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REVIEW ARTICLE

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Dual-energy computed tomography — possible applications in the diagnosis of rheumatic diseases

ABSTRACT

Over the past two decades, the effectiveness of available therapies has increased significantly. Nowadays, the realistic goal in the treatment of rheumatic diseases such as rheumatoid arthritis (RA) is to achieve low disease activity or remission. Alongside this progress, the way of looking at rheumatic diseases has also evolved, as have the methods of assessing their activity. Nowadays, more and more attention is being paid to the inflammatory process within the joints, and this even applies to the inflammatory process at a subclinical level. At this stage, the inflammatory process is not visible on physical examination; imaging methods are necessary to detect it. In rheumatology, ultrasound (US) and magnetic resonance imaging (MRI) are used to assess inflammation. In the case of ultrasound, the objectivity of the assessment is still a major problem, while in the case of MRI — the time taken to perform it and its cost. For this reason, other imaging methods are still being sought to assess the inflammatory process of joints. Dual-energy computed tomography (DECT) may be one such method . By using two X-ray beams of different energies, it is possible to differentiate soft tissues much more accurately than is possible with conventional CT. Currently, the usefulness of DECT has been confirmed in the diagnosis of gout. The question to be answered is whether DECT will also allow the imaging of the inflammatory process within the joints.

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KEY WORDS: dual-energy computed tomography; ultrasonography; magnetic resonance

INTRODUCTION

Computed tomography (CT) is currently one of the most widely used imaging tests in medical diagnosis. The last two decades have seen a huge increase in the number of CT examinations performed annually. In the United States, approximately 70 million CT examinations are performed annually. In the United Kingdom, it is estimated that in recent years, the number of CT examinations performed has increased by 10% year on year [1]. In fact, today it is difficult to imagine modern medicine without CT examinations.

However, in the field of rheumatology, the role of CT examinations is relatively limited. Computed tomography (CT) is most often used to diagnose pulmonary lesions, which are unfortunately common in the course of many rheumatic diseases.

In inflammatory joint diseases (IJDs), ultrasound (US) and magnetic resonance imaging (MRI) play a much more important role among imaging tests. They make it possible to assess the presence of inflammation within the joints and especially within the synovial membrane (synovitis) and the tendon-muscle attachments (enthesitis), currently considered to be the most important in the pathogenesis of inflammatory diseases of the joints and spine [2]. It is the presence of inflammation that is associated with both increased disease activity and the risk of progression of radiological changes. On the oth-

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er hand, the absence of inflammation within the joints is indicative of the efficacy of ongoing therapy and the achievement of remission [2]. From the point of view of clinical practice, US and MRI are extremely important in the diagnostic process.

On US and MRI, synovitis and enthesis are visible in the form of increased vascular flow. On MRI, bone marrow edema (BME) can additionally be revealed.

Compared to these two examinations, a standard CT scan does not allow as much soft tissue differentiation to reveal the presence of synovitis, enthesis or BME.

DUAL-ENERGY COMPUTED TOMOGRAPHY (DECT)

From a theoretical point of view, *DECT* is not a completely new diagnostic tool. One mathematical and physical model was developed approximately 50 years ago — in the 1970s [3]. However, the image acquisition process itself required too much computer processing power for such a CT scanner to be feasible at the time. For this reason, it took so long for DECT to be introduced into clinical practice and today we can talk about a new option for CT imaging.

The very principle leading to DECT imaging is based on physical properties of X-rays. Depending on the energy that a quantum of X-ray carries, it interacts with matter in a different way and, most importantly, the absorption coefficient for a given material varies. Therefore, with a large difference in the energies of the X-ray beams used, better differentiation within the soft tissues is possible [4].

The DECT uses a low-energy X-ray beam of 80-100 keV and a high-energy X-ray beam of 140 keV [4]. The difference in energies between the two beams is large enough that they interact differently with soft tissues. The dominant mode of interaction for a low-energy beam is the photoelectric effect, while Compton scattering dominates for a high-energy beam [4]. In comparison, a traditional CT scan uses X-rays with energies in the order of 120 keV.

Obtaining two X-ray beams is currently based on two solutions in modern CT scanners. The first method is to use two X-ray tubes that are positioned perpendicular to each other, and the second method currently used is to change the voltage on one tube [4]. The method of obtaining the two beams of radiation is of little relevance to routine clinical practice. For the time being, the two methods can be considered equivalent.

MATERIAL DECOMPOSITION

The key to the wide range of DECT applications is the ability to perform material decomposition during the analysis of a previously performed examination. As previously mentioned, a DECT image is created based on the differences in tissue absorption coefficients between the two X-ray beams.

By using two beams of radiation, the composition of elements in the examined area can be accurately assessed. Therefore, even small lesions in soft tissues can be better differentiated [4].

