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Embossed X-ray computed tomography using a 50-μm-pixel flat panel detector

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Abstract

To perform quasi-three-dimensional (3D) X-ray computed tomography (CT), we improved a computer program of embossed CT system. First, we constructed a cone-beam X-ray CT scanner using a flat panel detector and a 0.1-mm-focus X-ray tube. We selected *xy* and *yz* tomograms with effective spatial resolutions of 35×35 μm^2, and embossed CT was performed by subtracting the shifted tomogram from the original. The shifted pixel numbers of *x* and *y* directions were both 3, a subtraction factor was 0.50, and the contrast resolution was maximized to 1.0. Quasi-3D tomograms of coronary arteries were observed at a high contrast with spatial resolutions of 100×100 μm^2.

Keywords: embossed tomography, cone beam, flat panel detector, 50 μm pixel, magnification tomography

1. Introduction

Recently, we developed several energy-dispersive X-ray computed tomography (CT) scanners to perform K-edge CT using iodine and gadolinium contrast media. In particular, photon-counting CT[1-4] is useful for selecting photon-energy range with a high energy resolution of 1% at 59.5 keV. Subsequently, we developed a beam-hardening CT scanner[5),6)] to control the effective photon energy utilizing the absorption of low-energy photons by the objects.

Embossed radiography is used to obtain quasi-three-dimensional (3D) image by subtracting the shifted image from the original radiogram and to improve the contrast resolution of the target region in the radiogram,

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and blood vessels are observed at a maximum contrast resolution of 1.0 using energy subtraction[7].

In our research, the major objectives are as follows: to obtain quasi-3D tomograms, to increase contrast resolutions of the target region, and to perform magnification tomography. Therefore, we performed embossed tomography using a cone-beam X-ray CT scanner and observed coronary arteries.

2. Experimental methods

2.1 Cone-beam CT

Figure 1 shows the block diagram of a cone-beam CT scanner used in this experiment. The scanner mainly consists of an X-ray generator (R-TEC, RXG-0120) with a 0.1-mm-focus tube, a turntable (Sigma Koki, SGSP-60YAW-OB), a flat panel detector (FPD: Hamamatsu, C7921CA-02), and a personal computer (PC). An object on the turntable is irradiated by the X-ray generator, magnified 720 radiograms are taken using the FPD, and tomograms are reconstructed using the PC. The turntable is driven by a stage controller (Sigma Koki, PAT-001), and the radiograms are sent to the PC using a network image transformer (Pleora Technologies, PT1000). The distance between the FPD and the X-ray focus is 0.50 m, and the distance from the focus to the turntable center is 0.35 m. Therefore, 1.4 times magnification tomograms are obtained, and the spatial resolution is improved to 0.7 times.

