THE IMPORTANCE OF PHYSIOLOGICAL SPINE EXTENSION – FROM BIRTH TO ADULTHOOD

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Introduction

Modern clinical rehabilitation is a dynamically developing field of medical sciences that plays a key role in the comprehensive management of patients with disorders of the musculoskeletal system. Scientific progress, advances in diagnostic technologies, and innovative therapeutic approaches have contributed to a substantial improvement in the effectiveness of rehabilitation interventions. The aim of this course script is to present the most important issues related to contemporary rehabilitation, based on scientific evidence and the authors' long-standing clinical experience.

The first part of the work addresses ethical conduct in patient care, which constitutes the foundation of professional therapeutic practice. In the context of clinical rehabilitation, a holistic approach is essential, taking into account not only the patient's physical condition but also psychological and social aspects.

Subsequent chapters focus on clinical and scientific issues, including the theoretical foundations of rehabilitation treatment, which are partly based on the principles of Euclidean geometry. Biomechanical relationships within the musculoskeletal system that are crucial for therapy planning are also discussed.

A substantial part of the script is devoted to diagnostic procedures, including methods for the assessment of balance, gait, range of motion, and muscle strength. Particular emphasis is placed on the use of modern diagnostic technologies, such as the DIERS system and the GRAIL laboratory, which enable precise analysis of patients' biomechanical parameters.

The script also extensively discusses the importance of proper body positioning, especially in the context of carrying infants. The most common mistakes are identified, and recommendations for optimal movement patterns are presented, which are of key importance for the prevention of postural defects and musculoskeletal disorders.

Another part of the script focuses on therapy planning, including the application of neurophysiological methods such as Vojta therapy and the NDT-Bobath concept. Scientific evidence supporting the effectiveness of these techniques is presented, together with practical aspects of their implementation in the treatment of patients with various functional impairments.

An indispensable component of the rehabilitation process is the monitoring of treatment outcomes, which enables evaluation of the effectiveness of applied interventions and adjustment of therapy to individual patient needs. In this context, the role of medical documentation, functional tests, and modern diagnostic tools is discussed.

In summary, this script constitutes a comprehensive overview of contemporary clinical rehabilitation, integrating theory with clinical practice. It is intended for therapists, physicians, students of medical sciences, and all those interested in the rehabilitation of patients with disorders of the musculoskeletal system. The authors hope that the knowledge presented will facilitate a better understanding of the principles of modern rehabilitation and contribute to improving the standards of patient care.

Red and Yellow Flags in Rehabilitation – Key Decision-Making Factors

Red flags – warning signs requiring further diagnostic evaluation or referral to a specialist

- Red flags indicate serious conditions or health threats that may require urgent medical intervention or modification of the therapeutic plan.
- Acute, sudden pain of unknown origin – especially when accompanied by fever, unexplained weight loss, or neurological symptoms.
- Night pain disproportionate to physical load – may suggest neoplastic, infectious, or inflammatory processes.
- Pain that does not change with posture or activity – may indicate visceral pathology or malignancy.
- Neurological symptoms (muscle weakness or paresis, sensory disturbances, urinary and fecal incontinence, balance disorders, diplopia) – may suggest spinal cord injury, nerve root syndromes, stroke, or other serious neurological conditions.
- Osteoporosis, pathological fractures, or suspected spinal instability – constitute contraindications to certain manual therapy techniques.
- Severe limitation of joint mobility accompanied by pain and swelling – may indicate joint infection, inflammatory arthritis, or rheumatoid arthritis.
- Abnormal response to therapy or worsening of symptoms after intervention – may indicate an incorrect diagnosis or underlying hidden pathology.
- History of cancer – may suggest metastatic involvement of the musculoskeletal system.
- High-energy trauma (traffic accident, fall from height) – possible vertebral fractures, internal hematomas, or organ injuries.
- Arterial hypertension or unstable cardiovascular diseases – may increase the risk of complications during manual therapy and physical therapy procedures.

Yellow flags – psychological and behavioural factors that may influence the rehabilitation process

- Yellow flags refer to psychosocial barriers in the treatment process and may contribute to chronicity of symptoms and reduced treatment effectiveness.
- Fear of movement (kinesiophobia) – the patient avoids activity due to fear of pain exacerbation.
- Depression or low mood – may lead to reduced motivation for rehabilitation and poorer therapeutic outcomes.
- Pain catastrophizing – the patient focuses exclusively on the negative aspects of pain and anticipates the worst possible outcomes.
- Patient beliefs and expectations regarding treatment – for example, the belief that only surgery can bring relief may negatively affect the effectiveness of conservative treatment.
- Lack of social support – social isolation and insufficient encouragement from relatives may reduce rehabilitation effectiveness.
- Negative experiences related to previous treatment – for example, earlier unsuccessful rehabilitation may lead to low motivation.
- Work-related problems or occupational stress – pressure related to returning to work may affect the patient's functioning and treatment outcomes.
- Chronic pain of unclear aetiology – the absence of a clear cause may suggest a psychogenic component.
- Overuse of analgesic medications or opioid dependence – may indicate chronic pain with a psychosomatic component.
- Poor adherence to therapeutic recommendations – avoidance of exercises, non-compliance with dietary advice, or failure to follow recommended lifestyle modifications.

The role of red and yellow flags in rehabilitation decision-making

Red flags require extended diagnostic work-up and often consultation with a medical specialist (e.g. neurologist, orthopaedist, oncologist). In many cases, they constitute a contraindication to initiating therapy or necessitate modification of the treatment plan.

Yellow flags are not a contraindication to rehabilitation; however, they may substantially affect treatment effectiveness. In such cases, psychological support, cognitive-behavioural strategies, and patient education should be considered.

In summary, both red and yellow flags require an individualised approach to the patient, and their identification is essential for appropriate planning of the rehabilitation process.

Ethical Attitude in Patient Care

Ethical conduct of the therapeutic team is reflected in the way cultural and professional values are selected and applied in accordance with their original intent, in order to establish an effective rehabilitation strategy. Noble motives underlying professional actions ensure the continuous development of respectful and dignified behaviour in interpersonal relationships. The direction of this process may be defined by a shift in human attitudes from "being someone" to "being for others" (Kiebzak & Kosztołowicz, 2003).

The implementation of these principles creates conditions that support patients' optimal recovery. Satisfaction derived from positive treatment outcomes should serve as an incentive for continuous professional development of both the therapeutic team and the patient (Kiebzak et al., 2008).

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Introduction to Clinical and Scientific Considerations

Contemporary care of patients with disorders of the musculoskeletal system, and in particular children with cerebral palsy (CP), should be based on key principles of therapeutic management.

- Fundamental principles of rehabilitation treatment (Kiebzak, 2003)
- Creating a safe and supportive environment for the patient and their family.
- Achieving maximal therapeutic outcomes with minimal use of resources – rationalisation of the treatment plan.
- Limiting iatrogenic effects.
- Clear, simple and effective "home exercise programmes".
- Technical principles of rehabilitation treatment (Kiebzak, 2015)
- Limitation and/or elimination of abnormal behaviours and motor stereotypes.
- Introduction of simple and effective correction of abnormal behaviours and motor stereotypes.

Rational implementation of treatment as a combination of neurophysiological therapeutic techniques, including, among others, the Vojta method, the NDT-Bobath concept, PNF, sensory integration (SI), kinesiology taping (KT), orthopaedic manual therapy (OMT) and C-M techniques.

The care plan for a child with cerebral palsy includes both diagnostic and therapeutic procedures. Functional diagnostics, documented in detail in the medical records, should comprise key examination techniques that enable straightforward determination of the patient's motor performance at the beginning of treatment, as well as monitoring of progress or lack of progress. Identifying a lack of therapeutic improvement is crucial for further clinical decision-making, including planning consultations with specialists such as a paediatrician, neurologist or orthopaedist. This is also important for preventing potential allegations from family members or public authorities, including the Professional Disciplinary Officer of the National Chamber of Physiotherapists (KIF).

