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**Short Communication**

# Imaging of Rheumatoid Arthritis in Finger Joints by Sagittal Optical Tomography

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## Summary

In early stages of rheumatoid arthritis some changes in joints arise due to an inflammatory process. In the case of transillumination with near infrared light these changes affect the radiation transport in joints. We performed first numerical simulations for a basic approach of a sagittal optical tomographic imaging method that led to promising results. For this purpose, the optical properties of the different tissue types in joints were measured and NMR images were used for geometrical model development and visualisation of rheumatoid arthritis.

***Key words***
Rheumatoid arthritis, finger joint, optical tomography

## Introduction

Chronic diseases like inflammable rheumatic diseases are of special importance because patients require an expensive long-term therapy and generally have to withdraw from working life soon. The most frequent inflammable rheumatic disease is rheumatoid arthritis (RA), an autoimmune disease. RA most frequently affects the finger joints. Steinbrocker (2) has divided the process of RA in joints in four stages (Fig. 1). Conventional diagnosis is principally made by clinical and laboratory examination of joints assisted by radiographs. For a specific therapy, a secure finding is indispensable. Unfortunately, radiographs suffer from poor contrast for soft tissue so that one cannot identify changes until cartilage and bone destruction is obvious (stage 3). Ultrasound and NMR examination enables recognition of changes of soft tissue (3) but the diagnostic benefit of ultrasound at finger joints is disputed. The safest method for recognition of early inflammatory arthritis is nuclear magnetic resonance imaging (NMR) in combination with contrast agents. But high costs argue against this method especially for small joints. The structural changes in early

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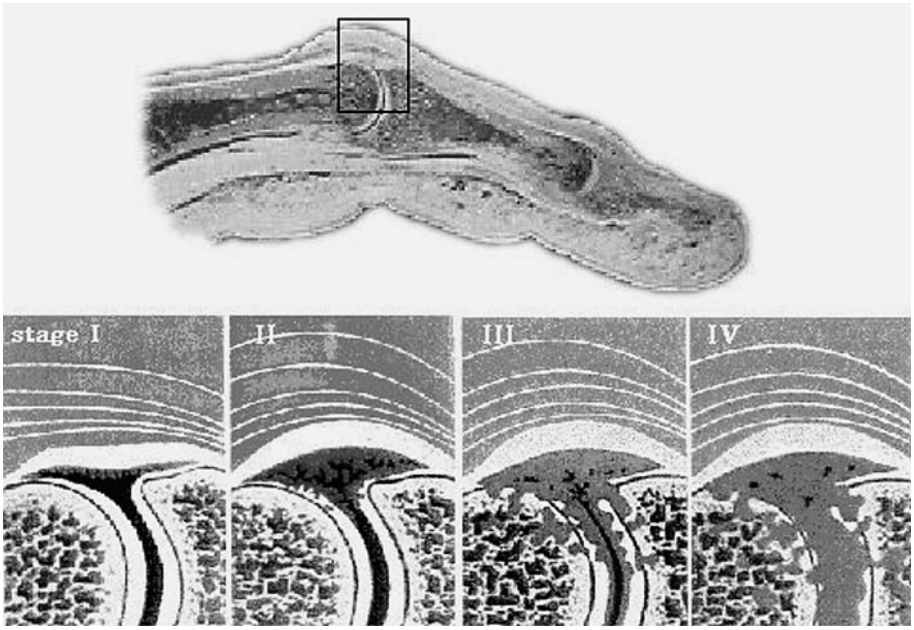


**Fig. 1.** Process of RA in joints according to Steinbrocker (2). Stage 1: synovialis is inflamed and gets uneven, fluid, lymphocytes, and cells penetrate into the synovia in the joint gap, synovial fluid gets turbid and the capsule swells up; stage 2: aggressive stroma (pannus) grows between capsule and cartilage; stage 3: due to expansion of pannus destruction of cartilage and bone occurs; stage 4: fibrous and osseous ankylosis arise.

