Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Assessment Myocardial Perfusion and Contraction by Karhunen-Loeve Transform on Scintigraphic Images

Oleg Blagosklonov, *Member, IEEE*, Laurent Comas, Pascal Berthout, Remy Sabbah, Josette Verdenet, Jean-Claude Cardot, and Michel Baud

***Abstract*—Theory and previous studies showed that KLT (an application of principal component transform for imaging) can be use for analysis of cardiac function. This paper presents the results of our studies concerning the applications of KLT for images smoothing, quantification of myocardial contraction, and improvement of inter-observer reproducibility in cardiac imaging. The paper also describes the use of 4D cardiac phantom to quantify Karhunen-Loeve images.**

I. Background

SCINTIGRAPHIC techniques are widely used to evaluate different parameters of cardiac function: myocardial perfusion, left ventricular ejection fraction, end-systolic and end-diastolic volumes, wall thickening etc. Quantitative analysis of the images sequences provides additional, clinically useful information. The Karhunen-Loeve transform (KLT) can be used for quantitative evaluation of cardiac function.

The KLT is a statistical representation technique based on the changing of space that allows the description of a phenomenon, measured in a pattern (observation) space whose elements are correlated, by means of uncorrelated parameters in another space in which the principal axes are ordered in terms of importance [1]-[3]. An important property of KLT is that, unlike the Fourier transform or the factorial analysis, the basic vectors are not known *a priori* but are "tailor made" for the given set of vectors.

In the case of cardiac scintigraphic images, the original space is a sequence of images obtained by a discrete time sampling of the behavior of the object. Linear filtering of the sequence considered as a time function allows the extraction of the dominant information. The featured space is that of the eigenvectors of the covariance matrix of the initial data. These vectors are ranked according to a decreasing variance order. Significant parameters are therefore selected by keeping vectors associated with a maximum amount of variance. The images of KLT are obtained by projection of the initial sequence on the ranked eigenvectors. An information compression may be obtained by expanding the initial sequence of images onto the most significant vectors of featured space. In our case, the first three images of KLT (KL0, KL1, and KL2) contain more than 95% of the information (in a statistical mode) and the following images contain only noise.

The first KLT image (KL0) is the sum of projections of initial sequence onto the components of the first eigenvector, and it is the "mean" image of the cardiac cycle; this image does not supply any information on temporal evaluation of pixels (Fig. 1).

The second KLT image (KL1) regroups pixels by families of temporal evolution without paying attention to the intensity of the pixels. Since components of the second eigenvector have opposite signs at systole and at diastole, on this image "ventricular" pixels have positive values, "atrial" pixels have negative values, and "noise" pixels have near zero values (Fig. 1).

KL2 image is very variable and its interpretation is difficult; however, this image is required for reconstruction of the initial sequence by inverse KLT (*i.e.* for spatio-temporal smoothing of image sequences).

KL0 vs. KL1 space illustrates the regrouping of pixels by families; "noise" corresponds not only to background noise but also to the pixels which had constant values during data acquisition (Fig. 2).

II. Images Smoothing

Visual analysis of gated blood pool (GBP) image sequences before and after smoothing by KLT showed that the reconstructed images were more noiseless. When looking at the series in cine mode, we found that reconstructed image sequences were also temporally smoothed. Analysis of the time-activity curves demonstrated that in “noise” regions time-activity curves were flatter after KLT smoothing whereas the curves were not changed in the left ventricular region. Furthermore, we found that the accuracy of end-diastolic and end-systolic edge detection was better on the filtered images.

We observed the same results when KLT was applied on gated myocardial single-photon emission computed tomography (gSPECT).

We concluded that the KLT can be used for both spatial and temporal smoothing of scintigraphic image sequences. This technique affects only the regions of noise and does not

Manuscript received April 23, 2006.
O. Blagosklonov (corresponding author), L. Comas, R. Sabbah, J. Verdent, J. C. Cardot, and M. Baud are with the Department of Nuclear Medicine, Jean Minjoz University Hospital, Besançon, 25030 France (phone: +33-381-66-82-94; fax: +33-381-66-93-96; e-mail: oleg.blagosklonov@univ-fcomte.fr).
P. Berthout is with the Department of Nuclear Medicine, St-Vincent Clinic, Besançon, 25044 France. (e-mail: pberthout@wanadoo.fr).

