THE CURRENT STATE OF THE ISSUE OF USING CONE BEAM COMPUTED TOMOGRAPHY IN THE DIAGNOSIS OF MUSCULOSKELETAL DISEASES

Sholokhova N.A. [1, 2],
Zharkov D.K. [1, 2],
Lezhnev D.A. [1, 3],
Vasilyev A.Yu. [1, 4],
Petrovskaya V.V. [1],
Lazarenko E.Yu. [1, 2],
Blinov N.N. [1],
Sergeeva A.D. [1]

[1] A.I. Yevdokimov Moscow State University of Medicine and Dentistry (Delegatskaya str. 20/1, Moscow 127473, Russian Federation)
[2] Children's State Hospital of St. Vladimir, Moscow Healthcare Department (Rubtsovsko-Dvortsovaya str. 1/3, Moscow 107014, Russian Federation)
[3] Russian Medical Academy of Continuous Professional Education (Barrikadnaya str. 2/1, Moscow 125993, Russian Federation)
[4] Central Research Institute of Radiation Diagnostics (Aviakonstruktora Milya str. 15/1, Moscow 125993, Russian Federation)

Corresponding author:
Daniil K. Zharkov,
e-mail: gaspardan@mail.ru

ABSTRACT

The high incidence rate and wide range of musculoskeletal pathologies determine the improvement of the diagnostic process. Late diagnosis leads to complications, which in turn increase the percentage of disability. Therefore, the search for the most informative method with the least radiation load on the patient remains an urgent problem for radiologists. Cone beam computed tomography (CBCT) is a modern and promising technique that has already found wide application in dentistry and otorhinolaryngology. Among the advantages of CBCT are: three-dimensional image; high spatial resolution; low radiation dose. Thanks to technical improvements in equipment and the introduction of new image processing protocols, it has become possible to expand the indications for conducting the researches, including the researches based on imaging of the upper and lower extremities. Based on the results of a CBCT examinations, we can evaluate: the shape and contour of the bone; solution of continuity of the bone and malposition of bone fragments; the structure of bone tissue and the pathological processes occurring in it (destruction, osteoporosis, osteosclerosis); joint congruence and changes in articular surfaces surrounding soft tissues. Therefore, CBCT can be introduced into the diagnostic process of bones and joints diseases. The use of this technique will find wide application in traumatology and orthopedics (fractures, dislocations, post-traumatic deformities, aseptic necrosis, osteoarthritis), rheumatology (rheumatoid arthritis, polyarthropathy, juvenile arthritis, gout), surgery (osteomyelitis), oncology (benign and malignant bone tumors) both in the adult population and in pediatric practice. This paper presents a review of the literature, which examines the degree of development of the issue of using CBCT and describes study protocols and protocols for processing the obtained images in the diagnosis of musculoskeletal diseases.

Key words: *radiology, cone beam computed tomography, osteoarticular system, musculoskeletal system*

Статья поступила: 29.05.2023
Статья принята: 18.10.2023
Статья опубликована: 05.12.2023

For citation: Sholokhova N.A., Zharkov D.K., Lezhnev D.A., Vasilyev A.Yu., Petrovskaya V.V., Lazarenko E.Yu., Blinov N.N., Sergeeva A.D. The current state of the issue of using cone beam computed tomography in the diagnosis of musculoskeletal diseases. *Acta biomedica scientifica*. 2023; 8(5): 182-191. doi: 10.29413/ABS.2023-8.5.20

СОВРЕМЕННОЕ СОСТОЯНИЕ ВОПРОСА ИСПОЛЬЗОВАНИЯ КОНУСНО-ЛУЧЕВОЙ КОМПЬЮТЕРНОЙ ТОМОГРАФИИ В ДИАГНОСТИКЕ ЗАБОЛЕВАНИЙ ОПОРНО-ДВИГАТЕЛЬНОГО АППАРАТА

Шолохова Н.А. [1, 2],
Жарков Д.К. [1, 2],
Лежнев Д.А. [1, 3],
Васильев А.Ю. [1, 4],
Петровская В.В. [1],
Лазаренко Е.Ю. [1, 2],
Блинов Н.Н. [1],
Сергеева А.Д. [1]

[1] ФГБОУ ВО «Московский государственный медико-стоматологический университет им. А.И. Евдокимова» Минздрава России (127473, г. Москва, ул. Делегатская, 20/1, Россия)
[2] ГБУЗ «Детская городская клиническая больница святого Владимира Департамента здравоохранения города Москвы» (107014, г. Москва, ул. Рубцовско-Дворцовая, 1/3, Россия)
[3] ФГБОУ ДПО «Российская медицинская академия непрерывного медицинского образования» Минздрава России (125993, г. Москва, ул. Баррикадная, 2/1, стр. 1, Россия)
[4] ООО «Центральный научно-исследовательский институт лучевой диагностики» (109431, г. Москва, ул. Авиаконструктора Миля, 15/1, Россия)

Автор, ответственный за переписку:
Жарков Даниил Константинович,
e-mail: gaspardan@mail.ru