inflammatory stages lead to a significant alteration of optical properties like scattering and absorption in proximal interphalangeal (PIP) finger joints (6). In earlier studies we used a simple transillumination technique with a red diode laser on the upper side of a finger joint and a CCD camera to capture the diffuse transmitted light on the underside (7). A complex analysis of the data obtained with huge computational effort provides information about the inflammatory status but no real image of the joint. An image representing the optical properties in the finger joint requires a tomographic method. A simple approach is to perform a sagittal scan in the central plane along the finger axis with illumination on one side and radiation detection on the opposite side. Klose et al. (5) developed mathematical methods that enable forward calculation and reconstruction of optical parameter distribution. Simulation of sagittal diffuse optical tomography of a PIP finger joint was performed in healthy and early inflammatory stage and results were compared to NMR images. Experimental examination with a sagittal optical tomograph is in progress.

## Materials and Methods

How does simulation of sagittal optical tomography work?

At first, a numerical model of the finger joint is required considering both the anatomical and optical properties of the joint (Fig. 2). Light transport through tissue is affected by absorption of water and chromophores, and scattering at structures like membranes, cell cores, or large molecules like lipids (1). The optical properties of tissue are therefore characterised by the absorption coefficient $\mu_a$, the scattering coefficient $\mu_s$, and the anisotropy factor g which considers the probability of scattering direction. In previous investigations (6) we determined optical proper-

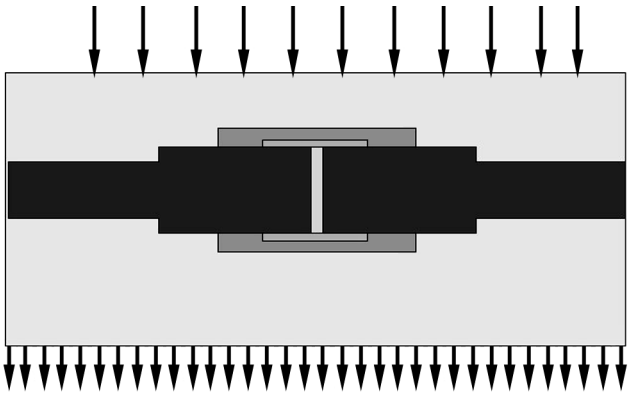

**Fig. 2.** Model of a PIP finger joint for forward calculation of light transfer, which consists of five components: bone, capsule, synovialis, synovial fluid, and surrounding tissue (muscle/ tendon/ skin) with corresponding optical properties (6).

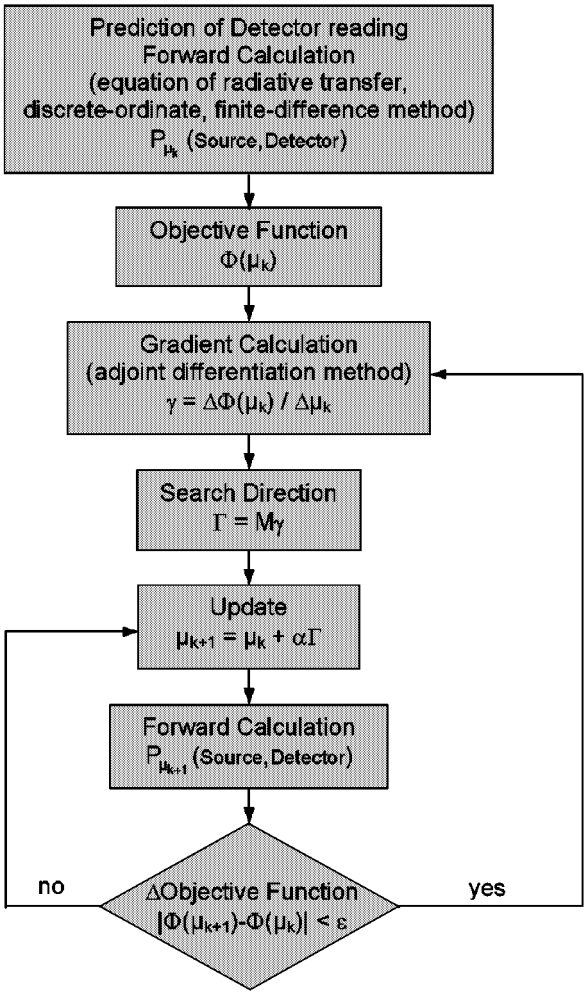


**Fig. 3.** Mathematical scheme for the reconstruction of optical parameters (5). The goal is to minimize the objective function (sum over the differences between measured and predicted detector readings for every source detector combination). The results are images representing the real distribution of optical parameters in the transilluminated plane.