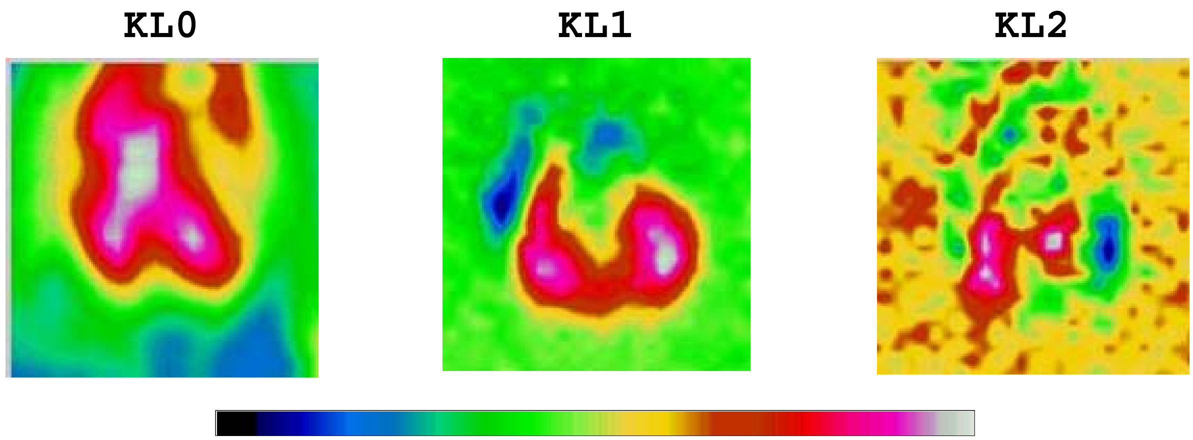

Fig. 1. "Principal" images of KLT from gated blood pool imaging in a healthy man.

modify the others (*e.g.* the left ventricular region).

III. Inter-observer Reproducibility

We compared the results of manual assessment of the left ventricular ejection fraction (LVEF) performed by two operators before and after KLT smoothing of the GBP images.

Data analysis was based on Bland-Altman method and intra-class correlation coefficient (ICC) for differences between left ventricular ejection fraction (LVEF) values found by two operators.

The intra-operator reproducibility was not affected by KLT smoothing; intra-class correlation coefficient was 0.98 before and after filtering. However, the inter-operator reproducibility was improved by the filtering; ICC was 0.91 and 0.98 before and after the smoothing by KLT respectively. The results of Bland-Altman analysis confirmed these findings.

Thus, the use of KLT enhances inter-operator reproducibility of GBP and facilitates contour recognition and visual comfort of operator, *i.e.* decreases interpretation time. Furthermore, automatic contour detection becomes more accurate, that improve temporal analysis of ventricular shape.

IV. Quantification

Visual analysis of KLT images obtained from GBP allows to distinguish the regions of myocardial dyskinesia and/or akinesia; this method may be used to diagnose heart diseases such as arrhythmogenic right ventricular dysplasia and right ventricular myocardial infarction [4].

Furthermore, GBP combine with KLT may be used for quantitative analysis of global ventricular contractile function [5]. Use of this method for evaluation of right ventricular contraction is more difficult because of non round form of this ventricle, that complicate the modelling and application of mathematical methods for assessing of the contraction.