РЕЗЮМЕ

Высокая частота заболеваемости и широкий спектр патологий опорно-двигательного аппарата обуславливают совершенствование диагностического процесса. Поздняя постановка диагноза приводит к возникновению осложнений, что в свою очередь повышает процент инвалидизации. Поэтому поиск наиболее информативного метода с наименьшей радиационной нагрузкой на пациента остаётся актуальной проблемой для радиологов. Конусно-лучевая компьютерная томография (КЛКТ) – современная и перспективная методика, которая уже нашла широкое применение в стоматологии и оториноларингологии. Среди преимуществ КЛКТ можно отметить: объёмное изображение; высокое пространственное разрешение; низкую дозу лучевой нагрузки. Благодаря техническому совершенствованию аппаратуры и появлению новых протоколов обработки изображений появилась возможность расширения показаний к выполнению исследований, в том числе и за счёт съёмки верхних и нижних конечностей. По результатам КЛКТ-исследования можно оценить: форму и контур кости; наличие нарушения целостности кости и положения костных отломков; структуру костной ткани и протекающие в ней патологические процессы (деструкция, остеопороз, остеосклероз); конгруэнтность сустава и изменения суставных поверхностей, окружающих мягкие ткани. Исходя из вышеперечисленного, КЛКТ можно внедрить в диагностический процесс заболеваний костно-суставной системы. Применение данной методики найдёт широкое применение в травматологии и ортопедии (переломы, вывихи, посттравматические деформации, асептические некрозы, остеоартрозы), ревматологии (ревматоидные артриты, полиартропатии, ювенильные артриты, подагра), хирургии (остеомиелиты), онкологии (доброкачественные и злокачественные новообразования костей) как у взрослого населения, так и в педиатрической практике. В данной работе представлен обзор литературы, в которой изучена степень разработанности вопроса применения КЛКТ и описаны протоколы исследования и обработки полученных изображений в диагностике заболеваний опорно-двигательного аппарата.

Ключевые слова: *лучевая диагностика, конусно-лучевая компьютерная томография, костно-суставная система, опорно-двигательный аппарат*

Статья поступила: 29.05.2023
Статья принята: 18.10.2023
Статья опубликована: 05.12.2023

Для цитирования: Шолохова Н.А., Жарков Д.К., Лежнев Д.А., Васильев А.Ю., Петровская В.В., Лазаренко Е.Ю., Блинов Н.Н., Сергеева А.Д. Современное состояние вопроса использования конусно-лучевой компьютерной томографии в диагностике заболеваний опорно-двигательного аппарата. *Acta biomedica scientifica*. 2023; 8(5): 182-191. doi: 10.29413/ABS.2023-8.5.20

RELEVANCE

The incidence of musculo-skeletal system pathology is an urgent problem affecting all age categories of the population. According to statistics, this group of diseases is widespread and occupies a stable 3rd place, second only to respiratory and circulatory diseases [1]. Along with this, high rates of disability remain, ranking 3rd in the structure of primary disability of the population [2]. At this background the necessity of constant search for optimal diagnostic approaches aimed at obtaining comprehensive information with simultaneous reduction of radiation load without loss of informativeness increases.

Radiography is considered the primary and routine method in the diagnosis of musculo-skeletal system diseases in both adults and children mainly due to its easy accessibility and rapidity [3, 4]. Shadow summation, however, can make it difficult to visualize changes in bone, especially when examining complex anatomical structures such as the hand and foot [5]. Multislice computed tomography is a highly informative method that gives a more informative picture of the disease, but is accompanied by a high dose of radiation exposure to the patient [3, 6].

Cone Beam Computed Tomography (CBCT tomography) has already found wide application in dentistry, maxillofacial surgery and otorhinolaryngology [7, 8]. Technical improvements in equipment have resulted in new-generation cone-beam tomographs capable of performing upper and lower extremity studies [8, 9].

THE AIM OF THE STUDY

To analyze the scientific information about the state of Cone Beam Computed Tomography application in diagnostics of musculo-skeletal system diseases.

RESULTS AND DISCUSSION

Cone Beam Computed Tomography (CBCT tomography) is a technique of layer-by-layer diagnostics based on computer reconstruction of the image obtained by circular scanning of an object with a cone-shaped beam of X-rays [10]. CBCT tomography scanners use a collimated X-ray beam in the shape of a cone, as opposed to the narrow fan-shaped beam of multislice computed tomography (MSCT). CBCT tomography has a pulsed radiation pattern, while MSCT is continuous. The obtained data projections are processed and during image reconstruction, the images can be combined into a single object for visualization [11, 12].

The first mention of CBCT tomography is provided by P. Mozzo et al. in 1998. The authors presented in their study a new type of computed tomography and its application in maxillofacial surgery and dentistry [9]. In the Russian literature in 2012 in the work of A.Yu. Vasiliev et al. raised the issue of CBCT tomography application in traumatology for the first time and presented a new generation of CBCT tomograph. The authors outlined the following advantages: high spatial resolution; absence of artefacts from metal structures; rapidity of the examination [7]. At the same time, the possibility of quantifying the level of bone mineralization has been observed for CBCT tomography [13].

The main advantage of CBCT tomography is considered to be its high spatial resolution, which allows obtaining information down to the smallest details of bone architectonics [12]. A special contribution among the domestic scientific literature is highlighted for a number of scientific articles by D.V. Makarova et al. (2014–2017), which demonstrated the possibilities of CBCT tomography in rheumatological practice. For example, in the authors' most recent work, 248 CBCT tomography examinations of hands and feet were analyzed. Variations such as osteoporosis, joint space narrowing, cystic remodelling, erosion, osteolysis, bone proliferation, and soft tissue changes were examined. According to the results of the study, CBCT tomography showed higher informativity than standard radiography, and together with low radiation exposure, CBCT tomography was recommended by the authors as a first-stage diagnostic technique [10].

At the same time, Y. Aurell et al. (2018) also reflected on the use of CBCT tomography in rheumatoid practice. In their study, the authors decided to assess the diagnostic capabilities of CBCT tomography in visualising bone erosions in rheumatoid arthritis and compare it with radiography. Their study included 30 patients with long-standing rheumatoid arthritis. CBCT tomography was able to differentiate bone erosions in all 30 cases, whereas radiography was only able to differentiate bone erosions in 26 cases. The authors pointed out that CBCT tomography has a higher sensitivity to detect erosions than standard radiography and recommend the technique both in initial diagnosis and in further dynamic follow-up [14].