ties of the main anatomic components in healthy and rheumatoid finger joints. The numerical model contains a simplified distribution of the optical properties corresponding to the main components of a finger joint.

In another step, the light transport through the finger is calculated by applying the theory of radiation transfer (4). For each of 10 source positions along the finger the detector response at 40 positions is calculated. This leads to $10 \times 40 = 400$ data. Due to the multiple scattering of light in tissue the transmission of light is deeply diffuse. Therefore nearly every position in the rectangle between sources and detectors is transilluminated. The 'measured' data are finally used as input for the reconstruction algorithm (Fig. 3). The results are images representing the distribution of optical parameters in the transilluminated plane.

## Results

For an exact documentation we made sagittal NMR images of two PIP joints of a 60 years old patient (Fig. 4) with comparison between non inflamed joint (Fig. 4.1) and inflammatory RA state (Fig. 4.2). The contrast agent in the inflamed joint verifies a physiological RA stage of 2 (Fig. 1). Beside the overall thickening of the finger the swollen capsule is clearly visible due to increased blood flow in the inflamed synovialis and the diffusion gradient into the affected partial volume. As we discovered during optical tissue parameter measurements (6), an inflammatory stage of 1 and 2 implies an increase in light scattering in the joint region. This is physiologically correlated to changes of the synovialis and an increase of the concentration of lipids and cells

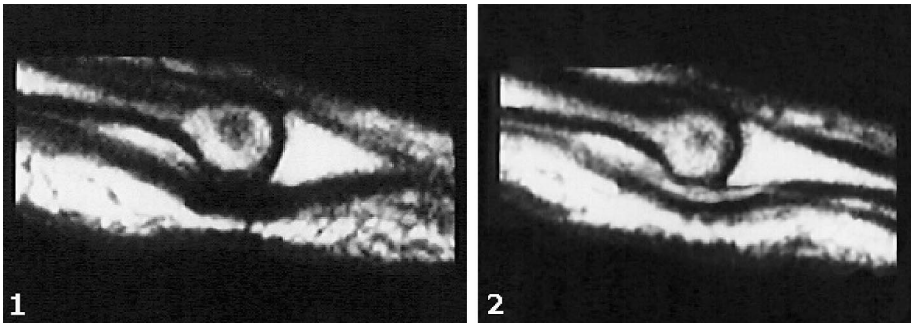


**Fig. 4.** NMR images of two PIP joints of a 60 years old patient, T1 weighted. 1 – no inflammation, no contrast agent; 2 – inflammatory RA state with contrast agent gadolinium.