A good example of such an element may be the iodine present in soft tissues. The absorption band for iodine for the K electron shell corresponds to an energy of the order of 33 keV. From a physical point of view, this means that low-energy radiation is twice as strongly absorbed by iodine as high-energy radiation [4]. Therefore, pathological changes such as, for example, areas of neovascularization, which are marked by a higher iodine concentration, will be much more apparent on DECT compared to standard CT scan.

The theoretical basis of material decomposition may seem relatively straightforward. However, from a clinical point of view, the appropriate use of this tool requires both a strong knowledge of anatomy and knowledge of the specific lesions explored in the examined area.

DECT IN RHEUMATOLOGY

Given that the most important element for the assessment of DECT is the use of material decomposition, it should come as no surprise that the best described application of DECT in rheumatology is the diagnosis of gout.

Singh et al. conducted a study that included 147 patients with gout [5]. Patients included in the study had both US and DECT.

In DECT, the knee joints, ankle joints and foot joints were assessed. The minimum volume of uric acid crystals that were visible in the images was 0.01 cm^3.

The same joints were assessed in the US examination as in the DECT. Linear probes with frequencies of 5-14 and 4.5-18 MHz were used to examine the knee joints, ankle joints and foot joints, respectively. The US examina-

tions were performed by experienced ultrasonographers who were not familiar with the results of DECT.

The examination of joint fluid for uric acid crystals was accepted as the gold standard for diagnosis by Singh et al. [5]. The sensitivity and specificity of DECT and US were 87% and 100% and 84% and 60%, respectively.

Based on the results of the present study, it can be concluded that DECT is a very good imaging method for the diagnosis of gout. With comparable sensitivity to US, the big advantage is the much higher specificity. In contrast, compared to the accepted gold standard of joint fluid examination for sodium urate crystals, the big advantage of DECT is that it is not invasive.

Another study in which a large group of patients was included is that conducted by M. Sotniczuk et al. The study included 120 patients with suspected gout [6]. In this study, aspiration of joint fluid could not be performed in all patients; therefore, a clinical diagnosis of gout was accepted as the gold standard.

In DECT, both shoulders, elbow joints, knee joints, hands and feet were assessed. In 96 patients, a picture typical of gout was found. However, based on clinical assessment, the disease was diagnosed in only 73 patients.

In the authors' opinion, DECT should not be used as the only tool for diagnosing gout. On the other hand, it is a very useful tool to improve the sensitivity and specificity of the current 2015 ACR/EULAR classification criteria, especially in patients in whom it has not been possible to collect joint fluid from the involved joints for examination [6].

INFLAMMATORY JOINT DISEASES (IJDS)

From a clinical practice perspective, a very interesting question that can be raised in the context of DECT is its utility in the diagnosis and monitoring of IJDs such as rheumatoid arthritis (RA) or psoriatic arthritis (PsA). At the moment, US can be considered the imaging examination of choice in this group of diseases, with MRI considered the gold standard.

Unfortunately, this is currently a question that cannot yet be answered. However, given the broad spectrum of image analysis by means of material decomposition, the usefulness of this method cannot be ruled out in the near future.

In such a situation, DECT could be an excellent complement to US and MRI. Compared to US, it would provide a more objective and reproducible assessment of inflammation. This is perhaps the greatest challenge for US imaging at present, in terms of the diagnosis and monitoring of joint inflammation. On the other hand, compared to MRI, DECT is a much faster examination and thus more comfortable for patients, who often suffer from pain associated with remaining in an uncomfortable position during a relatively long MRI examination.

LIMITATIONS

DECT is a very advanced imaging technique. The wide range of possibilities it offers through material decomposition requires both a very high level of theoretical knowledge of CT scans and knowledge of the disease itself [7]. As a result, developing an appropriate algorithm for evaluating the examination can involve a very large amount of time.

Another limitation of DECT, which is closely related to the examination technique itself, is the assessment of large joints such as the shoulder joint or hip joint. A decrease in the quality of the examination can be expected in this case, as the low-energy beam is strongly absorbed by the tissues, making subsequent material decomposition difficult [7].

Finally, it should be mentioned that such a comprehensive examination also requires closer cooperation between the rheumatologist and radiologist, which can also be very challenging in routine clinical practice. Without such cooperation, doubts may arise from the radiologist's point of view as to the correct interpretation of the examination results [7].

CONCLUSIONS

Undoubtedly, DECT represents an interesting CT imaging option that opens up several new diagnostic possibilities. Unfortunately, in terms of rheumatology, it is currently difficult to see this examination as representing as much of an advance in diagnostic imaging as US and MRI.

The main application of DECT in rheumatology may be the already very well described diagnosis of gout. Unfortunately, in the case of IJDs, the usefulness of this imaging method cannot be clearly indicated at present; further research in this direction is necessary.

CONFLICT OF INTEREST

Author declares no conflict of interest.

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