A scientific group headed by M. Posadzy (2018) published a study that demonstrates in detail the capabilities of CBCT tomography in diagnosing the main nosological forms of musculo-skeletal system diseases, such as traumatic changes (fracture, dislocation); tumours and tumour-like bone lesions; osteomyelitis; degenerative changes of joints. They also presented CBCT tomography of joints using contrast agent to study bone and cartilage changes. Following CBCT tomography, osteochondral changes with cystic rearrangement, the presence of intra-articular fragments of different density and proliferative lesions of the synovial membrane were visualized in detail. According to the authors, the results are comparable to magnetic resonance imaging (MRI), and therefore CBCT tomography can serve as an MRI analogue in patients with claustrophobia or other contraindications [12].

Platypodia is a common orthopedic disease characterized by collapse of the arcus pedis longitudinalis

pars medialis with deformity of the foot and talocrural joint [15]. Acquired platypodia in adults includes a wide range of ligament and tendon failures that can lead to curvature of the foot axis and disability [16]. "The gold" diagnostic standard is considered to be radiography of the foot with functional loading. A group of scientists C. de Cesar Netto et al. (2017) studied acquired platypodia in adults and conducted a retrospective study in which 20 patients underwent a CBCT tomography examination with functional loading in a standing position and without loading in a sitting position. In the results obtained, the authors observed high informativeness in both positions, but the studies with functional load had greater diagnostic value. In addition of assessing the platypodia degree, however, CBCT tomography provides a more detailed assessment of the bone and joints of the foot than standard radiography. The authors concluded that, in addition to statistically significant measurements similar to those obtained with traditional radiography, CBCT tomography may also be used to visualize a pattern that demonstrates the severity of bone abnormalities in detail [17].

As a result of its high resolution, CBCT tomography is able to visualise bone tissue changes as clearly as possible, whether it is a lytic lesion forming a cavity or the smallest microfracture. CBCT tomography can be widely used in such areas as traumatology and orthopaedics, rheumatology, surgery, oncology as a result of its diagnostic capabilities. The possibility of performing CBCT tomography examinations with functional loading has also been described and presented as an example for the diagnosis of acquired platypodia in adults [17]. New possibilities in the process of examining the bones and joints of the lower extremities can be achieved by using this technique. Considering the above, the use of CBCT tomography for musculoskeletal system examination becomes relevant both for adults and paediatric patients.

In 2017 in France, C. Borel et al. conducted a clinical trial of the ability of CBCT to diagnose latent navicular bone fractures. Forty-nine patients with clinical manifestations of navicular bone fracture and normal radiographic findings underwent additional CBCT and MRI. In considering the findings, CBCT tomography proved to be a highly informative and more informative diagnostic tool than radiography and was not inferior to MRI; additionally, CBCT is less cost-effective than MRI (Table 1). The authors note that CBCT tomography can act both as an adjunct and as a complete replacement for standard radiography in wrist joint injuries, especially when a navicular fracture is suspected [18].

German scientists J. Neubauer et al. (2018) conducted a retrospective study of CBCT tomography in navicular fractures. They included 102 patients who underwent standard radiography and CBCT tomography. In 2022, independently of this study, a study was published by E. Fitzpatrick et al. in which a meta-analysis of the scientific literature related to the use of CBCT tomography in wrist fractures was conducted. It was aimed to determine the diagnostic accuracy of CBCT tomography in acute wrist joint trauma. CBCT tomography has proven to be a highly informative tool that can replace or supplement radiographs (Table 1) [19, 20]. The British scientists also noted that CBCT tomography gives a more detailed image than MSCT, which improves visualization of the area of interest. They attribute this to the higher spatial resolution, which is 0.4–0.09 mm for CBCT tomography compared to 1–2 mm for MSCT [19].

Elbow joint injury is a high incidence cause of attendance at trauma wards. Standard radiography is quite often insufficient for correct diagnosis and treatment planning [21]. For the purpose of pre-investigation, trauma physicians prescribe MSCT, during which the patient is laid in the "superman" pose with the arm extended in the gentry [22, 23]. In cases of forced immobilization or severe pain in the patient, however, it is necessary to perform atypical patient positioning [23]. A group of German physicians in 2023 submitted a CBC tomograph with a dual robotic radiographic system without gentry, in which it became possible to perform examinations of the elbow joint in both flexed and unbent states without irradiating neighbouring anatomical regions. This work has proved not only high diagnostic value, but also made it possible to perform low-dose studies in people with limited joint motion, which is especially relevant in acute elbow joint trauma (Table 1) [23].

It is essential to assess the osteoregeneration process in order to avoid complications, alongside the detection of bone integrity and fragment position. A group of scientists L.C. Farracho et al. (2020) in an attempt to improve the diagnostic process, analyzed 52 CBCT tomography studies of patients with navicular fracture performed in the 6th week of immobilization and compared them with standard radiography. The Swiss authors considered that CBCT tomography allows trabecular bridge formation and cortical fusion to be traced, unlike radiography, which gives more reliable information on bone consolidation. The high role of CBCT tomography in the diagnosis of both conventional and concealed navicular fractures and a more informative picture of bone fragment displacements were also highlighted. Experts have observed a rather low radiation dose received by the patient [24].

Delayed diagnosis or missed rupture of the navicular ligament may result in the development of post-traumatic osteoarthritis of the wrist [25]. A group of German experts J.E. Dornberger et al. (2021) described CBCT arthrography and demonstrated it in the diagnostic process of navicular ligament rupture. The authors performed a prospective analysis and compared conventional arthrography, MSCT arthrography and CBCT arthrography. The obtained results of CBCT tomography provided full three-dimensional images, the diagnostic value of which is high and not inferior to those of MSCT (Table 1). However, CBCT tomography is accompanied by a low radiation load on the patient (compared to MSCT). As a conclusion, scientists recommend CBCT arthrography as an accurate tool in the diagnosis of navicular ligament rupture [26].