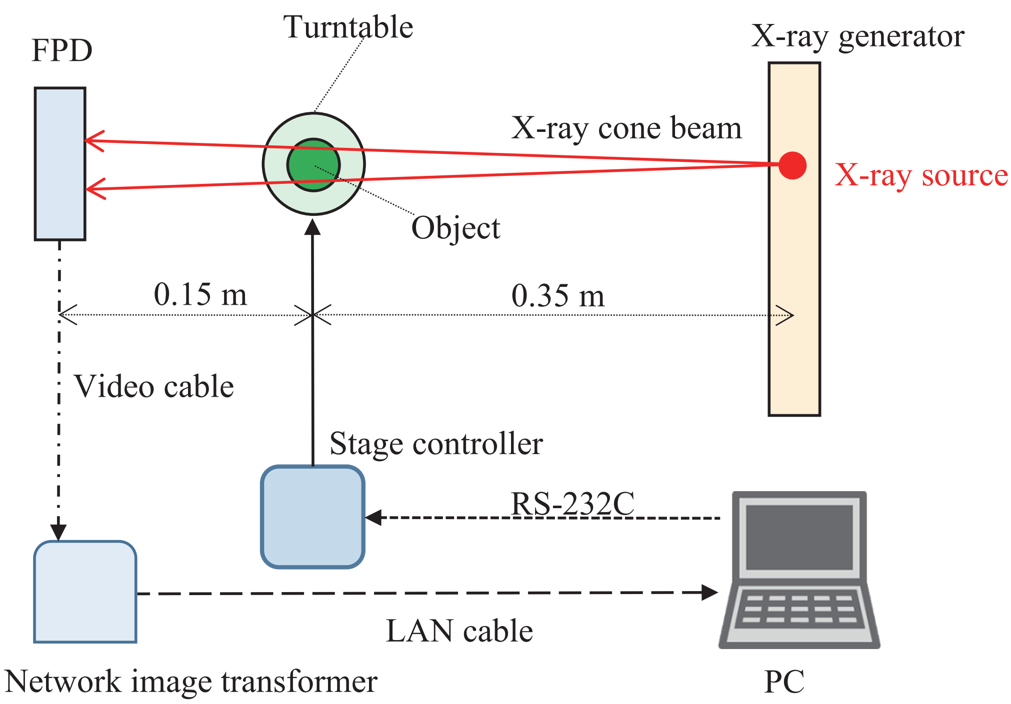

Fig. 1. Block diagram of the cone-beam X-ray CT scanner using a 0.1-mm-focus tube and an FPD.

2.2 Embossed CT

Eq. 1 shows the principle of embossed tomography using subtraction. The embossed tomogram $E(x, y)$ was written by:

$$E(x, y) = O(x, y) - k\,O(x-a, y-b), \qquad (1)$$

where $O(x, y)$ is the normal original tomogram obtained using cone-beam CT, $O(x\text{-}a, y\text{-}b)$ is the shifted tomogram, k is the subtraction factor ($0<k<1$), and a and b are shifted pixel numbers. When controlling image contrast of the target region, the contrast resolution increases up to the maximum of 1.0.

2.3 X-ray dose rate and spectra

X-ray dose rate was measured using a dosimeter (RaySafe, X2) to calculate the incident dose for the object at the turntable center using a 3.0-mm-thickness aluminum (Al) filter. Subsequently, the X-ray spectra were measured using a cadmium telluride detector system (Amptek, XR-100T) using the Al filter.

2.4 Dog-heart phantom

In this experiment, we used a real dog-heart phantom created about 20 years ago. The operation was carried out according to the rules of animal experiments in our university (28-014).

3. Results

3.1 X-ray dose rate and spectra

Tube voltage dependence of the X-ray dose rate at a tube current of 0.50 mA is shown in Fig. 2. The dose rate increased with increasing tube voltage and was 2.16 mGy/s at a tube voltage of 80 kV. Although the dose rate was not proportional to the second power of the tube voltage, the dose rates were quite stable at a tube voltage range from 50 to 110 kV.

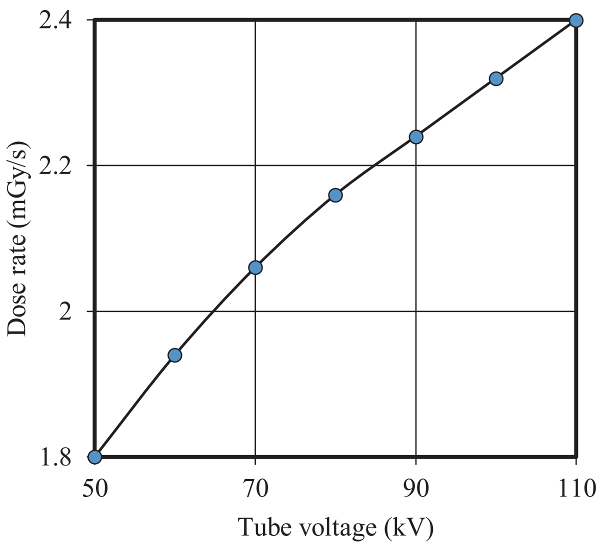

Fig. 2. X-ray dose rate measured using a semiconductor dosimeter placed 0.35 m from the X-ray source.