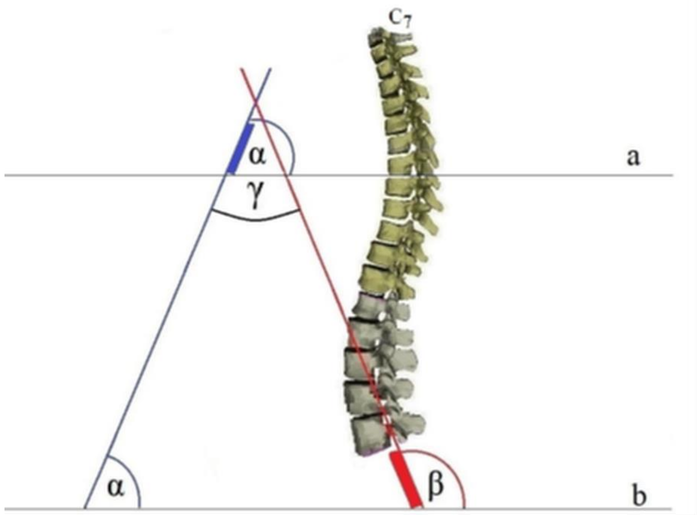
In therapeutic management, long-term clinical experience indicates the effectiveness of combining different neurophysiological treatment techniques. The primary objective of therapy is functional diagnosis and the formulation and achievement of short-term (proximal) and long-term (distal) treatment goals.

Foundations of Euclidean Geometry in Rehabilitation Planning

The aforementioned long-term clinical experience indicates the need to incorporate, into the theoretical foundations of planning care for a child with cerebral palsy, the concept of physiological spinal extension as an essential component of optimal functioning in the environment. An analysis of the relevant literature and the results of the authors' own studies (Kiebzak et al., 2010; Kiebzak, Żurawska et al., 2017) demonstrated the necessity of identifying biomechanical parameters and their interrelationships that allow for the description of body posture, particularly in the sitting position.

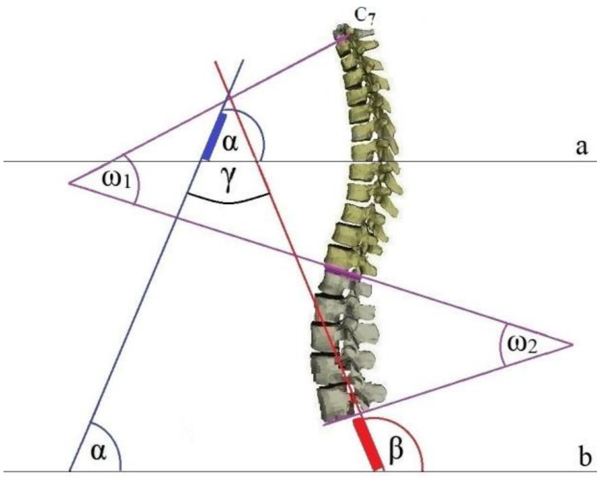
Parameters identified through the authors' clinical observations and the present scientific work demonstrate a close relationship between the simultaneous movements of selected body segments, namely the sternal body and the sacrum, as well as between thoracic kyphosis and lumbar lordosis. Euclidean geometry (Isayama & Yasukouchi, 1995; Kordos, 2010; Łuczyński & Opal, 1964) proved useful in addressing these assumptions, showing that the common relationships between the indicated body segments – the so-called "common meaning" (Kosztołowicz, 2001; Wierciński, 2011) – may serve as a method for postural assessment in the sitting position.

A key element of this concept is the fact that the line representing the sternal body (blue segment) and the line representing the sacrum (red segment) can be inscribed within a triangle, and that movement of one component of this system induces movement of the remaining components. The sternal body, in relation to the horizontal line and the sagittal axis of the body "a", forms the angle α, whereas the sacrum, in relation to the horizontal line and the sagittal axis of the body “b”, forms the angle β. The common reference for the sternal angle α and the sacral angle β is the angle γ (Fig. 1).



Ryc. 1 Common position of the sternum and sacrum in the triangle (Kiebak W. Positioning of the sternum and sacrum in relation to the spine curvatures as a method of assessing body posture while sitting. UJK 2018)

As a consequence of the mutual relationship between the movements of the sternal body and the sacrum, changes occur in the spinal curvatures of the thoracic segment (ω1) and the lumbar segment (ω2) (Fig. 2).

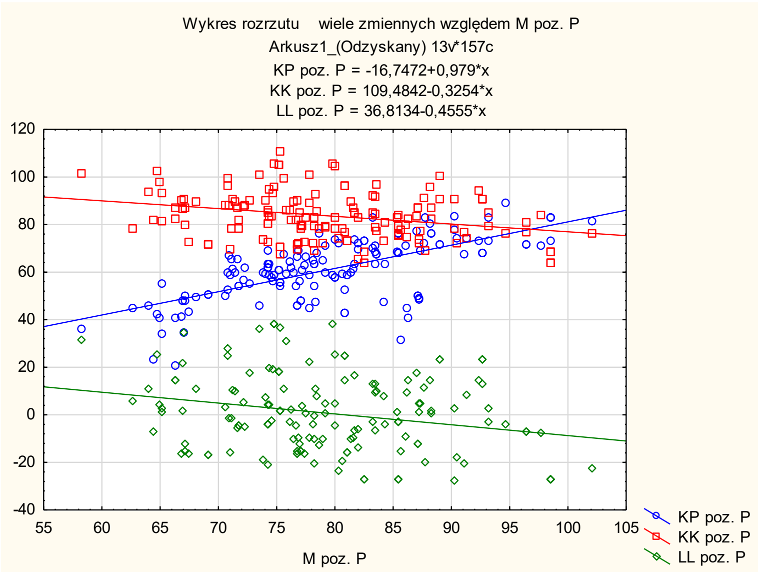


Ryc. 2 The common position of the sternum and sacrum in the triangle in relation to thoracic kyphosis and lumbar lordosis (Kiebak W. The position of the sternum and sacrum in relation to the curvatures of the spine as a method of evaluating the body posture)

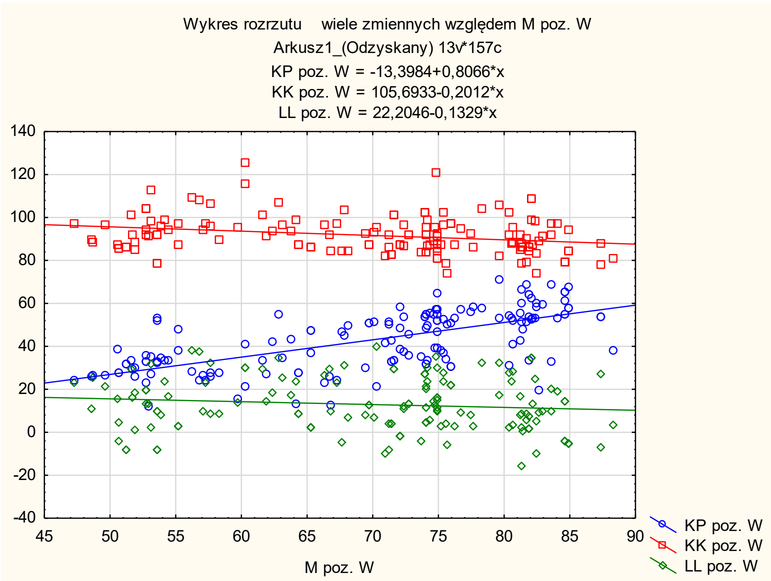
A key element of body posture in this approach is pelvic alignment. When the pelvis is positioned in the desired increased anterior tilt, the inclination of the sacrum and the lower part of the lumbar spine increases anteriorly, which, through active postural behaviour, results in an increase in lumbar lordosis and a desirable posterior repositioning of the head.

Conversely, when anterior pelvic tilt is reduced, the sacrum rotates posteriorly, which subsequently leads to a reduction in lumbar lordosis (Barrey et al., 2006), an increase in thoracic kyphosis, a change in the orientation of the rib cage, and anterior displacement of the head (Caneiro et al., 2010), as typically observed in an incorrect, passive form of relaxed sitting posture.

