Femur Detection in Radiographs using Template-based Registration

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Abstract. This article describes a method for the automatic detection of the proximal femur in radiographs using a template-based mutual information registration method. It will be part of a planned, larger system for automated estimation of osteoporosis in the femoral neck. Our multi-step optimization process achieves a successful registration rate of 70% to 95%.

1 Introduction

Osteoporosis is a metabolic disease of the skeletal system, which leads to several million fractures every year, mainly with elderly women. Beside the spine and the distal radius, the femoral neck is particularly affected. This leads to a substantial mobility restriction of the patients.

2 Motivation

The treatment of a fracture of the femoral neck depends on the type of the fracture and the bone quality. Commonly, the estimation of bone quality of the acutely injured patient has to take place with a radiograph of the pelvis, which is made by routine if a fracture of the femoral neck is suspected. The evaluation is carried out by a physician and depends to a considerable degree on the quality of the radiograph as well as the experience of the physician.

This work is part of a larger project with the aim of providing a sophisticated decision support system for surgeons when selecting the appropriate operative procedure. Methods of pattern recognition will be used for an application that estimates the grade of osteoporosis of patients with hip fractures on the basis of radiographs. It will integrate seamlessly into clinical work-flow. One requirement for the osteoporosis analysis is the automatic localization of the femur in order to place regions of interest (ROI) reproducibly onto the radiograph. This work presents a method, results and evaluation for a robust detection of the un-fractured femur in digital hip overview radiographs.

3 State of Research

Due to the superimpositions in radiographs and variations in shape and position of the patient, segmentation of the femur in radiographs is a challenging task. The most promising methods described so far have been published by Behiels [1, 2] and base on active shape models and show a success-rate of approximately 70%. One of the main causes for the missing 30% seems to be the disregard of variations in position. Consequently, Behiels suggests enhancing the model with these variations. The risk of getting an unspecific model may increase by the mixture of the independent variations in shape and position.

The literature describes different methods for the analysis of regions of interest in radiographs to estimate the grade of osteoporosis. Publications (e.g. [3, 4]) focus on gray-level, structure, texture or fractal analysis and simply use manually positioned regions. The manual placement of regions of interest leads to inter- and intra-observer variations.

Fully automatic analysis of osteoporosis from radiographs is already possible with commercial systems. Their drawback is the restriction to measurements of peripheral bones, e.g. the hand, that are in a considerable distance to the fractured site.

4 Benefit

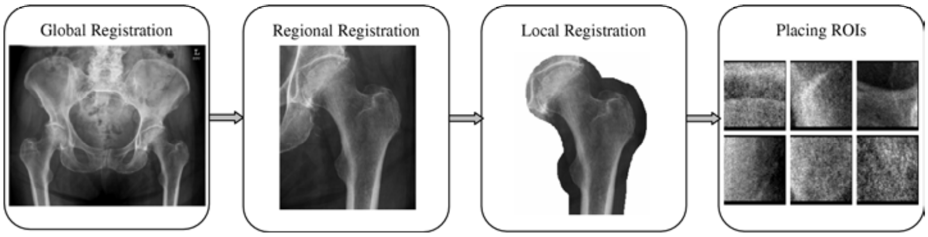
A decision support system might ease the pre-operative planning, supporting the surgeon in the decision for an appropriate implant and operation method - depending on the actual local quality of the fractured osteoporotic bone.

5 Methods

The primary aim of our work is the correct position of regions of interest onto radiographs. As the analysis in the fractured side is difficult and questionable, the regions for the analysis of osteoporosis will be placed at the contralateral un-fractured femur. This is valid, because there is a good correlation of the mechanical properties of the bone between both sides [5]. To achieve this, a pixel-precise segmentation of the femur is not necessary. We suggest to register a template onto the radiograph to perform the localization of the femur.

In order to detect the proximal femur, a sample radiograph serves as a template and is registered with a patient's radiograph. Our tests with different intensity based registration metrics showed the best results when using mutual information as registration metric. This, for a monomodal registration problem surprising outcome, finds its explanation in the projective characteristics of hip overview radiographs. The brightness of the bony structure in the femur varies considerably due to loss of bone mineral density. Additionally, the gray values of soft tissue surrounding the bone vary extensively with the patient's constitution which leads to different ratios in intensities of bony and soft tissue areas. A special challenge in the detection of the femur is a pendulous abdomen that sets

Fig. 1. The main tasks of the processing pipeline. Each task is subdivided in specialized processing steps. Global, regional and local registration use different regions of the images and process them in four zoom levels to achieve a more robust registration.



a heavy bias over the proximal femur region in some images. These challenges showed to be solved best by a multimodal registration method.

