Characterizing Patterns in Phase Contrast X-Ray Computed Tomography Images of the Patellar Cartilage with Deep Transfer Learning

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Abstract

This study aims to systematically assess the efficacy of deep transfer learning methods for classifying between healthy and diseased tissue patterns as obtained in Phase contrast X-ray computed tomography (PCI-CT) of the human cartilage matrix. We extracted features from two different convolutional neural network architectures, CaffeNet and Inception-v3 for characterizing such patterns. These features were quantitatively evaluated in a supervised classification task measured by the area (AUC) under the Receiver Operating Characteristic (ROC) curve as well as with unsupervised clustering using t-Distributed Stochastic Neighbor Embedding (t-SNE). The best classification performance, for CaffeNet, was observed when using features from the last convolutional layer and the last fully connected layer (AUCs > 0.91). Meanwhile, off-the-shelf features from Inception-v3 produced similar classification performance (AUC > 0.95). Visualization of clustering results, confirmed adequate characterization of chondrocyte patterns for reliably distinguishing between healthy and osteoarthritic tissue classes. Such techniques, can be potentially used for detecting the presence of osteoarthritis related changes in the human patellar cartilage.

1 Introduction

Phase-contrast X-ray computed tomography (PCI-CT) is an imaging technique capable of visualizing the internal architecture of tissues at micrometer resolution [1]. This acquisition methodology exploits the fact that X-rays are not just absorbed when passing through matter but also refracted producing a more pronounced contrast when compared to conventional absorption based X-ray imaging modalities. This allows PCI to be effective in imaging tissue types where the conventional absorption contrast is either unable to resolve the differences between soft tissue types, i.e., breast, or is poor/absent, i.e., cartilage. There is a huge potential for such a technique to be used for early detection of degenerative cartilage structural changes associated with osteoarthritis (OA, widely recognized as one of the leading causes of disability worldwide. In this context, the adept visualization of the cartilage matrix using PCI-CT has been demonstrated previously.

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We have previously [2, 3] shown that PCI-CT images can be characterized effectively with 2D or 3D texture features, in a computer aided diagnostics framework. In this study, we aim to investigate the effectiveness of CNNs in characterizing degenerative changes occurring due to osteoarthritis in PCI-CT images of the cartilage through the application of supervised as well as unsupervised methods.

2 Data

Two healthy and three osteoarthritic cylinder-shaped osteochondral samples (diameter: $7mm$) were extracted within $48h$ postmortem from the lateral facet of the four human patellae using a shell auger. These samples were subject to PCI-CT imaging with an analyzer-based imaging (ABI) scheme where a parallel monochromatic beam of synchrotron radiation (X-rays of energy 26keV) was used to irradiate the sample. The images were acquired at the European Synchrotron Radiation Facility (ESRF, France). Further details about the experimental setup can be found in [1]. Chondrocyte patterns were annotated with 2-D square ROIs in the radial zone of the cartilage matrix on the acquired PCI-CT images of all five specimens. 842 square ROIs, each of size 101 pixels were annotated in total, of which 439 were osteoarthritic and 403 were healthy. Detailed information regarding specimen preparation, imaging setup and ground truth extraction is avaliable in our previously published studies[1, 2].

3 Methods

For characterizing the patterns in the cartilage matrix, in this study we have used and compared the performance of two different pre-trained convolutional neural networks (CNNs): CaffeNet and Inception-v3, which were trained on the Imagenet database. We have have also fine-tuned the CaffeNet and tested the classification performance. The features obtained were used in a classification task, with a support vector machine (SVM), for distinguishing between healthy and osteoarthritic ROIs. The SVM was trained while ensuring that ROIs from the same subject are not used for both training and testing purposes. Receiver operating curves (ROC) were generated for each classification. Furthermore, we explored the use of an unsupervised dimension reduction technique known as t-Distributed Stochastic Neighbor Embedding (t-SNE), for analyzing the representative power of the features for distinguishing between healthy and osteoarthritic ROIs.