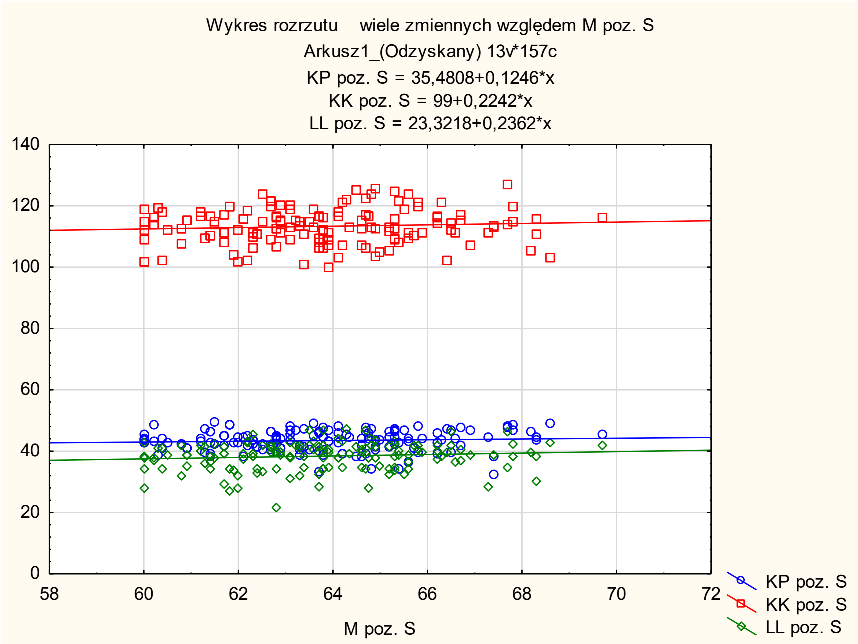
This relationship provides evidence for the existence of interdependent interactions between individual body segments (Caneiro et al., 2010; Ghandhari et al., 2013).



Ryc. 3 Passive position (own material by Kiebzak, Żurawski)



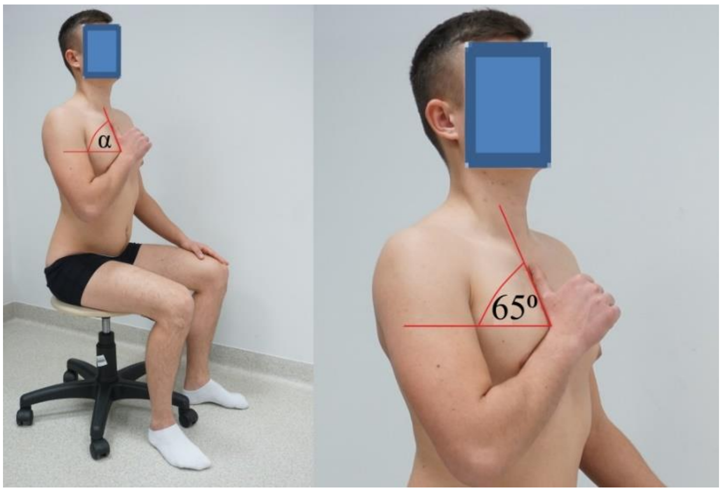
Ryc. 4 Forced position (own material by Kiebzak, Żurawski)



Ryc. 5 Corrected position (own material Kiebzak, Żurawski)

The relationships between the sternal body angle and thoracic kyphosis (blue), lumbar lordosis (green), and the sacrum (red) in the different postural conditions are presented in Figures 3–5 (own material; Kiebzak, 2018).

The presented figures indicate a favourable clinical value of the relationship between the sternal body angle and thoracic kyphosis, lumbar lordosis, and the sacrum in the recommended corrected posture. They demonstrate close, statistically significant associations and empirically confirmed relationships. The key element of these considerations is positioning the sternal body at an angle of approximately 65 degrees relative to the sagittal axis of the body (Fig. 6) (Kiebzak, 2018).



Ryc. 6 Practical setting of the sternum body to an angle of approximately 65° (Kiebzak 2018)

The relationships described above are determined by:

a. Consistent sensorimotor experiences as described within the Bobath concept (Mateja & Gogola, 1998).

b. Appropriate development of sensory integration levels (Ayres; Przyrowski, 2001).

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The Importance of Body Positioning During Infant Carrying

In the care of children at developmental risk, appropriate positioning strategies, including carrying methods, are of particular importance, as incorrect handling may reinforce abnormal motor patterns. The lack of published studies describing optimal ways of carrying infants is consistent with the authors' own clinical observations, which indicate that infants are commonly carried in a manner that leads to improper head alignment, overload of the spinal joints, and unfavourable conditions for normal development of the hip joints. This observation provided the motivation to present principles of physiological infant carrying during the first year of life.

The authors' observations are based on approximately 7,500 children treated at the Regional Specialist Children's Hospital and the Clinical Rehabilitation Department of the Świętokrzyskie Centre for Paediatrics in Kielce. The high frequency and often extreme forms of incorrect carrying observed in outpatient practice have inspired, and continue to inspire, the authors to seek appropriate clinical solutions. The development of physiological body posture already in early life should form the basis for healthy movement behaviours, including, among others, the prevention of musculoskeletal disorders.

Errors in Infant Carrying

Long-term clinical experience indicates that parents carry their children in highly variable ways, which may influence the developing spinal curvatures and disturb the child's motor development (Fig. 7).

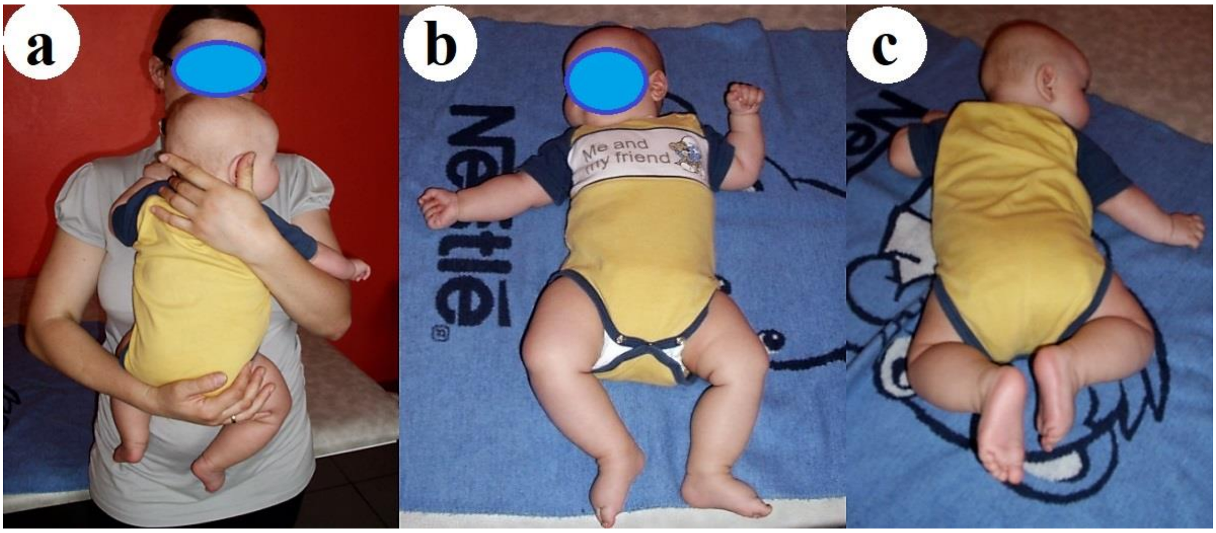
Ryc. 7 Examples of different body positions of a baby while carrying it (Wojciech Kiebzak, Arkadiusz Żurawski et al. 2020).

Among the most frequently observed errors during infant carrying are:

a. Excessive flexion of the lower limbs, leading to flattening or even kyphotic alignment of the lumbar spine. This may delay the development of independent acquisition of a correct sitting posture and locomotion (Vojta, 1988). Increased thoracic kyphosis and reduced lumbar lordosis are associated with the occurrence of discopathy, which constitutes a serious clinical problem in older children (Żurawski, Kiebzak et al., 2019). This posture is also accompanied by excessive head extension and shoulder retraction (Fig. 8).