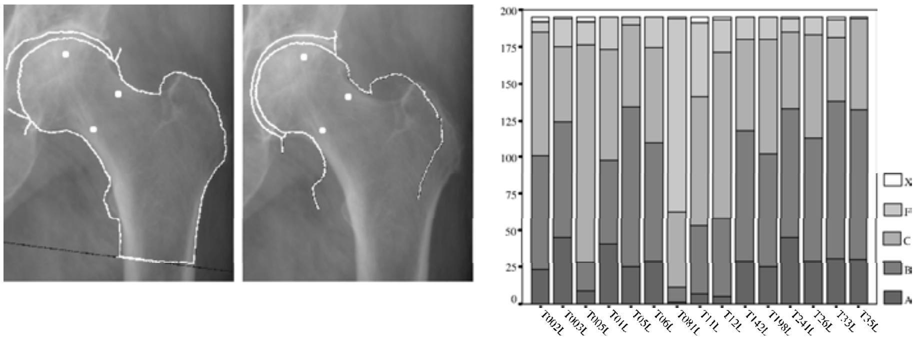
The information about the location of the regions of interest, contained in the template, is mapped onto the radiograph. These regions of interest, that may be placed e.g. in accordance with the classification of Singh et al. [6], allow a statistical analysis for the estimation of osteoporosis.

The registration of the template with the radiograph is a multi-step optimization process (fig. 1). In order to start this process, the physician has to assign the system the side of the un-fractured femur. With this information, the software uses the template for the specified side and starts a three-step registration process. First, the *global registration* maps a complete radiograph with the pelvis and both femura to gain a principle location and a basic adaptation to the patient's size. The following *regional registration* uses a clipping of the template image that surrounds the assigned, un-fractured proximal femur roughly and handles variations in flexion, adduction and rotation. The *local registration* finally concentrates on a very narrow region of the proximal femur and is responsible for the fine-tuning of the registration.

For the improvement of stability, every registration step incorporates a four-level image scale pyramid. With succeeding pyramid-levels, the radiograph is successively increased in resolution, until the registration is executed with the full resolution of the radiograph. Additionally, in each of these levels the degrees of freedom of the optimizer are adapted. This means that each level's registration starts with an almost pure translation transformation. The range for rotation and uniform scaling is increased incrementally so that in the end all three transformations apply with their full weight. The combination of translation, rotation and uniform scaling showed the best registration results with a minimum of anatomically impossible transformations.

The described methods have been implemented in a clinically usable application. The software toolkit ITK [7] provided the framework for data handling and image processing algorithms. It enabled us to test and implement different metrics, methods and strategies in a very flexible way.

Fig. 2. (a), (b) Result images categorized in groups A and B. The 3 dots in the femoral head and neck helped to decide if potential regions of interest might be within the femur. (c) Accumulated number of radiographs registered in categories A-X per template.



(a) Category A (b) Category B (c)

6 Results and Discussion

In order to verify the quality of the processing pipeline, 195 radiographs, obtained from Innsbruck University Hospital (courtesy of Prof. Jaschke), have been registered with 15 different templates. The templates are a random sample of these radiographs. In order to verify the processing pipeline's output, the 2925 results have been analyzed by expert visual inspection and were categorized in 5 groups:

A: The outline of the template image matches perfectly the contour of the femur.
B: The outline of the template image is not perfectly aligned with the contour of the femur but is close enough to place ROIs correctly onto the femur.
C: The outline of the template is related to the contour of the femur but the mapping is not sufficient for a good placement of ROIs.
F: The outline of the template was placed somewhere in the image, no evident relation with the contour of the femur can be seen.
X: The registration failed.

Figures 2a and 2b show example images of successful registrations categorized as A and B.

Our method showed to be robust even with artifacts from implants and extremely varying image quality. We succeeded in placing fields of measurement objectively and reproducibly in over 70% of these 195 samples of radiographs using template T33L (fig. 2c). This is in the same range of success as Behiels' method [2] using active contours. These 70% were reached with a single template. Taking variations of shape into account by using the best out of 4 different templates (T33L, T241L, T198L, T05L), a success rate of over 95% has been achieved.

So far, there is no automatic method to determine which of the four templates shows the best registration because the metric value of mutual information is not comparable over different registrations, only statistical tendencies have been noticed. A manual inspection of the four registration results should be of little effort for the physician. As the regions of interest have not yet been analyzed for osteoporosis, it is not yet possible to estimate the difference in the osteoporosis assessment for different templates with little variations in the registration quality.

Depending on the size of the images and the combination of template and patient's radiograph, the automatic process of matching these two images takes about 1.5 minutes for a 2828×2320 pixels image on a 1.8 GHz P4 computer.

In future work, we want to consider both, positional variations and inter-individual shape variations by using a 3D shape model for the generation of the templates. We anticipate that this extends the method to be able to correctly register radiographs, which have been taken when the patient has not been positioned optimally. This might improve the success rate of the method to a level where it can be implemented into clinical software.

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