TABLE 1

DIAGNOSTIC ACCURACY INDICATORS OF CBCT TOMOGRAPHY AS PROVIDED IN SCIENTIFIC PUBLICATIONS

Nature of injury and anatomical area		Sensitivity, %	Specificity, %
Borel C. et al. (2017) [18]			
Navicular fracture		100	97
Neubauer J. et al. (2018) [20]			
Navicular fracture		93	96
Fitzpatrick E. et al. (2022) [19]			
Navicular fracture		87.7	99.2
Wrist joint fracture		93.5	99.9
Wrist fracture		90.6	100
Distal radius fracture		90	100
Kunz A.S. et al. (2023) [23]			
Elbow joint	conventional fracture	94–100	94–97
	fracture with articular surface involvement	90–97	97
	multi-fragment fracture	96	95–98
Gibney B. et al. (2019) [27]			
Wrist joint fracture		98.3	100
Dornberger J.E. et al. (2021) [26]			
Scaphalunate ligament rupture		100	95

CBCT tomography is a highly informative technique that provides reliable information about the presence and nature of the injury. According to a number of authors, CBCT tomography has a high diagnostic value in determining musculo-skeletal system diseases of traumatic nature [18–20, 23, 24, 26]. Meanwhile, scientists observe a low dose of radiation exposure received by the patient during the study [23, 24, 26]. It becomes particularly relevant in medical institutions and hospitals specializing in traumatology and orthopaedics. Consideration should also be given to introducing CBCT tomography into the outpatient practice of district trauma centres.

Another important aspect is the active use of CBCT tomography in everyday medical activities. In particular, T. Jacques et al. (2021) analyzed the practical clinical effect of the CBCT tomography integration in the emergency department of radiology, comparing this technique with MSCT in the diagnosis of traumatic changes of the extremities. The authors report not only good visualization and low radiation exposure, but also less time spent on examination and fewer diagnostic procedures. With the introduction of CBCT tomography as an alternative to MSCT, specialists have not only achieved a reduction in radiation dose, but also increased office throughput [27].

Irish scientists B. Gibney et al. (2019) demonstrated their experience of introducing CBCT tomography into everyday medical practice. In their work, they conducted a comparative study of standard radiography and CBCT tomography as part of the diagnostic process in wrist joint bone fractures. In the results obtained, CBCT tomography proved to be a more informative tool, being able to visualize fracture lines not visible on radiography in more than 50 % of cases. They also conducted a diagnostic value analysis, in which the methodology showed high results, and its accuracy reached 99.1 % (Table 1). The authors consider CBCT tomography to be a new diagnostic standard, considering its high resolution and low radiation exposure [28], since wrist joint injuries are widespread and radiographs are not very informative.

To date, osteomyelitis remains an urgent problem in general and paediatric surgery. Inflammatory bone diseases of various etiologies represent 6.5 % of the total structure of musculo-skeletal system diseases [29]. The study by N.A. Sholokhova et al. (2023) addressed the use of CBCT tomography in the examination of children with inflammatory diseases of both specific and nonspecific nature. Clinical cases were presented that demonstrated not only the primary diagnostic potential of CBCT tomography, but also its possibilities in control-dynamic follow-up. The authors have mentioned the high diagnostic informativeness of the technique and the crucial role of CBCT tomography in making the final diagnosis as well as in planning surgical treatment. The publication summarized the radiation doses received by the patients during the course of the examination. For instance, in primary and control-dynamic CBCT tomography examinations, the total radiation dose was 0.13 mSv, which is 10 times less than one MSCT study [30].

The second important advantage of CBCT is the low radiation dose per patient. American authors J.B. Ludlow et al. (2018) used anthropomorphic phantoms simulating wrist, ankle and knee joints. The radiation dose received was 1.3-21.1 μSv for CBCT and 9.1–204 μSv for MSCT. Considering this, it was concluded that the effective dose of CBCT tomography is 90 % lower than that of MSCT [31]. According to other data, the radiation dose of CBCT is 6–19 times lower than that of MSCT. These conclusions were reached by the group of scientists J. Koivisto et al. (2021). These were based on a comparison of MSCT and CBCT tomography doses from an anthropomorphic adult hand phantom study. This resulted in a radiation exposure of 2.0–6.7 μSv for CBCT and 37.4 μSv for MSCT [22].

Musculo-skeletal system impairments can occur in a person in any condition and at any age group. Considering the presence of a number of diseases of the musculo-skeletal system associated with pregnancy, the improvement of radial diagnostic examination is of particular relevance. It is essential to obtain as much information as possible with as little radiation exposure as possible. A. Katlapa et al. (2022) became interested in this issue and conducted an experimental study, where they calculated the received dose of radiation to the fetus during the examination of the elbow and knee joint in each trimester of pregnancy. To do this, scientists used anthropomorphic phantoms simulating the mother's body, arms and legs. Fetal dose was measured at three levels corresponding to each trimester of pregnancy. The results varied: 3.4–6.0 μGy for the knee joint and 2.9–7.7 μGy for the cubitus. The dose received depended on fetal depth and gestational age. Additionally, the scientists conducted supplementary studies: with the use of a protective shield, which reduced the radiation dose by 43 % (knee joint) and 51 % (elbow joint); with turning the body away from the hole in the gentry – as a result, the received dose was reduced by 62 %. In conclusion, the authors concluded that upper and lower extremities diagnosis by CBCT tomography does not carry radiation harm to the foetus [32].

There is another advantage of CBCT tomography – fewer significant artefacts from the surgical hardware. It provides significant advantages in monitoring the osteoregeneration process in patients after metallic osteosynthesis (MOS) [5]. This question has been raised by G.M. Osgood et al. who compared radiographs and CBCT tomography images, assessing: cortical bone, trabecular bone, contour of the large metal side plate, thread-to-bone interface, bridging ossification, fracture line and callus formation. Following the results, CBCT tomography outperformed standard radiography in visualizing the bone healing process, providing a more detailed picture of bone callus formation, overlap of the bony trabecula and residual fracture line. Additionally, CBCT tomography made it possible to clearly define the bone-to-screw boundaries, which aids in determining early MOS attenuation. It assumes particular relevance in detecting complications such as nonunion and the occurrence of infection [33].