Ryc. 8 Kyphotization of the lumbar spine in case of improper carrying of the child (Wojciech Kiebzak, Arkadiusz Żurawski et al. 2020).

b. carrying the baby on the front with the head rotated to one side (Fig. 9a).



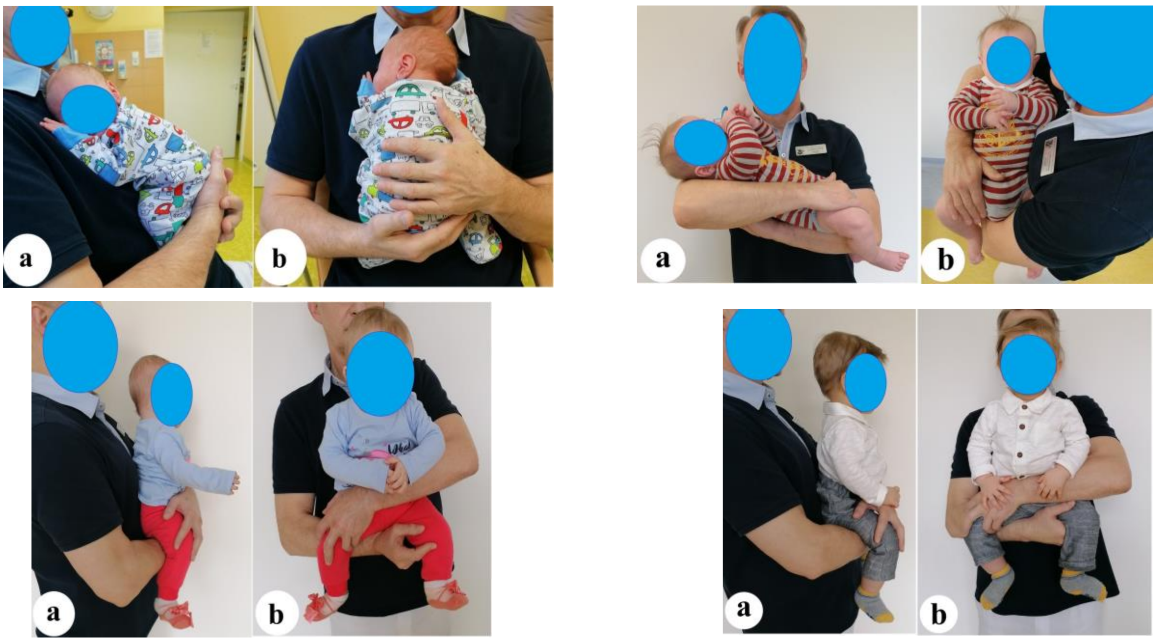
Ryc. 9 The influence of the baby's position during carrying on the induction of the asymmetric tonic neck reflex (Wojciech Kiebzak, Arkadiusz Żurawski et al. 2020).

Carrying an infant with the head rotated to one side may induce or exacerbate existing dysfunctions, such as the persistence of pathological tonic reflexes, including the **asymmetric tonic neck reflex (ATNR)** (Fig. 9b). The ATNR is elicited by rotation of the head to one side, resulting in tonic extension of the limbs on the face side and tonic flexion of the limbs on the occipital side. This reflex determines the alignment of the head, spine and limbs, leading to disturbances in the weight-bearing and support functions of the upper limbs (Fig. 9c).

Recommended infant carrying methods

Depending on the stage of functional development, the authors propose four methods of infant carrying as an element of stimulation of normal psychomotor development and consolidation of the effects of rehabilitation therapy:

1. Carrying infants up to the expected date of delivery (preterm infants) (upper left panel; sagittal and frontal planes).
2. Carrying infants aged from birth to approximately 4.5 months (upper right panel; sagittal and frontal planes).
3. Carrying infants aged approximately 4.5 to 8 months (lower left panel; sagittal and frontal planes).
4. Carrying infants older than 8 months (lower right panel; sagittal and frontal planes).



Wojciech Kiebzak. Basics of physiological carrying babies. Pol Ann Med. 2021;28(1): 89–93.

Ryc. 10 Recommended ways to carry babies in the first year of life.

Below is a faithful, publication-ready English translation of the provided section (kept in a scientific tone, without stylistic inflation and without strengthening causal claims beyond the original text).

It is recommended to verify the infant's position in the caregiver's arms in front of a mirror, with particular attention paid to the alignment of the body axis in the sagittal and frontal planes.

The authors' own clinical observations indicate a lack of widely accepted recommendations regarding optimal infant carrying. This is also confirmed by a literature review conducted for the purposes of this study, which revealed a lack of publications addressing this issue.

Therefore, the aim of this work is to present—based on biomechanical analysis and the authors' clinical experience—the most frequently observed incorrect infant carrying methods, as well as to describe those carrying strategies that create the most favourable conditions for psychomotor development.

In early development, the infant spine is not prepared to bear axial loads. For this reason, carrying infants in an upright position should primarily be avoided. Such positioning may disturb the formation of physiological spinal curvatures and, consequently, may lead to abnormal development of the entire musculoskeletal system (Vaivre-Douret et al., 2004; Nakano et al., 2010; Dreischarf et al., 2016). During the first year of life, the trunk muscles do not provide sufficient stabilisation of the spine (Nakano et al., 2010).

Positioning the spine in flexed postures results in a ten-fold increase in compressive and shear forces acting on the lower segments of the spine (Dreischarf et al., 2016). Consequently, maintaining a flexed lumbar posture during carrying may promote disturbances in vertebral development due to increased compressive loading of the anterior parts of the vertebral bodies, potentially leading to vertebral wedging (Nakano et al., 2010).

Flexed spinal postures are also associated with an increase in intramedullary pressure, which may impair blood flow and perfusion, leading to disturbances in oxidative metabolism within spinal neuronal mitochondria (Dey et al., 2012), and consequently affecting axonal transport and neural conduction (Dunsirn et al., 2016). Circulatory disturbances in the form of hypovascularisation within vertebral structures may result in growth disturbances of the vertebrae, which has been reported to correlate with the occurrence of structural scoliosis (Heripret et al., 1961).

Disturbances of spinal curvatures in the sagittal plane may provoke deformities in the remaining planes of the spine, contributing to the development of postural defects in increasingly younger children (Zmyślna et al., 2019).

Remaining in flexed postures may also disrupt the respiratory cycle, resulting in reduced lung volumes and minute ventilation (Landers et al., 2003), as well as decreased forced expiratory volume in one second and forced vital capacity (Lin et al., 2006). Maintaining infants in flexed positions may further be associated with disturbances in swallowing (Simão et al., 2013), intestinal peristalsis (Peeters et al., 2013), and intestinal gas transit (Dainese et al., 2003).

On the other hand, appropriate positioning of infants has been shown to exert beneficial effects on neuromuscular development (Short et al., 1996) and motor organisation (Neu et al., 1997; Keller et al., 2003). De Graaf-Peters et al. reported that supporting spinal alignment has a positive influence on infants' motor abilities (de Graaf-Peters, 2006). Moreover, children who are positioned in a way that supports correct body alignment during early life demonstrate a greater range of active movements and increased movement dynamics of the limbs later in development (Lin et al., 2006). This is of particular importance for the development of upper-limb support functions, which form the basis for subsequent motor skills such as standing and walking.

The importance of body positioning is also confirmed by Van Balen et al. (2012), who emphasised the high variability of postural control between 4 and 18 months of age. As early as 4 months of age, infants are able to select muscle recruitment strategies that are optimal for the task being performed (Van Balen et al., 2012). For this reason, once the infant begins to control body orientation in space, progression to higher carrying positions is recommended, with the infant positioned facing away from the caregiver.