Figure 3 shows the X-ray spectra used in the cone-beam CT. We observed two peaks of characteristic X rays of tungsten Kα and Kβ. The bremsstrahlung peak energy was approximately 40 keV using the Al filter, and the maximum energy 82 keV did not correspond to the tube voltage of 80 kV.

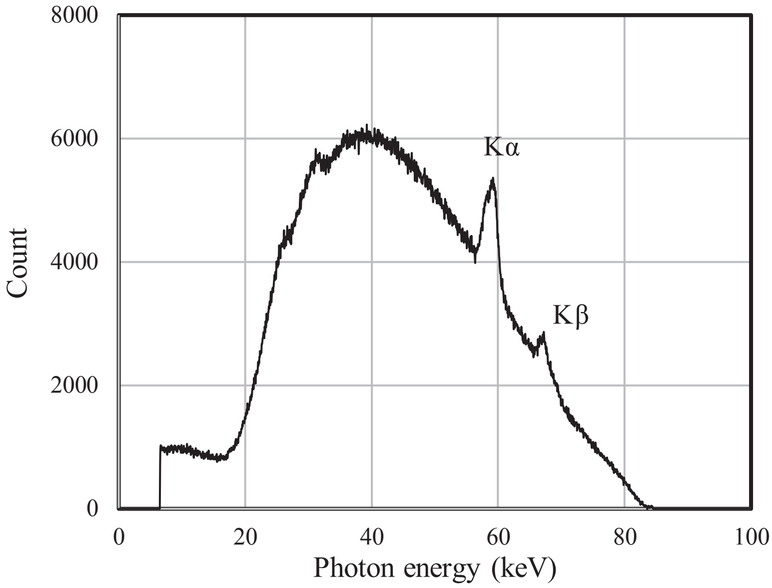

Fig. 3. X-ray spectra used in this experiment at a tube voltage of 80 kV.

3.2 Embossed CT

As previously described, the tomograms are reconstructed from 720 radiograms of a dog-heart apex taken using the FPD (Fig. 4). Fine coronary arteries were observed in magnification radiography.