In their study, a group of German scientists T. Patzer et al. (2022) analyzed the diagnostic accuracy of CBCT tomography using additional iterative algorithms to reduce artefacts from surgical hardware for postoperative assessment after bone grafting. The study included the following criteria: joint screw position (specificity – 98.21 %, sensitivity – 100 %, accuracy – 98.75 %); screw loosening (specificity – 98.53 %, sensitivity – 100 %, accuracy – 98.75 %); implant failure (specificity – 100 %, sensitivity – 100 %, accuracy – 100 %); fragmentary dislocation (specificity – 100 %, sensitivity – 95.83 %, accuracy – 98.75 %); delayed healing/nonunion (specificity – 98.11 %, sensitivity – 96.30 %, accuracy – 97.50 %). Having obtained high rates, CBCT tomography has been shown to be a reliable diagnostic device for postoperative evaluation and detection of complications after MOS placement [34].

In 2021, J. Dartus et al. conducted a retrospective study comparing MSCT and CBCT tomography images obtained during total knee replacement. Their objective was to identify the most informative diagnostic tool that yielded the least amount of metallic artefacts. The analysis was performed for the following anatomical zones: tibial plateau; trochlearis component; posterior condyles; patella. The assessment was carried out us-

ing a Likert response scale by two independent experts. In the results obtained, CBCT tomography provided informative knee prosthesis data by optimizing image quality and using an algorithm to reduce artefacts from surgical hardware. According to the authors, CBCT tomography provides a more detailed picture with few artefacts from the surgical hardware, in contrast to MSCT. It will help the specialist to diagnose emerging complications such as implant loosening in a timely manner [35].

The Italian research group of G. Carrafiello et al. (2012) was the first to describe percutaneous biopsy of the affected bone using CBCT tomography in XperGuide mode. XperGuide has been demonstrated in 17 patients with a technical success rate of 100 %. An adequate specimen for histological examination for definitive diagnosis was obtained in 15 patients; in the remaining 2 patients, the material obtained was insufficient. Scientists analyzed the technique and calculated its diagnostic value – sensitivity 90.91 %, specificity 100 %, accuracy 94.12 % [36].

Meanwhile, Chinese physicians J.F. Liu et al. (2018) described the technique of percutaneous biopsy of the affected bone using flat-panel CBCT tomography and demonstrated its capabilities. Having analyzed the diagnostic value, the authors obtained high values: sensitivity 95.5 %, specificity 83.3 %, accuracy 93.7 %. The technical success rate of percutaneous biopsy using CBCT tomography was 100 %. This study represents the promising potential of CBCT tomography navigation systems in the diagnostic process of bone and joint diseases [37].

Notwithstanding all the advantages described above, the disadvantages of CBCT tomography should also be mentioned. These include high sensitivity to artefacts as a result of motion. Attempting to overcome this problem, a group of American scientists of A. Sisniega et al. (2019) developed a protocol to compensate for dynamic fuzziness in lower extremity examinations based on a three-dimensional "autofocus" algorithm. From the obtained results, the researchers concluded that this protocol is highly effective in eliminating motion artefacts, improving the diagnostic quality of the image [38].

In 2008, in a research study by G.H. Chen et al. presented a method of image reconstruction – Prior Image Constrained Compressed Sensing (PICCS). The distinguishing feature of PICCS concerned that a sparse version of the image is reconstructed instead of the target image. The authors demonstrated the application of the algorithm on the exclusion of dynamic artifacts caused by heartbeat during a CT study [39]. The research team of S. Hatamikia et al. (2023), however, was the first to demonstrate and describe the use of PICCS to suppress metallic artefacts in puncture biopsy using a CBCT tomography machine with a C-arc. The authors observed that this protocol showed high quality of the images obtained, and also due to the CBCT tomography technique, the procedure is accompanied by low radiation exposure [40]. Considering the above, the PICCS reconstruction method may become more relevant in the diagnostic process of musculo-skeletal system disorders with its ability to suppress both dynamic blurring and artefacts from surgical hardware.

CBCT tomography can be fully considered a highly informative low-dose radiotherapy technique. Coupled with the improvement of the hardware equipment itself, there is an active development of image processing and reconstruction protocols. It allows for the levelling of artefacts, which in turn improves image quality. Creation and development of new modes give CBCT tomography an opportunity to open new directions of its application in clinical medicine.

CONCLUSION

CBCT tomography is a modern promising technique that has a number of advantages in the diagnosis of musculo-skeletal system pathology. CBCT tomography examinations can detect the smallest changes in bone architectonics down to microcracks as a result of its high resolution. According to the results, CBCT tomography has a high diagnostic accuracy in detecting diseases, especially bone and joint injuries in the upper and lower extremities. However, CBCT tomography has a low radiation load on the patient, which is especially important in paediatric practice. There are also many image reconstruction protocols and techniques that improve the quality of the images obtained and expand the diagnostic horizon of this technique. Based on the above mentioned, CBCT tomography can be a full-fledged alternative to MSCT in the diagnosis of pathology of the bone and joint system.

Funding

No sources of funding were provided for the study.

Conflict of interest

The authors declare that this study, its topic, subject matter and content do not involve competing interests. Any opinions expressed in the article are those of the authors of the original article.