It should be emphasised that it is not always possible to apply the proposed optimal infant-carrying patterns. Nevertheless, considering the number and potential severity of complications associated with prolonged positioning in non-optimal postures, efforts should be made to achieve the best possible correction of spinal alignment during carrying. The proposed proprietary carrying positions are intended to ensure both infant safety and caregiver comfort. Achieving an optimal preventive effect requires frequent monitoring of the carrying technique in front of a mirror and verification of the infant's body alignment in all planes, in order to ensure proper positioning of the head, spine and limbs (Nakano et al., 2010).

The presence of abnormal reactions in infants often forces caregivers to adopt inappropriate carrying strategies. In attempting to adapt to abnormal motor patterns, parents may carry their children in a way that reinforces existing dysfunctions. In such situations, it is difficult to determine whether the primary factor is the abnormal motor pattern itself or the inappropriate carrying method. Incorrect carrying techniques do not necessarily lead to the described complications, particularly when applied for a short period of time. However, based on the authors' clinical observations, the search for appropriate carrying methods and the implementation of correct handling strategies are especially important in infants presenting with neurodevelopmental disorders and in children who are carried frequently and for prolonged periods during the day.

Postural re-education, recommended already at an early stage of life (Mikołajczyk & Jankowicz-Szymańska, 2015), plays an important role in the management of spinal pain disorders. Furthermore, the results of studies investigating the use of the "corrected posture"—that is, physiological spinal extension—in the treatment of various musculoskeletal conditions, including disorders of the head, neck and thoracic inlet, developmental hip dislocation (Kiebzak & Żurawski, 2016), idiopathic toe walking (Szopa & Domagalska-Szopa, 2016), and severe traumatic brain injury (Kiebzak, Wysocka & Żurawski, 2015), should encourage further in-depth and multidirectional research, including investigations of balance reactions (Wilczyński, 2014).

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Diagnostic procedure.

Balance Assessment

Balance is a key component in the evaluation of neurological patients with cerebral palsy (CP), including those presenting with gait disorders. Accurate assessment enables identification of functional deficits and appropriate therapy planning. The most important balance assessment methods are presented below:

- **Romberg test** – used to assess postural stability. The patient stands with the feet together and the arms alongside the body, first with the eyes open and then with the eyes closed. The test is considered positive if the patient loses balance after closing the eyes, which may indicate impaired proprioception or cerebellar dysfunction.

- **Berg Balance Scale (BBS)** – consists of 14 tasks assessing static and dynamic balance, such as sitting down, standing up, standing with the eyes closed, and standing on one leg. Each task is scored from 0 to 4 points, with a maximum total score of 56. A score below 45 points indicates an increased risk of falls (Berg et al., 1992).
- **Tinetti Test (Performance-Oriented Mobility Assessment – POMA)** – comprises two parts: balance (9 items) and gait (7 items). The maximum total score is 28 points; a score below 19 points indicates a high risk of falls (Tinetti, 1986).
- **Timed Up and Go (TUG) test** – the patient stands up from a chair, walks 3 metres, turns around, returns, and sits down. A time greater than 13.5 seconds indicates an increased risk of falls (Podsiadlo & Richardson, 1991).
- **Dynamic Gait Index (DGI)** – assesses the ability to modify gait in response to changing task demands. It consists of 8 items, with a maximum score of 24 points; a score below 19 points indicates an increased risk of falls (Shumway-Cook & Woollacott, 2000).
- **Computerised posturography** – an advanced balance assessment method that measures the patient's ability to maintain stability under various sensory conditions. It allows for quantitative evaluation of postural control and identification of specific deficits (Nashner, 1997).

Clinical significance of balance assessment

Accurate balance assessment allows for:

- identification of specific postural deficits,
- evaluation of fall risk,
- monitoring of rehabilitation progress, and
- adjustment of therapeutic programmes to individual patient needs.

The selection of appropriate assessment tools should be tailored to the patient's clinical condition and the availability of diagnostic equipment.

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Gait Assessment

Gait assessment is a key component of neurological diagnostics, enabling the identification of specific movement disorders and appropriate therapy planning. The most important gait assessment methods are presented below:

- **Clinical observation** – a basic method based on visual assessment of the patient during walking. The clinician evaluates movement symmetry, step length, rhythm, coordination and the presence of compensatory strategies. This method is fast and does not require specialised equipment; however, its accuracy depends on the examiner’s clinical experience.
- **Timed Up and Go (TUG) test** – the patient stands up from a chair, walks 3 metres, turns around, returns and sits down. The task completion time is recorded; a time greater than 13.5 seconds indicates an increased risk of falls (Podsiadlo & Richardson, 1991).
- **Dynamic Gait Index (DGI)** – consists of 8 tasks assessing the patient’s ability to modify gait in response to changing task demands, such as changes in walking speed, head turns or obstacle negotiation. The maximum score is 24 points; a score below 19 points indicates an increased risk of falls (Shumway-Cook & Woollacott, 2000).

- **Functional Gait Assessment (FGA)** – an extended version of the DGI, including additional tasks such as backward walking and walking on the toes. It is considered more sensitive in detecting subtle gait impairments (Wrisley & Kumar, 2010).
- **Instrumented gait analysis using computer-based systems** – advanced technologies, such as the DIERS system, enable three-dimensional biomechanical gait analysis, including kinematic and kinetic parameters such as joint angles, joint moments and plantar pressure distribution. This allows for precise identification of gait abnormalities and monitoring of rehabilitation outcomes (Markiewicz et al., 2015).

Clinical significance of gait assessment

Accurate gait assessment enables:

- identification of specific pathological gait patterns, such as spastic, ataxic and parkinsonian gait,
- evaluation of fall risk and related complications,
- monitoring of the effectiveness of therapeutic interventions and rehabilitation progress, and
- planning of individualised rehabilitation programmes tailored to the patient's needs.

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Range of Motion Assessment

Range of motion (ROM) assessment is a key component in the diagnostic evaluation of neurological patients with gait disorders. It enables identification of joint mobility limitations that may influence gait patterns and overall functional performance. The main ROM assessment methods and their clinical relevance are presented below.

Methods of range of motion assessment

- **Goniometric measurements** – the goniometer is a commonly used clinical tool for ROM assessment. It allows precise measurement of joint angles during both active and passive movements. Studies have demonstrated that goniometric measurements are reliable and reproducible, making them a standard method for ROM evaluation (Norkin & White, 2016).
- **Inclinometers** – these devices measure the inclination angles of body segments relative to the vertical axis. They are particularly useful for assessing spinal mobility. Inclinometers provide accurate measurements and are easy to use in clinical settings (Mayer et al., 1984).
- **SFTR method (Sagittal–Frontal–Transverse–Rotation)** – this system assesses ROM in three anatomical planes: sagittal, frontal and transverse. It enables a comprehensive evaluation of joint mobility and is particularly useful for clinical documentation (Kapandji, 2007).
- **Modern technologies** – with technological advances, smartphone applications and computer-based systems for ROM assessment have been introduced. Studies comparing traditional goniometers with mobile applications have demonstrated comparable measurement accuracy, suggesting their potential applicability in clinical practice (Jones et al., 2014).

Clinical significance of range of motion assessment

Accurate ROM assessment enables:

- identification of mobility restrictions that may affect gait patterns and lead to compensatory movement strategies,

- planning of individualised rehabilitation programmes aimed at restoring normal joint mobility,
- monitoring of therapeutic progress and modification of interventions based on obtained results, and
- evaluation of the effectiveness of applied therapeutic methods.

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Muscle Strength Assessment

Muscle strength assessment is a key component in the diagnostic evaluation of neurological patients with gait disorders. It enables identification of functional deficits, monitoring of rehabilitation progress, and planning of individualised therapeutic programmes. The most important methods of muscle strength assessment are presented below.

Muscle strength rating scales

- **Medical Research Council (MRC) scale** – a six-point scale used to grade muscle strength:
  - **0** – no visible or palpable muscle contraction
  - **1** – trace contraction without joint movement
  - **2** – full range of motion with gravity eliminated
  - **3** – full range of motion against gravity
  - **4** – movement against external resistance
  - **5** – normal muscle strength

The MRC scale is widely used in clinical practice because of its simplicity and practicality. Studies have confirmed its good reliability and validity in the assessment of muscle strength in neurological patients (Paternostro-Sluga et al., 2008).