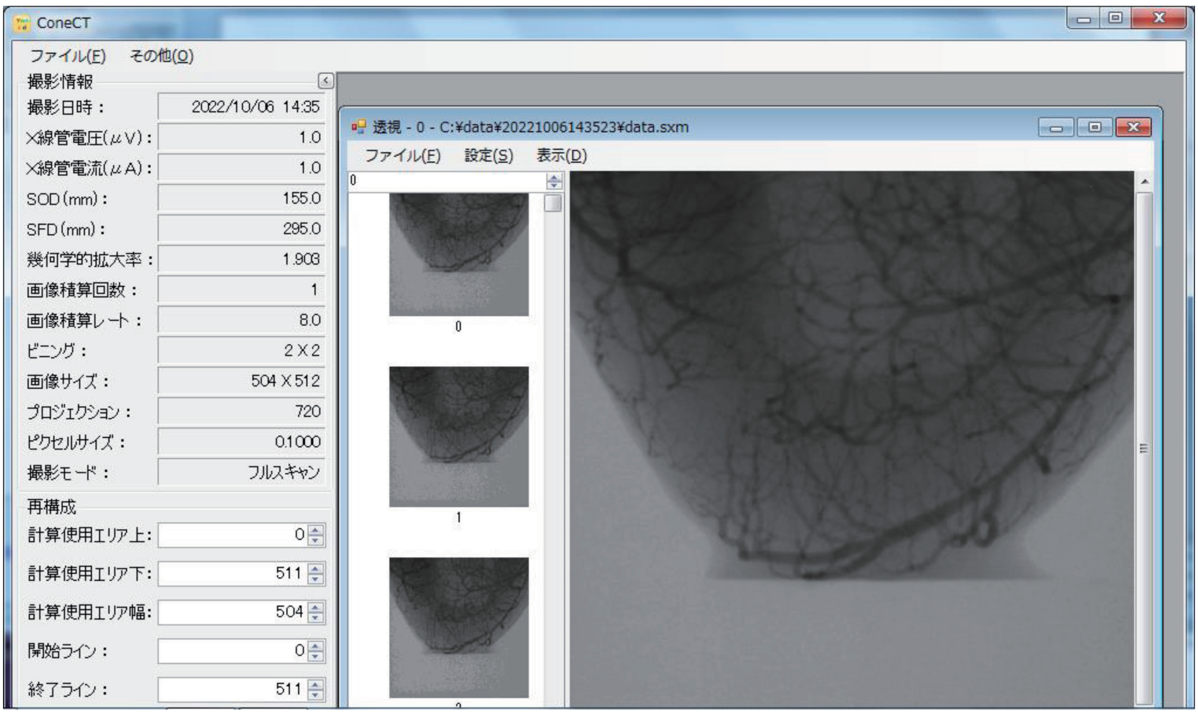

Fig. 4. 720 radiograms used to perform cone-beam CT.

Figure 5 indicates three *xy* tomograms in the computer program, and the embossed tomogram is calculated by subtracting the shifted tomogram (File 2) from the original tomogram (File 1). In embossed CT, the shifted pixel numbers of *x* and *y* directions were both 3, and the subtraction factor was a constant of 0.5. Utilizing embossed CT, quasi-3D arteries were observed at a high contrast.