REFERENCES

1. Oleynikova TA, Pozhidaeva DN, Oreshko AYu. Prevalence survey of musculoskeletal and connective tissue disorders in the Russian Federation. *Farmakoekonomika. Modern Pharmacoeconomics and Pharmacoepidemiology.* 2019; 12(1): 5-13. (In Russ.). [Олейникова Т.А., Пожидаева Д.Н., Орешко А.Ю. Мониторинг заболеваемости патологиями костно-мышечной системы и соединительной ткани в Российской Федерации. Фармакоэкономика. *Современная фармакоэкономика и фармакоэпидемиология.* 2019; 12(1): 5-13]. doi: 10.17749/2070-4909.2019.12.1.5-13

2. Tikhonova GI, Gorchakova TYu. Problems of health of the working age population and its information support. *Bulletin of the South-Russian State Technical University (NPI).* 2022; 15(4): 228-245. (In Russ.). [Тихонова Г.И., Горчакова Т.Ю. Про-

блемы здоровья населения трудоспособного возраста и его информационного обеспечения. *Вестник Южно-Российского государственного технического университета (НПИ)*. 2022; 15(4): 228-245]. doi: 10.17213/2075-2067-2022-4-228-245

3. Minaev SV, Filipieva NV, Leskin VV, Zagumennova IYu, Rostova NP, Shamadaev EZ. Radiological methods in diagnostics of acute haematogenous osteomyelitis in children. *Doctor.Ru*. 2018; 5(149): 32-36. (In Russ.). [Минаев С.В., Филипьева Н.В., Лескин В.В., Загуменнова И.Ю., Ростова Н.П., Шамадаев Э.З. Применение лучевых методов в диагностике острого гематогенного остеомиелита у детей. *Доктор.Ру*. 2018; 5(149): 32-36]. doi: 10.31550/1727-2378-2018-149-5-32-36

4. Sholokhova NA. Visualization of lesions of metaphyses and epiphyses of bones in newborns and young children. *Radiology – Practice*. 2021; 5(89): 82-90. (In Russ.). [Шолохова Н.А. Визуализация поражений метафизов и эпифизов костей у новорожденных и детей раннего возраста. *Радиология – практика*. 2021; 5(89): 82-92]. doi: 10.52560/2713-0118-2021-5-82-90

5. Ricci PM, Boldini M, Bonfante E, Sambugaro E, Vecchini E, Schenal G, et al. Cone-beam computed tomography compared to X-ray in diagnosis of extremities bone fractures: A study of 198 cases. *Eur J Radiol Open*. 2019; 6: 119-121. doi: 10.1016/j.ejro.2019.01.009

6. Sholokhova NA, Ganieva AM, Lezhnev DA. Current state of complex radiology issue of osteomyelitis in children and adolescents. *Vestnik SurGU. Meditsina*. 2019; 4(42): 8-13. (In Russ.). [Шолохова Н.А., Ганиева А.М., Лежнев Д.А. Современное состояние вопроса комплексной лучевой диагностики остеомиелита у детей и подростков. *Вестник СурГу. Медицина*. 2019; 4(42): 8-13]. doi: 10.34822/2304-9448-2019-4-8-13

7. Vasil'ev AYu, Blinov Jr. NN, Egorova EA. Cone beam computer tomography – new technology of research in traumatology. *Medical Visualization*. 2012; 4: 65-68. (In Russ.). [Васильев А.Ю., Блинов Н.Н. (мл.), Егорова Е.А. Конусно-лучевая компьютерная томография – новая технология исследования в травматологии. *Медицинская визуализация*. 2012; 4: 65-68].

8. Titov AD. Cone beam computed tomography **(**CBCT). *Central Science Bulletin*. 2017; 10(27): 27-28. (In Russ.). [Титов А.Д. Конус-лучевая компьютерная томография (КЛКТ). *Центральный научный вестник*. 2017; 10(27): 27-28].

9. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: Preliminary results. *Eur Radiol*. 1998; 8(9): 1558-1564. doi: 10.1007/s003300050586

10. Kushnir KV, Makarova DV, Lezhnev DA. Cone-beam computed tomography in rheumatology. *MIA Medical Bulletin*. 2017; 1(86): 56-60. (In Russ.). [Кушнир К.В., Макарова Д.В., Лежнев Д.А. Значение конусно-лучевой компьютерной томографии в ревматологической практике. *Медицинский вестник МВД*. 2017; 1(86): 56-60].

11. Mys K, Varga P, Stockmans F, Gueorguiev B, Neumann V, Vanovermeire O, et al. High-resolution cone-beam computed tomography is a fast and promising technique to quantify bone microstructure and mechanics of the distal radius. *Calcified Tissue Int*. 2021; 108(3): 314-323. doi: 10.1007/s00223-020-00773-5

12. Posadzy M, Desimpel J, Vanhoenacker F. Cone beam CT of the musculoskeletal system: Clinical applications. *Insights Imaging*. 2018; 9(1): 35-45. doi: 10.1007/s13244-017-0582-1

13. Lezhnev DA, Vislobokova EV, Kiselnikova LP, Sholokhova NA, Smyslenova MV, Truten VP. Analysis of mineral density of calcified tissues in children with X-linked hypophosphatemic rickets and hypophosphatasia using cone beam computed tomography data. *Int J Biomed*. 2021; 11(1): 53-57. doi: 10.21103/Article11(1)_OA11

14. Aurell Y, Andersson M, Forslind K. Cone-beam computed tomography, a new low-dose three-dimensional imaging technique for assessment of bone erosions in rheumatoid arthritis: Reliability assessment and comparison with conventional radiography – A BARFOT study. *Scand J Rheumatol*. 2018; 47(3): 173-177. doi: 10.1080/03009742.2017.1381988

15. Deland JT. Adult-acquired flatfoot deformity. *J Am Acad Orthop Surg*. 2008; 16(7): 399-406. doi: 10.5435/00124635-200807000-00005

16. Henry JK, Shakked R, Ellis SJ. Adult-acquired flatfoot deformity. *Foot Ankle Orthop*. 2019; 4(1): 2473011418820847. doi: 10.1177/2473011418820847