Quantitative analysis of LV global contraction is more easy to perform. Presented results showed that standard

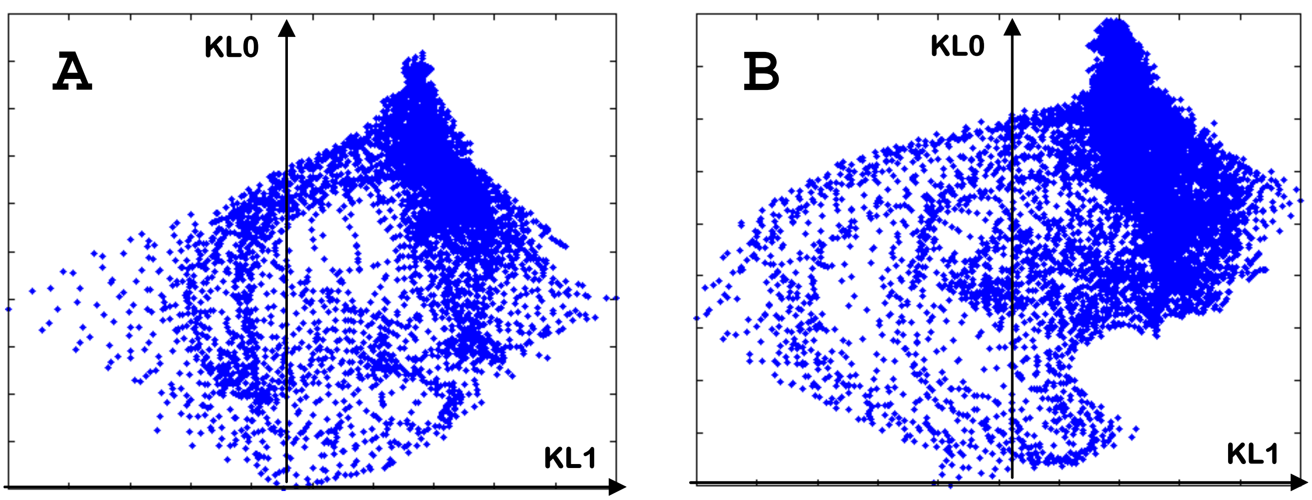

Fig. 2. KL0 vs. KL1 space: pixels distribution in a healthy man (A) and in a patient after myocardial infraction (B)

deviation of intensity in LV region on KL1 image may characterize global myocardial contraction (Fig. 4).

The comparison of the scores in segments on gSPECT vs. KLT images showed that the differences were not significant in more than 90% of segments (the difference was less than 2 points). Moreover, intra-class correlation analysis showed excellent correlation between the scores in the segments (ICC were 0.93 and 0.85 for perfusion vs. KL0 images and for contraction vs. KL1 images).

V. Use of the 4D Cardiac Phantom

For this study we used the 4D NURBS cardiac torso phantom (4D-NCAT) developed at the University of North Carolina at Chapel Hill. The heart is generated by using a volume of 256 images of 256*256 pixels. The field of view was 40cm. The duration of the cardiac cycle was 60 beats per minute and 8 volumes per cycle were obtained. A lesion is defined in NCAT as an independent volume which is subtracted from normal thoracic volume. Three localizations of lesion were proposed corresponding to main coronary artery territories (anterior, lateral, inferior). Any combinations of cardiac function can be simulated – a perfusion defect with normal contraction, an abnormal kinetics without perfusion defect, and a perfusion defect associated to a kinetic defect.

The model and some quantitave parameters were evaluted by QGS software (Cedar Sinai comercial software) which is routinely used. This study showed that NCAT model seemed well adapted to the measurement of perfusion and kinetic defects.

The Karhunen-Loeve transform applied to myocardial gated SPECT was validated on the 4D NCAT modified model. Its interest was to show how to quantify the perfusion and kinetics anomalies with only two images, KL0 for perfusion and KL1 for kinetics .

VI. Conclusion

KLT is a powerful tool of 4D image processing in nuclear cardiology. Use of KLT for smoothing and/or quantification provides clinically useful data facilitating the interpretation.

References

[1] S. Watanabe, "Karhunen-Loeve expansion and factor analysis, theoretical remarks and applications," in *Trans. 4th Prague Conf. Information Theory, Statistical Decision Functions, and Random Processes*, Prague, 1965, pp. 635–60.