- **Lovett scale** – similar to the MRC scale, it grades muscle strength on a six-point scale from 0 to 5, where 0 indicates no contraction and 5 indicates normal muscle strength. It is commonly used in neurology to assess the severity of peripheral nerve injury and to monitor rehabilitation progress.

Instrumented methods of muscle strength assessment

- **Handheld dynamometry** – the use of a handheld dynamometer enables objective measurement of handgrip strength. It is a simple and non-invasive method that has been widely applied in the assessment of sarcopenia and in predicting functional status in older adults (Lauretani et al., 2003).
- **Isokinetic muscle strength testing** – isokinetic devices allow muscle strength to be assessed at a constant angular velocity, enabling detailed analysis of both concentric and eccentric muscle actions. This method is particularly useful for identifying muscle imbalances and for planning rehabilitation programmes (Drouin et al., 2004).

Clinical significance of muscle strength assessment

Accurate muscle strength assessment enables:

- identification of functional deficits affecting gait and posture,
- monitoring of rehabilitation progress and adjustment of therapeutic programmes,
- prediction of fall risk and other complications associated with muscle weakness, and
- planning of interventions aimed at improving the quality of life of patients with neurological disorders.

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Modern Diagnostic Systems

Contemporary neurological diagnostics increasingly rely on advanced technologies that enable precise assessment of gait disorders. Selected modern diagnostic systems are presented below.

DIERS system

The DIERS system is an advanced tool for posture and gait analysis that enables three-dimensional biomechanical assessment of the patient. It uses surface topography scanning technology, allowing non-invasive and rapid acquisition of accurate data on body geometry, load distribution and gait kinematic parameters. Studies have shown that the DIERS system is effective in identifying postural and gait abnormalities, which is of substantial importance for rehabilitation planning (Markiewicz et al., 2015).

GRAIL (Gait Real-time Analysis Interactive Lab)

GRAIL is an advanced system combining an instrumented treadmill, motion analysis and virtual reality. It enables gait assessment under realistic and interactive conditions, allowing identification of subtle impairments and adjustment of therapy to the individual needs of the patient. Research indicates that the use of the GRAIL system in rehabilitation may lead to significant improvement in gait function in neurological patients (van Kammen et al., 2017).

Smart insoles

Smart insoles are modern devices equipped with sensors measuring plantar pressure, acceleration and other biomechanical parameters during walking. They allow continuous monitoring of gait patterns in everyday environments, which is particularly useful in the assessment of patients with Parkinson's disease. Platforms based on smart insoles provide valuable data that can support both diagnostic and therapeutic processes (Boucharas et al., 2022).

Clinical relevance of modern diagnostic systems

The introduction of modern diagnostic systems into clinical practice enables:

- precise and objective assessment of gait disorders,
- early detection of abnormalities, allowing faster implementation of appropriate therapy,
- personalisation of rehabilitation programmes based on individual patient needs, and
- monitoring of therapeutic progress and real-time adjustment of interventions.

Integration of these technologies with traditional diagnostic methods contributes to improved quality of care for patients with gait disorders and increases the effectiveness of therapeutic interventions.

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Monitoring the Treatment Process in Physiotherapy

Monitoring the treatment process in physiotherapy is a key element in ensuring both therapeutic effectiveness and patient safety. Systematic assessment of progress enables the rehabilitation plan to be adjusted to the patient's current needs, facilitates early identification of potential problems, and supports optimisation of therapeutic outcomes.

Methods for monitoring progress in physiotherapy

1. **Medical documentation**
   Detailed clinical documentation allows continuous tracking of changes in the patient's condition, evaluation of the effectiveness of applied interventions, and planning of further therapeutic actions. Recording parameters such as range of motion, muscle strength and pain intensity is essential for objective assessment of treatment progress.
2. **Functional tests**
   The use of standardised tests, such as the 6-Minute Walk Test and the Tinetti scale, enables evaluation of the patient's ability to perform activities of daily living and monitoring of functional changes over time. The 6-Minute Walk Test is widely used to assess physical capacity in patients with respiratory and cardiovascular diseases, and its results correlate with overall health status (Enright, 2003).
3. **Outcome and rating scales**
   The application of scales assessing pain, quality of life or level of disability enables quantitative evaluation of the patient's subjective symptoms and their changes during therapy. An example is the Oswestry Disability Index, which is considered one of the most reliable tools for assessing disability related to low back pain (Fairbank & Pynsent, 2000).
4. **Imaging and functional imaging diagnostics**
   Techniques such as ultrasonography (US) are used to monitor the healing process and

to assess treatment effectiveness, particularly in sports rehabilitation. Ultrasound enables real-time evaluation of joint mobility, muscle and tendon motion, and blood flow within vessels. It is a non-invasive method that provides valuable information on the structure and function of soft tissues (Whittaker et al., 2007).

5. **Modern technologies**
   Contemporary diagnostic and therapeutic devices, such as motion analysis systems and mobile applications, enable precise monitoring of patient progress and more effective rehabilitation planning. Integration of these technologies into physiotherapy practice benefits both clinicians and patients. An example is the use of mobile applications to monitor patients' physical activity, allowing continuous tracking of progress and adjustment of treatment plans (Lu et al., 2018).

Clinical significance of treatment monitoring

Regular monitoring of rehabilitation progress enables:

- **individualisation and modification of therapy**, by adjusting exercises and therapeutic techniques in response to changes in the patient's condition,
- **enhancement of patient motivation**, as objective evidence of improvement can increase engagement in the rehabilitation process and improve adherence,
- **evaluation of treatment effectiveness**, through systematic verification of therapeutic methods and their potential modification, and
- **maintenance of comprehensive medical documentation**, which is essential from both clinical and legal perspectives, ensuring traceability of care and informed clinical decision-making.

In conclusion, monitoring the treatment process in physiotherapy is an indispensable component of effective clinical practice, ensuring optimal outcomes and patient safety.

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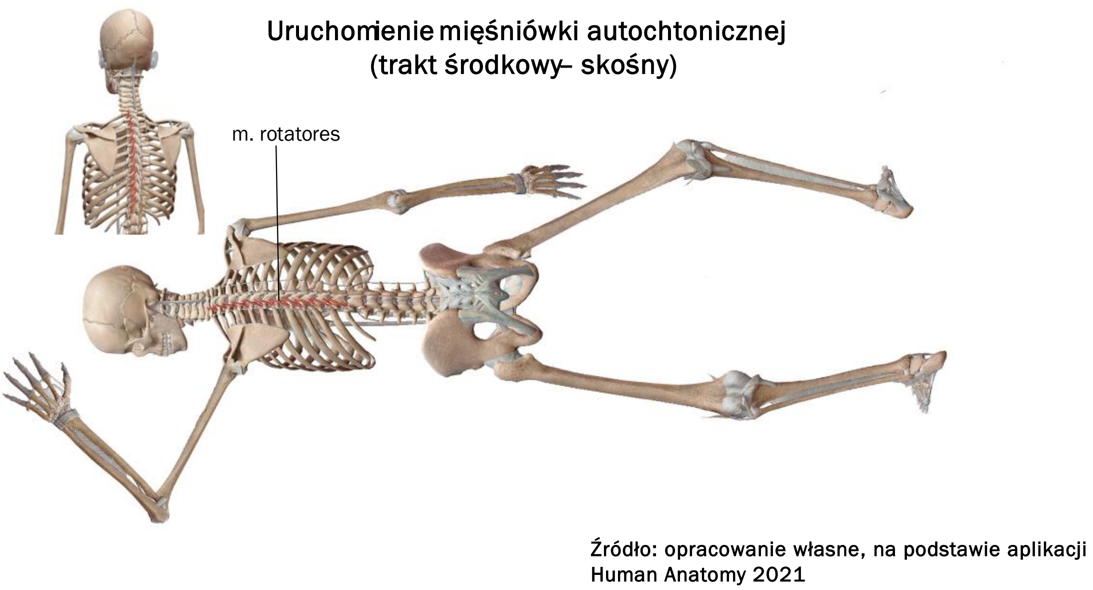
Fundamentals of therapy planning

Based on the authors' long-standing clinical experience, the Vojta method is considered the primary component of the therapeutic approach. During its application, natural movement patterns emerge, including spinal extension, activation of the deep (autochthonous) spinal muscles (Fig. 11), and centring of the axial joints.