17. de Cesar Netto C, Schon LC, Thawait GK, da Fonseca LF, Chinanuvathana A, Zbijewski WB, et al. Flexible adult acquired flatfoot deformity: comparison between weight-bearing and non-weight-bearing measurements using cone-beam computed tomography. *J Bone Joint Surg Am*. 2017; 99(18): e98. doi: 10.2106/JBJS.16.01366

18. Borel C, Larbi A, Delclaux S, Lapegue F, Chiavassa-Gandois H, Sans N, et al. Diagnostic value of cone beam computed tomography (CBCT) in occult scaphoid and wrist fractures. *Eur J Radiol*. 2017; 97: 59-64. doi: 10.1016/j.ejrad.2017.10.010

19. Fitzpatrick E, Sharma V, Rojoa D, Raheman F, Singh H. The use of cone-beam computed tomography (CBCT) in radiocarpal fractures: A diagnostic test accuracy meta-analysis. *Skeletal Radiol*. 2022; 51(5): 923-934. doi: 10.1007/s00256-021-03883-9

20. Neubauer J, Benndarf M, Ehritt-Braun C, Reising K, Yilmaz T, Christopher K, et al. Comparison of the diagnostic accuracy of cone beam computed tomography and radiography for scaphoid fractures. *Sci Rep*. 2018; 8(1): 3906. doi: 10.1038/s41598-018-22331-8

21. Acar K, Aksay E, Oray D, Imamoğlu T, Gunay E. Utility of computed tomography in elbow trauma patients with normal X-ray study and positive elbow extension test. *J Emerg Med*. 2016; 50(3): 444-448. doi: 10.1016/j.jemermed.2015.03.009

22. Koivisto J, van Eijnatten M, Ludlow J, Kiljunen T, Shi XQ, Wolff J. Comparative dosimetry of radiography device, MSCT device and two CBCT devices in the elbow region. *J Appl Clin Med Phys*. 2021; 22(5): 128-138. doi: 10.1002/acm2.13245

23. Kunz AS, Schmalzl J, Huflage H, Luetkens KS, Patzer TS, Kuhl PJ, et al. Twin robotic gantry-free cone-beam CT in acute elbow trauma. *Radiology*. 2023; 306(3): e221200. doi: 10.1148/radiol.221200

24. Farracho LC, Moutinot B, Neroladaki A, Hamard M, Gorican K, Poletti PA, et al. Determining diagnosis of scaphoid healing: Comparison of cone beam CT and X-ray after six weeks of immobilization. *Eur J Radiol Open*. 2020; 7: 100251. doi: 10.1016/j.ejro.2020.100251

25. Pliefke J, Stengel D, Rademacher G, Mutze S, Ekkernkamp A, Eisenschenk A. Diagnostic accuracy of plain radiographs and cineradiography in diagnosing traumatic scapholunate dissociation. *Skeletal Radiol*. 2008; 37(2): 139-145. doi: 10.1007/s00256-007-0410-7

26. Dornberger JE, Rademacher G, Stengel D, Hönning A, Dipl-Phys GS, Eisenschenk A, et al. What is the diagnostic accuracy of flat-panel cone-beam CT arthrography for diagnosis of scapholunate ligament tears? *Clin Orthop Relat Res*. 2021; 479(1): 151-160. doi: 10.1097/CORR.0000000000001425

27. Gibney B, Smith M, Moughty A, Kavanagh EC, Hynes D, MacMahon PJ. Incorporating cone-beam CT into the diagnostic algorithm for suspected radiocarpal fractures: A new standard of care? *AJR Am J Roentgenol*. 2019; 213(5): 1117-1123. doi: 10.2214/AJR.19.21478

28. Jacques T, Morel V, Dartus J, Badr S, Demondion X, Cotton A. Impact of introducing extremity cone-beam CT in an emergency radiology department: A population-based study. *Orthop Traumatol Surg Res*. 2021; 107(2): 102834. doi: 10.1016/j.otsr.2021.102834

29. Trushin PV, Razin MP. Chronic osteomyelitis of tubular bones: modern view on the problem. *Medical Newsletter of Vyatka*. 2023; 1(77): 114-119. (In Russ.). [Трушин П.В., Разин М.П. Хронический остеомиелит трубчатых костей: современный взгляд на проблему. *Вятский медицинский вестник*. 2023; 1(77): 114-119]. doi: 10.24412/2220-7880-2023-1-114-119

30. Sholokhova NA, Zharkov DK. Cone beam computed tomography in the diagnosis of limb osteomyelitis in children and adolescents (literature review with clinical observations). *Radiology – Practice*. 2023; (2): 11-23. (In Russ.). [Шолохова Н.А., Жарков Д.К. Конусно-лучевая компьютерная томография в диагностике остеомиелита конечностей у детей и подростков (обзор литературы с клиническими наблюдениями). *Радиология – практика*. 2023; 2(98): 11-23]. doi: 10.52560/2713-0118-2023-2-11-23

31. Ludlow JB, Johnson BK, Ivanovic M. Estimation of effective doses from MDCT and CBCT imaging of extremities. *J Radiol Prot*. 2018; 38(4): 1371-1383. doi: 10.1088/1361-6498/aae44b

32. Katlapa A, Kaartinen SM, Henrik Koivisto J, Matikka H. Radiation exposure to fetus from extremity CBCT examinations. *Eur J Radiol*. 2022; 156: 110548. doi: 10.1016/j.ejrad.2022.110548

33. Osgood GM, Thawait GK, Hafezi-Nejad N, Shakoor D, Shaner A, Yorkston J, et al. Image quality of cone beam computed tomography for evaluation of extremity fractures in the presence of metal hardware: Visual grading characteristics analysis. *Br J Radiol*. 2017; 90(1073): 20160539. doi: 10.1259/bjr.20160539