[2] Y. T. Chien and K. S. Fu, "On the generalized Karhunen-Loeve expansion," *IEEE Trans. Information Theory*, vol. 13, pp. 518–20, May 1967.

[3] K. Fukunaga and W. L. G. Koontz, "Application of the Karhunen-Loeve expansion to feature selection and ordering," *IEEE Trans. Comp*, vol. C-19, pp. 311–18, Oct 1970.

[4] O. Blagosklonov, G. I. Storozhakov, J. Verdenet, A. Sabbah, and J.C. Cardot, "[Quantitative analysis of images obtained at radionuclide ventriculography for assessment of contractility of right ventricular myocardium]," *Kardiologiia*, vol. 40, pp. 51-4, Jun. 2000.

[5] O. Blagosklonov, A. Sabbah, J. Verdenet, and J. Cardot, "Application of Karhunen-Loeve transform in nuclear cardiology: spatio-temporal smoothing and quantitative image analysis," *Comp in Cardiolog* , vol. 27, pp. 299-302, Sep. 2000.

[6] L. Comas, P. Berthout, R. Sabbah, J. P. Daspet, O. Blagosklonov, M. Baud, J. Verdenet, and J. C.Cardot, "Use of a 4-D Cardiac Phantom to Quantify Karhunen-Loeve Images Applied to Myocardial Gated SPECT," *Comp in Cardiolog* , vol. 32, pp. 541-4, Sep. 2005.

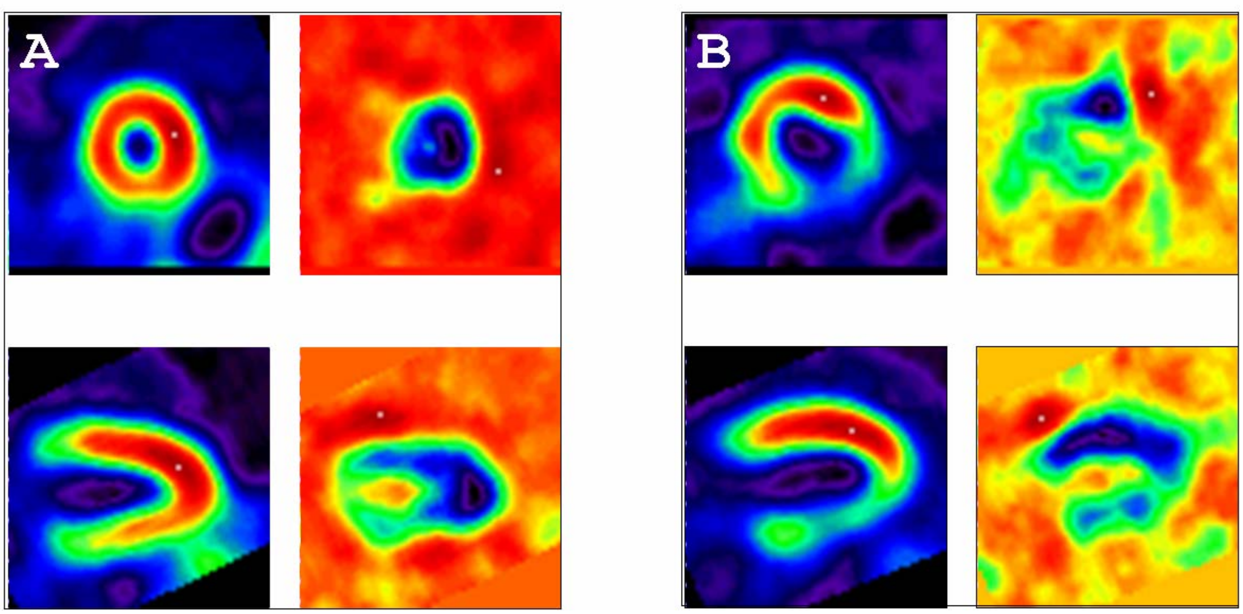

Fig. 4. KL0 and KL1 images from gSPECT in a healthy man (A) and in a patient after myocardial infraction (B) – short axis (top line) and horizontal long axis (bottom line).