4 Results

The results from the classification experiments are summarize in Table 1. For features extracted from a pre-trained CaffeNet, the best classification performance was obtained using the features extracted from the last convolutional layer (conv5, AUC= 0.91) and the last layer (fc8, AUC= 0.91). Classification with the fine-tuned CaffeNet results in an AUC of 0.96. Features from all inception modules can accurately distinguish between the two classes (AUC > 0.95), with no significant differences in performance seen through the different layers.

Table 1: Comparison of AUC (mean $\pm$ standard deviation) values obtained for the different features used in this study.

CaffeNet	**AUC**	**Inception-v3**	**AUC**
conv1	0.56 ± 0.36	*inception1*	0.93 ± 0.13
conv2	0.77 ± 0.31	*inception2*	0.96 ± 0.06
conv3	0.80 ± 0.22	*inception3*	0.96 ± 0.07
conv4	0.83 ± 0.19	*inception4*	0.94 ± 0.12
conv5	0.91 ± 0.08	*inception5*	0.96 ± 0.07
fc6	0.81 ± 0.17	*inception6*	0.94 ± 0.12
fc7	0.90 ± 0.10	*inception7*	0.94 ± 0.12
fc8	0.91 ± 0.08	*inception8*	0.94 ± 0.11
		inception9	0.96 ± 0.08
FT	0.96 ± 0.07	*inception10*	0.95 ± 0.07

We have also explored the visualization of features from both networks using t-SNE (Fig.1). The visualizations produced distinct clustering of healthy and diseased ROIs, in-line with classification performance as obtained.

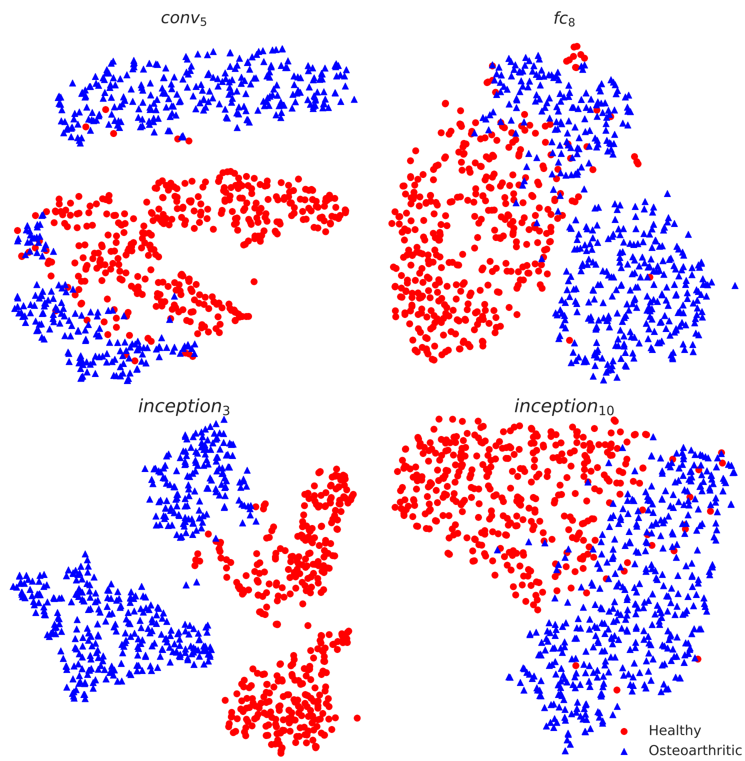

Figure 1: Visualization of a few high-dimensional features obtained using t-SNE dimension reduction

5 Conclusion

This study shows the applicability of deep transfer learning techniques to classify healthy and osteoarthritic chondrcyte patterns acquired from PCI-CT imaging of the human patellar cartilage. We explored the utility of feature representations extracted from two different convolutional networks: CaffeNet, as well as Inception-v3. Overall our results demonstrate the potential for using such deep-transfer learning approaches, for detecting the presence osteoarthritis, in a computer-aided diagnosis framework.

References

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