34. Patzer TS, Grunz JP, Huflage H, Conrads N, Veldhoen S, Schmalzl J, et al. Combining gantry-free cone-beam computed tomography with iterative metal artefact reduction for surgical follow-up imaging of the appendicular skeleton. *Eur J Radiol*. 2022; 155: 110465. doi: 10.1016/j.ejrad.2022.110465

35. Dartus J, Jacques T, Martinot P, Pasquier G, Cotten A, Migaud H, et al. The advantages of cone-beam computerised tomography (CT) in pain management following total knee arthroplasty, in comparison with conventional multi-detector CT. *Orthop Traumatol Surg Res*. 2021; 107(3): 102874. doi: 10.1016/j.otsr.2021.102874

36. Carrafiello G, Fontana F, Mangini M, Ierardi AM, Cotta E, Floridi C, et al. Initial experience with percutaneous biopsies of bone lesions using XperGuide cone-beam CT (CBCT): Technical note. *Radiol Med*. 2012; 117(8): 1386-1397. doi: 10.1007/s11547-012-0788-1

37. Liu JF, Jiao DC, Ren JZ, Zhang WG, Han XW. Percutaneous bone biopsy using a flat-panel cone beam computed tomography virtual navigation system. *Saudi Med J*. 2018; 39(5): 519-523. doi: 10.15537/smj.2018.5.21872

38. Sisniega A, Thawait GK, Shakoor D, Siewerdsen JH, Demehri S, Zbijewski W. Motion compensation in extremity cone-beam computed tomography. *Skeletal Radiol*. 2019; 48(12): 1999-2007. doi: 10.1007/s00256-019-03241-w

39. Chen GH, Tang J, Leng S. Prior image constrained compressed sensing (PICCS): A method to accurately reconstruct dynamic CT images from highly undersampled projection data sets. *Med Phys*. 2008; 35(2): 660-663. doi: 10.1118/1.2836423

40. Hatamikia S, Biguri A, Kronreif G, Russ T, Kettenbach J, Birkfellner W. Source-detector trajectory optimization for CBCT metal artifact reduction based on PICCS reconstruction. *Z Med Phys*. 2023; S0939-3889(23)00009-0. doi: 10.1016/j.zemedi.2023.02.001

Information about the authors

Nataliya A. Sholokhova – Cand. Sc. (Med.), Docent, Associate Professor at the Department of Radiology, A.I. Yevdokimov Moscow State University of Medicine and Dentistry; Head of the Department of Radiodiagnostics, Children's State Hospital of St. Vladimir, Moscow Healthcare Department, e-mail: sholohova@bk.ru, https://orcid.org/0000-0002-0412-4938

Daniil K. Zharkov – Postgraduate at the Department of Radiology, A.I. Yevdokimov Moscow State University of Medicine and Dentistry; physician at the Department of Radiodiagnostics, Children's State Hospital of St. Vladimir, Moscow Healthcare Department, e-mail: gaspardan@mail.ru, https://orcid.org/0000-0001-6675-775X

Dmitry A. Lezhnev – Dr. Sc. (Med.), Professor, Honored Physician of the Russian Federation, Head of the Department of Radiology, A.I. Yevdokimov Moscow State University of Medicine and Dentistry; Professor at the Department of Therapeutic Dentistry, Russian Medical Academy of Continuous Professional Education, e-mail: lezhnevd@mail.ru, https://orcid.org/0000-0002-7163-2553

Aleksandr Yu. Vasilyev – Dr. Sc. (Med.), Professor, Corresponding Member of RAS, Professor at the Department of Radiology, A.I. Yevdokimov Moscow State University of Medicine and Dentistry; Head, Central Research Institute of Radiation Diagnostics, e-mail: auv62@mail.ru, https://orcid.org/0000-0002-0635-4438

Viktoriya V. Petrovskaya – Dr. Sc. (Med.), Professor at the Department of Radiology, A.I. Yevdokimov Moscow State University of Medicine and Dentistry, e-mail: vvpetrovskay@ya.ru, https://orcid.org/0000-0001-8298-9913

Ekaterina Yu. Lazarenko – Postgraduate at the Department of Radiology, A.I. Yevdokimov Moscow State University of Medicine and Dentistry; physician at the Department of Radiodiagnostics, Children's State Hospital of St. Vladimir, Moscow Healthcare Department, e-mail: lazarenko.katherina@yandex.ru, https://orcid.org/0000-0002-3937-5796

Nikolay N. Blinov – Dr. Sc. (Tech.), Professor at the Department of Radiology, A.I. Yevdokimov Moscow State University of Medicine and Dentistry, e-mail: nblinov@amico.ru, https://orcid.org/0000-0002-0385-3864

Anna D. Sergeeva – Clinical Resident at the Department of Radiology, A.I. Yevdokimov Moscow State University of Medicine and Dentistry, e-mail: anna.ostashienko@gmail.com, https://orcid.org/0000-0003-1026-5216

Authors' contribution:

Sholokhova N.A. – creating the research area concept and study design; approving the final version of the article before its submission for publication.

Zharkov D.K. – significant contribution to the study: literature analysis; writing the text; participation in the collection of material; editing the article before its submission for publication.

Lezhnev D.A. – formulating the study purpose; developing the concept and design of the article; editing the text; approving the final version of the publication – taking responsibility for all aspects of the work, the integrity of all parts of the article and its final version.

Vasiliev A.Yu. – formulating the study purpose; developing the concept and design of the article; editing the text; approving the final version of the article before its submission for publication.

Petrovskaya V.V. – editing the text; approving the final version of the article before its submission for publication.

Lazarenko E.Yu. – editing the article before its submission for publication.

Blinov N.N. – editing the text; approving the final version of the article before its submission for publication.

Sergeyeva A.D. – editing the article before its submission for publication.

The article was published as part of the All-Russian Research and Practical Conference with international participation, dedicated to the 25th anniversary of the Irkutsk Scientific Centre of Surgery and Traumatology.