These elements are incorporated into a comprehensive therapeutic programme, including stimulation of movement patterns, for example according to the NDT-Bobath concept, as part of an integrated treatment strategy that also includes, among others, kinesiology taping (KT), sensory integration (SI), the Castillo–Morales concept, and proprioceptive neuromuscular facilitation (PNF).



Ryc. 11 Aktywowanie mięśniówki autochtonicznej w odruchowym pełzaniu wg Vojty (materiał własny Kiebzak).

The therapeutic interventions have a reflex-based character and are initiated by eye movement.

Figure 12 presents a schematic illustration of the mechanisms underlying the induction of postural and locomotor control.

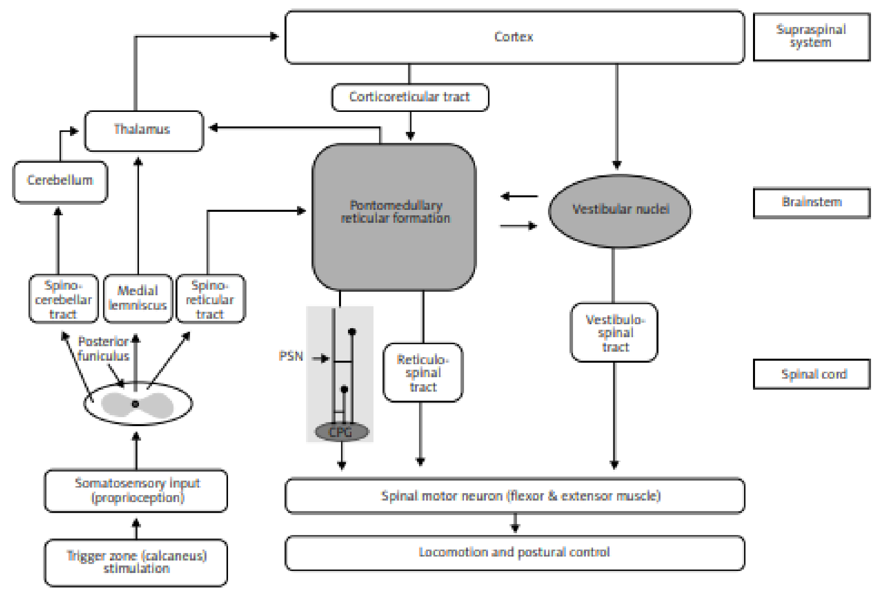


Figure 1. Summary of mechanisms in the brainstem and spinal cord in reflex creeping in Vojta therapy
CPG – central pattern generator, PSN – propriospinal neuron.

Ryc. 12 The overall mechanism activated in the brainstem and spinal cord during reflex crawling in Vojta therapy (Sun-Young Ha, Wojciech Kiebzak et al. 2023)

- Sun-Young Ha, Wojciech Kiebzak, Yun-Hee Sung. The impact of reflex creeping in Vojta therapy on locomotion and postural control. Medical Studies/Studia Medyczne 2023; 39 (2): 192–197
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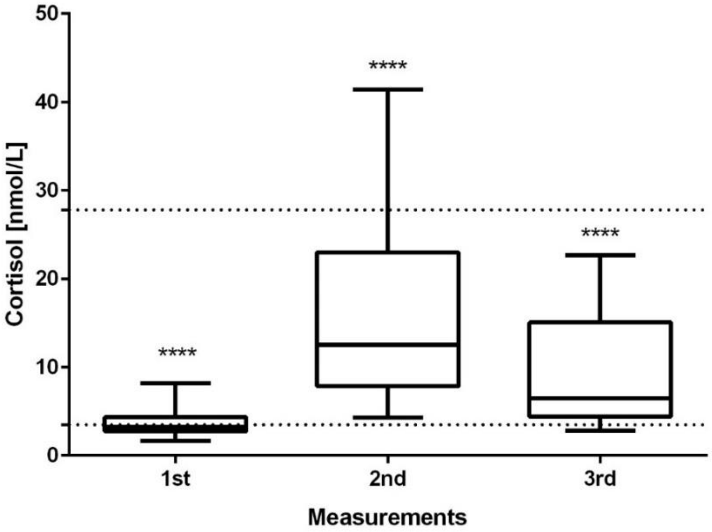
Safety during therapy

An important element of therapy planning is awareness that the child's desirable responses are being deliberately elicited. This is particularly relevant given that neurodevelopmental disorders constitute a serious health problem, affecting approximately 3–4% of children (Blackburn, 2012). Interestingly, in low-income countries the prevalence of such disorders is reported to be approximately 0.5%, which is mainly related to the high neonatal mortality rate (Durkin, 2002). Improved survival of preterm infants—one of the Millennium Development Goals—represents a major challenge for comprehensive care of the developing child. In this population, the prevalence of central coordination disorder (CCD) ranges from 23% to 42% and decreases with increasing gestational maturity at birth (Ding, 2009).

Early recognition of developmental disorders is difficult (Hadders-Algra, 2004). A particularly important component of this process is the planned detection of CCD, which allows evaluation of both the dynamics and the direction of developmental changes (Kiebzak, 2003). A wide range of diagnostic tools is used in this process, including assessments according to Prechtl, Hellbrügge and Vojta. Neurodevelopmental disorders identified during diagnostic evaluation require early intervention aimed at eliminating or reducing existing dysfunctions (Blauw-Hospers, 2005; Blauw-Hospers, 2007). The first effects of early intervention include improvement in social interaction and in the quality of neurological reflexes, which precede improvements in spontaneous motor activity and postural reactions according to the Vojta concept (Kiebzak, 2016). In the authors' opinion, follow-up of children with CCD should be long-term, as it allows identification of important associations, for example with visual perception (Kiebzak, 2012). It should be emphasised that, in addition to achieving normal clinical parameters, the principal goal of diagnostic and therapeutic management is improvement in quality of life.

According to the authors, the above-mentioned therapeutic approaches often involve maintaining forced postures and muscle stretching in treated children (Vojta, 2007). These procedures frequently cause discomfort, which in turn may induce a lack of a sense of safety and activate basic defence mechanisms of the body, primarily through the release of glucocorticoids (stress hormones). Initially, adrenaline and noradrenaline are released, which subsequently potentiate the effects of cortisol. Cortisol regulates numerous physiological and pathophysiological processes, including the stress response, by increasing energy availability (e.g. by promoting glucose release into the bloodstream and stimulating gluconeogenesis), increasing blood pressure, and altering mood and behaviour to facilitate defence against perceived threat (Torrente-Rodríguez, 2020). Chronically elevated cortisol levels are a major cause of Cushing's syndrome (Casals, 2020) and are also associated with reduced immune function, delayed wound healing, obesity, and damage to hippocampal cells, which may subsequently impair cognitive development (Hewagalamulage et al., 2016; Szeszko et al., 2018).

Therefore, particular attention should be paid to the assessment of cortisol levels in children with disorders of central nervous system activity who present with CCD. In this group, it is especially important to determine whether physiotherapy interventions induce disturbances in cortisol secretion and/or maintenance of physiological cortisol levels, which could have further negative consequences. The authors' own results indicate that therapeutic intervention is associated with a statistically significant increase in salivary cortisol concentration; however, this increase is transient and remains within normative ranges (Kiebzak, Żurawski et al., 2021).



Ryc. 13 Comparison of cortisol concentrations in infant saliva samples collected before, during, and after Vojta rehabilitation. Statistically significant differences ($p<0.05$) were analyzed using a two-sided paired T-test. Lines indicate the normal range between minimum and maximum values.