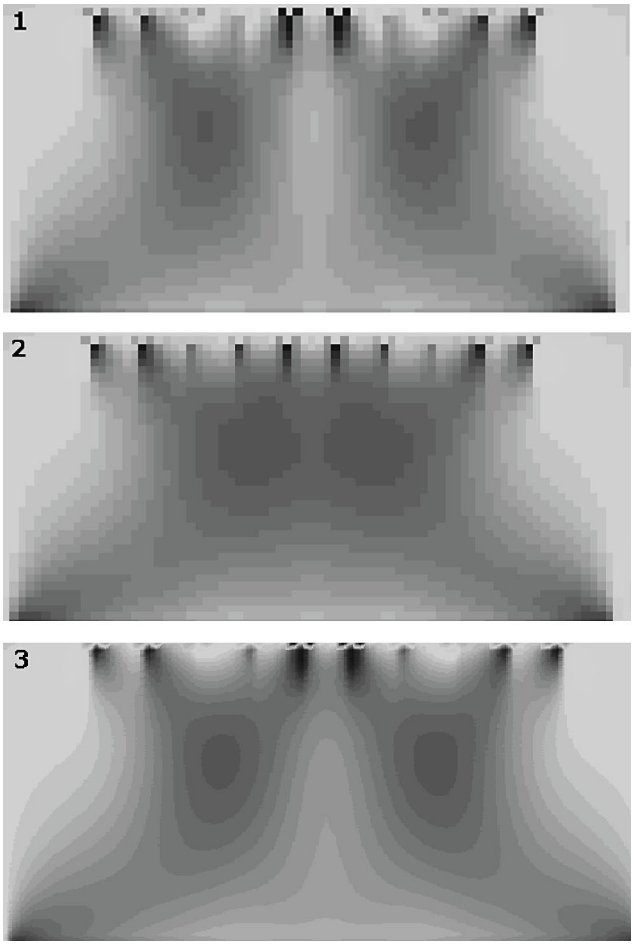


**Fig. 5.** Reconstructed scattering coefficient $\mu_s$ in the transilluminated plane of the model (Fig. 2). 1 – healthy stage; 2 – synovialis and synovial fluid with optical properties of inflamed stage; 3 – only synovial fluid inflamed, dark areas indicate high scattering.

in the synovia. This was basically confirmed by the results of the optical reconstruction. The distribution of the reconstructed scattering coefficient $\mu_s$ in the transilluminated plane of the model shows an obvious difference between healthy and inflamed state (Fig. 5). In the healthy state (Fig. 5.1) the joint gap is clearly visible as a low scattering area. Contrary to that the inflamed state (Fig. 5.2) shows high scattering at location of joint gap and capsule resp. synovialis. If only synovial fluid is changed from healthy to inflamed state (Fig. 5.3) the scattering distribution is similar to that of the healthy state. This indicates that for optical transillumination changes in synovialis are more evidently recognised than changes in the synovia. The decrease in scattering to the left and to the right side is due to the decrease in the number of sources and detectors in this region. Therefore these outer positions are less transilluminated. This causes a lack of information for exact reconstruction. The high scattering spots beneath the source positions and the increase in scattering in the direction of the outer detector positions are artefacts too. The results for the distribution of absorbers are not shown because the changes are very small.

## Outlook

First simulations of sagittal optical tomography of RA in finger joints point out that this imaging method will be sensitive to changes in the scattering behaviour in the joint. This will make an alteration of the expanded capsule better to visualise than changes in the narrow joint gap. In the near future we will perform clinical measurements with an experimental setup to find out if sagittal images of optical properties can safely detect the state of inflammation. For this purpose, we will embed the finger and the optical scanning head in a scattering fluid because this will lead to optimal conditions for light coupling in the finger and to optimal reconstruction results. In addition, new specific fluorescent marker offer the possibility to combine optical tomography with fluorescent imaging techniques. So, by combination of scattering, higher absorption and fluorescence inflamed areas will be characterised at improved resolution and accuracy. Therefore we expect optical tomography to become a useful tool to assist rheumatologists in early diagnosis of RA.

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## Darstellung von rheumatoider Arthritis in Fingergelenken mittels Sagittaler Optischer Tomographie

Im Frühstadium der rheumatoiden Arthritis kommt es in Gelenken durch einen entzündlichen Prozess zu Veränderungen, die bei einer Durchleuchtung mit nah infrarotem Licht den Strahlungstransport beeinflussen. Wir haben erste Simulationsrechnungen für einen einfachen Ansatz einer sagittalen, optisch tomographischen Bildgebung von PIP-Gelenken durchgeführt, die zu viel-

versprechenden Ergebnissen führten. Dafür wurden die optischen Eigenschaften der unterschiedlichen Gewebetypen in Gelenken gemessen und MRT-Bilder für die geometrische Modellbildung und die Visualisierung der rheumatoiden Arthritis genutzt.

***Schlüsselwörter***
Rheumatoide Arthritis, Fingergelenk, Optische Tomographie

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