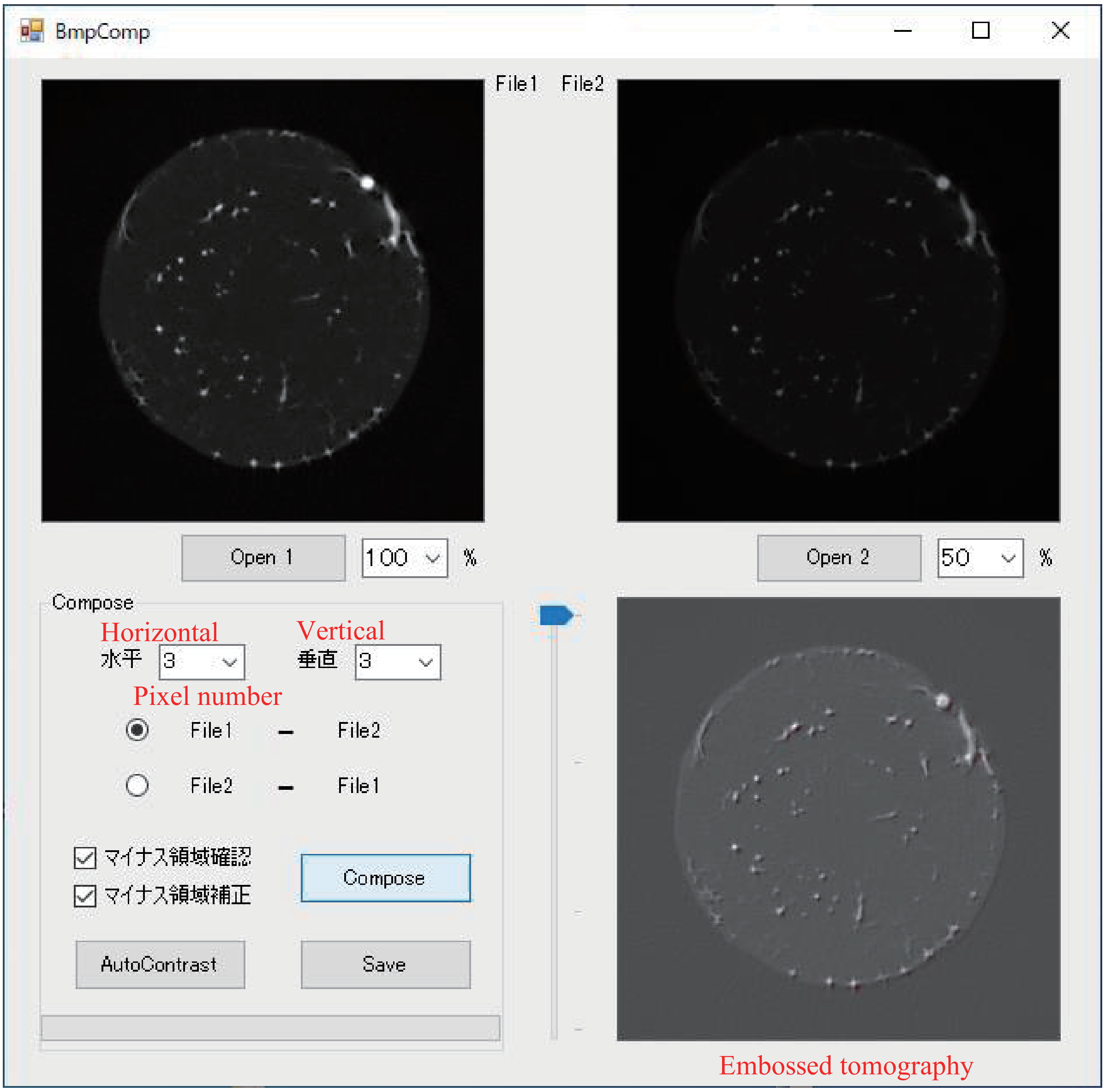

Fig. 5. The original (File 1), subtraction (File 2), and quasi-3D embossed tomograms of a dog heart in *xy* axis.

The *yz* tomograms in the program are shown in Fig. 6. The shifted pixel number and the subtraction factor were the same as in Fig. 5. Multiplying the subtraction factor reduce the image contrast of arteries, and quasi-3D image was obtained using embossed CT.

