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OCT inspection of degenerative and rheumatic tendinous cords

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ABSTRACT

Surgical repair of the mitral valve complex presents high mortality rates, strongly dependent on the surgical procedure. Intensity and polarization sensitive OCT are explored as a feasible degradation inspection method for rheumatic and degenerative chords.

Keywords: optical coherence tomography, mitral valve, tendinous cords, degenerative mitral valve disease, rheumatic mitral valve disease

1. INTRODUCTION

Degenerative mitral valve disease, rheumatic mitral valve disease, endocarditis and ischemic mitral valve disease are the principal pathologies affecting the mitral valve and the valvar complex [1]. Defects on the mitral valve complex imply blood regurgitation from the left ventricle to the atrium, causing blood pressure and volume increase in the left side of the heart. Once the disease is detected, the mitral valve complex must be repaired or replaced by a mechanical prosthesis [2]. Surgical guidelines have been established to assess the best treatment on each scenario [3]. The procedure depends on the pathology itself and on the elements of the valve affected, but it is strongly influenced by the health conditions, risk factors and age of the patient.

Mitral valve repair is preferred to mitral valve replacement as it reduces operative mortality [4]. More conservative interventions imply a better prognostic, reducing recovering time and symptoms and extending the reoperation rate. However, all the affected valve components should be excised in the first intervention, as future reoperations increase the mortality rate considerably: around 5% mortality after the first intervention, 7% after the second and 17% after the third intervention. In case of emergency surgery, these rates are of around 20%, 30% and 40% respectively [4]. On the one side, excising all the affected tissue is vital. On the other side, the reduction of the excised tissue, if under healthy conditions, improves the prognosis and reduces mortality rate. This is especially relevant in cases of endocarditis, affected by infection of the heart tissue, and rheumatic valve, where the cords and valve present calcium deposits and can be fully calcified tissue.

Tendinous cords are formed by a dense collagen core, surrounded by a spongy collagen and elastin layer. Under healthy conditions, cords present parallel and homogenous distribution of collagen bundles. When cords become pathological, the elastin amount increases breaking the collagen bundles, mucopolysaccharides fill the gaps of collagen and, in some cases, also calcium deposits appear. Degradation of the cords can affect the core, the spongy layer or both [5]. When only the core is affected, it remains hidden during surgical repair from the surgeon viewpoint. Therefore, a diagnosis tool will be desirable to assess the pathological status of the tendinous cords under intraoperative scenarios with the cord diagnosis provided within the surgery workflow.

Optical Coherence Tomography (OCT) and Polarization Sensitive Optical Coherence Tomography (PS-OCT) are proposed to evaluate the cross section of the tendinous cords. OCT provides information about tissue structure and homogeneity, highlighting elements with different refractive indexes and attenuation coefficients.

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PS-OCT is sensitive to the phase delay produced by birefringent tissues, such as ordered fibers of collagen [6]. The combination of both techniques can provide accurate information for the characterization of different components in the cords, such as collagen, mucopolysaccharides and calcium deposits.

2. MATERIALS AND METHODS

Human tendinous cords from the mitral valve are excised from a donor and from two patients intervened of degenerative mitral valve disease and rheumatic mitral valve disease. Measured cords are diagnosed by an experienced cardiovascular surgeon. Specimens are preserved in a 1% solution of glutaraldehyde at a temperature of 7ºC upon OCT measurements and at 23ºC during the measurement.
The OCT system is Thorlabs OCS1300SS, working at 1325nm with 100nm FWHM. The imaging region is of 10 mm x 3 mm lateral by depth. Penetration is digitalized with 512 pixels for 3mm, which for tendinous cords ($n \approx 1.3897$ measured in the OCT images [7]) is reduced to 2.158 mm. Lateral dimension is digitalized in 1024 pixels (phase image) and 4096 pixels (intensity image). Phase retardation is digitalized from 0º to 180º in steps of 0.7º.

The fringes present in the phase image are due to the birefringence of the collagenous tissue. This affects differently the horizontal and vertical components of the detected signal, producing a phase difference from 0º to 180º. The birefringence of the specimens is obtained from the phase retardation information following Equation 1, where z is the period of fringes and λ_0 the OCT center wavelength [6]: example

