limb lengthening surgery methods.

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References