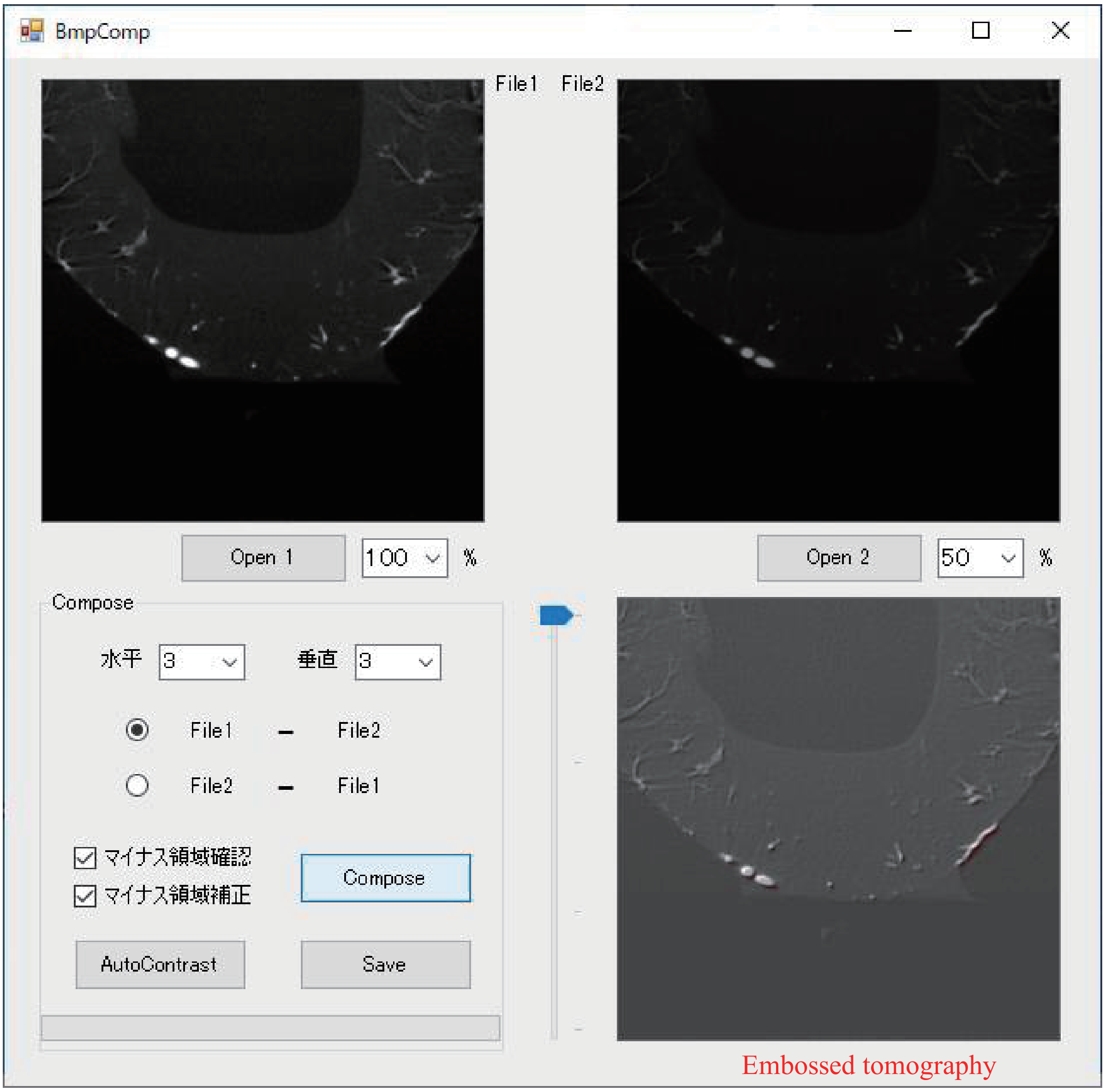

Fig. 6. The original (File 1), subtraction (File 2), and quasi-3D embossed tomograms of the dog heart in *yz* axis.

4. Discussion

Table 1 shows specifications of the embossed cone-beam CT scanner using a 0.1-mm-focus X-ray tube. The dimensions of the FPD detector were 50×50 mm^2, and the pixel dimensions were 50×50 μm^2. In this scanner, we used 1.4-time magnification radiography, the spatial resolutions were approximately 35×35 μm^2. For embossed tomography, the pixel-shifting method was used, and the spatial resolution fell with increasing shifted pixel number. The shifted pixel numbers of x and y directions were both 3, the resolutions of embossed CT were approximately 100×100 μm^2.

Table 1. Specifications of embossed CT.

Specifications	
Beam type	Cone
X-ray-focus diameter (mm)	Approx. 0.1
Detector	FPD
Detector dimensions of FPD (mm)	50×50
Turntable diameter (mm)	60
Rotation step (º)	0.5
Total rotation angle (º)	360
Scanning time (min)	6.0
Reconstructed pixel dimensions (μm^2)	50×50
Spatial resolutions of cone-beam CT (μm^2)	Approx. 35×35
Spatial resolutions of embossed CT (μm^2)	Approx. 100×100
Incident dose (mGy)	778

This cone-beam CT scanner was developed to perform non-destructive testing, and therefore, the scanning time was quite long and was 6.0 min. However, the scanning time can be reduced to below 1.0 min, and the incident dose for CT can also be reduced by reducing tube current.

In this experiment, the same-energy subtraction was used to confirm the effect similar to phase-contrast tomography. However, the energy-subtraction tomography is useful for visualizing fine blood vessels when using contrast media of iodine and gadolinium.

In the measurement of X-ray spectra, the maximum energy was high compared with the tube voltage, which is equal to the electron accelerating voltage. Such phenomena are considered to occur due to ripples in the Cockcroft high-voltage circuit. Therefore, the X-ray spectra must be measured to accurately determine the tube voltage.

5. Conclusions

We performed X-ray embossed CT using cone beams and a 0.1-mm-focus tube, and quasi-3D tomograms were obtained at a high contrast by subtracting the shifted tomogram from the original. Using the embossed CT, the contrast resolution of low-contrast region can be maximized to 1.0, fine blood vessels might be visualized at a high contrast.

Acknowledgments

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