$$\delta = \frac{\pi\lambda_0}{2\pi z} = \frac{\lambda_0}{2z} \tag{1}$$

3. RESULTS AND DISCUSSION

Control specimen exhibits homogeneous intensity levels (Fig. 1a, 1d). The fringes effect in the intensity image is an artifact due to tissue birefringence in the OCT dual channel detection. Tissue shows a homogeneous texture, produced by the cross section imaging of collagen bundles. This is maintained along the whole chord. Phase retardation shows a robust parallel fringe pattern in depth (Fig. 1g). This is due to the parallel and uniform distribution of collagen in all the circumference of the cord. In the case of *rheumatic* specimen intensity images (Fig. 1b, 1e), the fringes pattern is not present on the surface, which corresponds to calcified tissue. In the phase retardation image (Fig. 1h), the fringes pattern is present below the surface, corresponding to the core of collagen. Despite being covered with a calcified spongy layer, the core shows normal collagen composition. The *degenerative* specimen (Fig. 1c) is likely to the normal one, but showing smaller radius. Looking at the longitudinal cut (Fig. 1f), there are some intensity anomalies apart from the intensity fringes. These anomalies correspond to tissue remodeling after the self-repair of internal damage, alternating collagen parallel distribution [8]. The phase retardation (Fig. 1i) is regular, but blurred when compared to the control one.

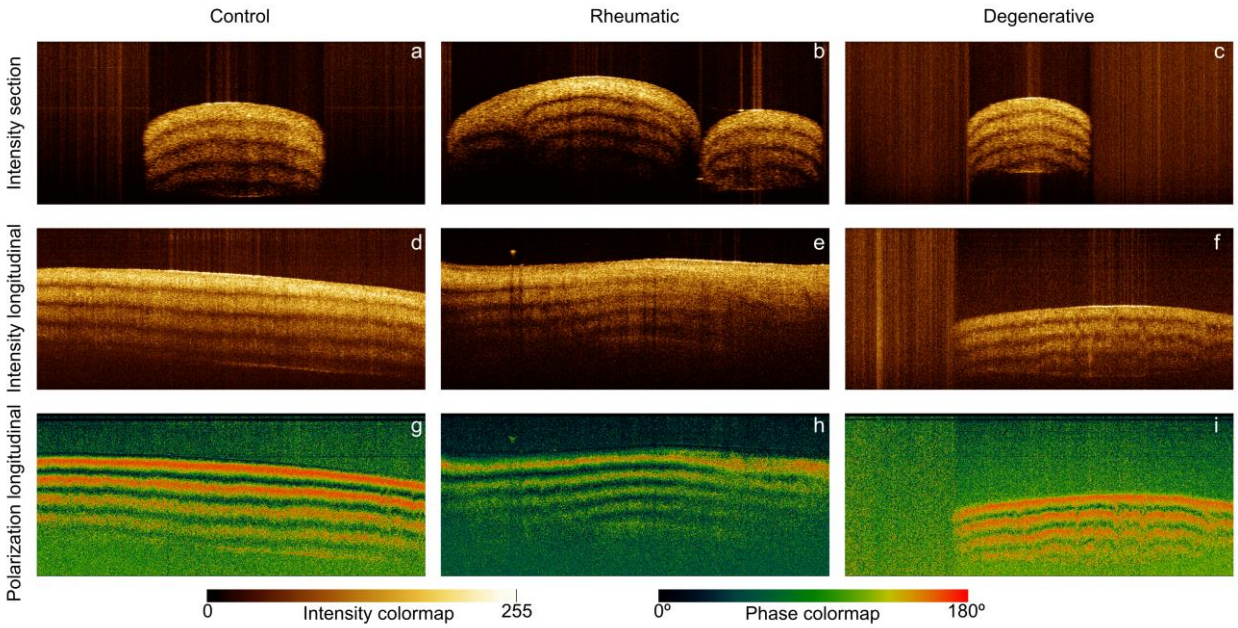

Figure 1. OCT images corresponding with a control chord (left column), rheumatic chord (center column) and degenerative chord (center column). Intensity OCT is used to produce a transversal section of the chords (a, b, c). Intensity (d, e, f) and polarization sensitive (g, h, i) OCT are used to produce co-registered longitudinal section of the chords.

The birefringence parameter is calculated from the phase retardation in (Fig. 1g, 1h, 1i) according to Equation 1. The control specimen presents a birefringence, obtained from Figure 1g of $\delta=3.3\cdot10^{-3}$. Rheumatic presents $\delta=2.8\cdot10^{-}$ and degenerative presents $\delta=2.6\cdot10^{-3}$. The birefringence in the pathological chords is slightly smaller than the control sample, due to collagen loss and remodeling.

4. CONCLUSIONS

Intensity OCT and PS-OCT have been used to characterize and compare tendinous cords from human mitral valves. Healthy cords show homogeneous intensity distribution and strong parallel phase patterns. Rheumatic and degenerative specimens show weaker birefringence patterns and less homogeneity. The birefringence pattern in those two cases is lower than in the control sample. The combination of both OCT techniques allows visualization of the core of the tendinous cords, providing useful structural information. In the case of rheumatic tissue, the core of the cord can be correctly imaged and the birefringence parameter obtained. This technique can potentially help surgeons during intervention, giving a deeper insight of the condition of the valvar complex.

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