Structural Properties in Ruptured Mitral Chordae Tendineae Measured by Synchrotron-Based X-ray Phase Tomography

Objective: Association with structural property and rupture of chordae tendineae in mitral valve complex is still unclear. Synchrotron-based X-ray phase tomography (XPCT) is a powerful tool to measure biological properties in soft tissues with much higher image contrast than the absorption-based imaging. To investigate association between structural property and rupture of chordae tendineae, we measured and compared tissue density in ruptured and healthy mitral chordae tendineae using XPCT.

Methods: The XPCT system was based on an X-ray Talbot grating interferometer in the bending-magnet synchrotron beamline, and located 200 m from an X-ray source. The X-ray energy for XPCT was set to 20 keV. The effective pixel size was 7.8 μm, and density resolution was 1 mg/cm³. Ruptured and healthy mitral chordae were sampled from patients with mitral regurgitation and cadaver. Ruptured mitral chordae tendineae were fixed with 5% formalin after resection at the surgery. Healthy chordae tendineae were extracted from hearts of cadaver fixed with 5% formalin, and were also sampled from patients with mitral regurgitation. They were set in the specially designed container filled with 1% agarose gel and scanned by XPCT. Clear XPCT imaging data of mitral valve complex, including papillary muscle and chordae tendineae, was obtained (Figure A). The XPCT imaging data was converted into 16-bit TIFF images of each tomography slice with custom-made original software. Further image processing and analysis of the tomography data were performed using the ImageJ software, and density was calculated (Figure B). The density of chorda tendinea near the ruptured portion was calculated in ruptured mitral chordae tendineae, while the density of chorda tendinea attaching on rough zone was calculated as healthy chordae tendineae. All measurements were performed using marginal chordae tendineae.

Results: Six chordae tendineae in 3 patients with mitral valve regurgitation due to rupture of chordae tendineae (rupture group) and 12 chordae tendineae in 12 cadavers (control group) were scanned. Mean age was 70.2±3.0 in rupture group and 67.2±14.1 years old in control group (p=0.4927). All scans of chorda tendineae with XPCT were successfully performed. Mean densities were 1.0288±0.0043 in rupture group and 1.0848±0.0147 g/cm³ in control group (p<0.0001), and density based on Synchrotron-based X-ray phase tomography in ruptured mitral chordae tendineae was significantly lower compared with healthy chorda tendinea (Figure C). In addition, 3 healthy chordae tendineae from patients with mitral regurgitation were scanned, and the density was higher than that in rupture group (healthy chordae tendineae from patients with mitral regurgitation: 1.0630±0.0069 vs. rupture group: 1.0288±0.0043 g/cm³, p=0.0054).

Conclusions: Synchrotron-based X-ray phase tomography made it possible to measure tissue density in mitral chordae tendineae. Low density in mitral chordae tendineae might be associate with the mechanism of rupture of mitral chordae tendineae.

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Figure A. Three dimensional image of mitral valve complex reconstructed from XPCT images.
*: Papillary muscle, †: Chordae tendineae.

Figure B shows method of calculation of the density in chordae tendineae.
Calculation was performed using ImageJ software on axial XPCT image at target level of marginal chordae tendineae.
*: Marginal chorda tendinea.

Figure C. Comparison of density between rupture and control group.
Density in rupture group was significantly lower than control group. *: p<0.05.