The use of the Vojta method in the treatment of developmental risk and subsequent complications is supported by the conclusions of the cited authors (Sanz-Mengibar, Menéndez-Pardiñas & Santonja-Medina, 2021), who reported that Vojta therapy accelerates the achievement of locomotor milestones in children with cerebral palsy younger than 18 months.

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Clinical Effects of Therapy

Introduction

Rehabilitation of patients with postural defects and movement dysfunctions requires not only individually tailored therapeutic methods, but also reliable assessment of treatment effectiveness. Monitoring the clinical effects of therapy enables adaptation of rehabilitation strategies to the patient's current needs and allows objective evaluation of achieved progress. Early identification of changes in biomechanical parameters and their appropriate correction may prevent further progression of postural disorders and reduce the risk of pain-related and functional complications later in life.

Contemporary postural diagnostics and evaluation of therapeutic outcomes increasingly rely on advanced tools that enable precise analysis of changes within the musculoskeletal system. One of the most advanced systems used in studies on treatment effects is the DIERS Formetric 4D system, which enables three-dimensional, completely non-invasive assessment of spinal and pelvic morphology. This technology allows accurate evaluation of thoracic kyphosis and lumbar lordosis angles, vertebral rotation and lateral deviation, thereby supporting comprehensive monitoring of therapeutic progress and optimisation of rehabilitation interventions (Zmyślna et al., 2019).

The implementation of the DIERS Formetric 4D system represents an important step towards improving the objectivity of postural assessment and reducing errors associated with subjective visual evaluation. Studies have shown that this technology enables effective monitoring of treatment outcomes both in patients with postural defects and in individuals with spinal pain syndromes. Owing to the possibility of repeated, non-invasive measurements, the DIERS system supports both diagnostics and evaluation of the effectiveness of various rehabilitation approaches, including neurophysiological therapies such as the Vojta method and proprioceptive neuromuscular facilitation (PNF) (Zmyślna et al., 2019).

The available evidence confirms that appropriately selected therapeutic strategies, combined with modern diagnostic methods, can effectively improve postural parameters, reduce pain and enhance motor function. The following sections present clinically documented effects of therapy supported by scientific studies, together with an analysis of treatment effectiveness.

Effectiveness of therapeutic methods

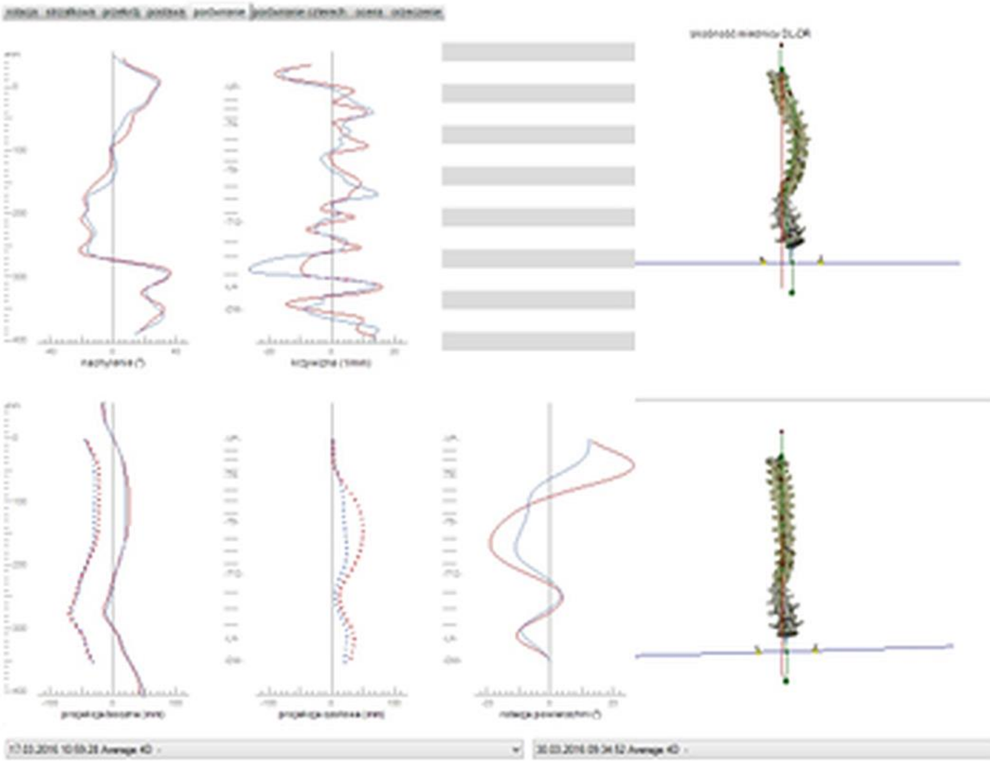
PNF and Vojta therapy in children with postural defects

Therapy based on the concept of proprioceptive neuromuscular facilitation (PNF) and the Vojta method represents one of the most effective approaches in the rehabilitation of children with postural defects. The combination of these two methods facilitates activation of postural muscles, normalisation of muscle tone and restoration of correct movement patterns.

In a study conducted in a group of children aged 8–15 years, a significant reduction in the thoracic kyphosis angle and a decrease in lateral spinal deviations were observed after a four-week therapeutic programme based on these techniques (Zmyślna, Kiebzak & Żurawski, 2019).

Analysis of the results confirmed that patients receiving combined PNF and Vojta therapy achieved a clear improvement in the thoracic kyphosis angle. In addition, vertebral rotation and lateral deviation of the spinal axis were reduced, indicating the effectiveness of the intervention in improving postural stability. Particularly marked improvements were observed in children presenting with more pronounced postural defects, supporting the effectiveness of neurophysiological methods in normalising body biomechanics (Zmyślna, Kiebzak & Żurawski, 2019).

The study also highlighted the role of the DIERS Formetric 4D system, which enabled precise evaluation of therapeutic progress and objective monitoring of changes in spinal alignment. The use of this technology allowed accurate quantification of kyphosis correction and verification of treatment effects across different anatomical planes.



Ryc. 14 Comparison of the angle of thoracic kyphosis before and after therapy (own material by Kiebzak, Żurawski)

McKenzie and Vojta methods in the treatment of discopathy-related pain syndromes

The combination of the McKenzie method and the Vojta method represents an effective therapeutic approach in the management of spine-related pain syndromes associated with discopathy. The McKenzie method is based on individually selected repeated movements aimed at pain reduction and restoration of normal spinal function through symptom centralisation. In contrast, the Vojta method activates unconscious movement patterns, thereby supporting stabilisation and improvement of postural control.

Studies conducted in a group of patients with spine-related pain syndromes demonstrated that the application of both methods resulted in complete pain reduction within 3–12 days after initiation of therapy. In addition, analysis of biomechanical parameters revealed significant changes in spinal alignment, including a reduction of the thoracic kyphosis angle by 7.95° and an increase in the lumbar lordosis angle by 7.6°, indicating the effectiveness of the intervention in restoring physiological spinal curvatures (Żurawski & Kiebzak, 2019).

Evaluation of treatment outcomes was performed using the DIERS Formetric 4D system, which enabled precise monitoring of postural changes. The study confirmed that an appropriate combination of neurophysiological therapy and specific mechanical techniques may lead to substantial improvement in postural parameters and elimination of pain in patients with discopathy.

Table 2. Changes of parameters in 28 patients aged 15–17 years old during the treatment in the Department of Orthopedics and Traumatology of the Świętokrzyskie Center for Pediatrics in Kielce, Poland

Parameter	Change revealed during the examination		p
	baseline	final	
Trunk inclination [°]	2.87	1.04	< 0.05
Angle of thoracic kyphosis [°]	39.08	31.14	< 0.05
Angle of lumbar lordosis [°]	28.88	36.48	< 0.05
Lateral deviation [mm]	7.21	–1.71	< 0.05
Trunk torsion [°]	3.83	–0.81	< 0.05
Surface rotation [°]	4.72	3.11	< 0.05
Pelvic obliquity [°]	1.84	–1.96	< 0.05

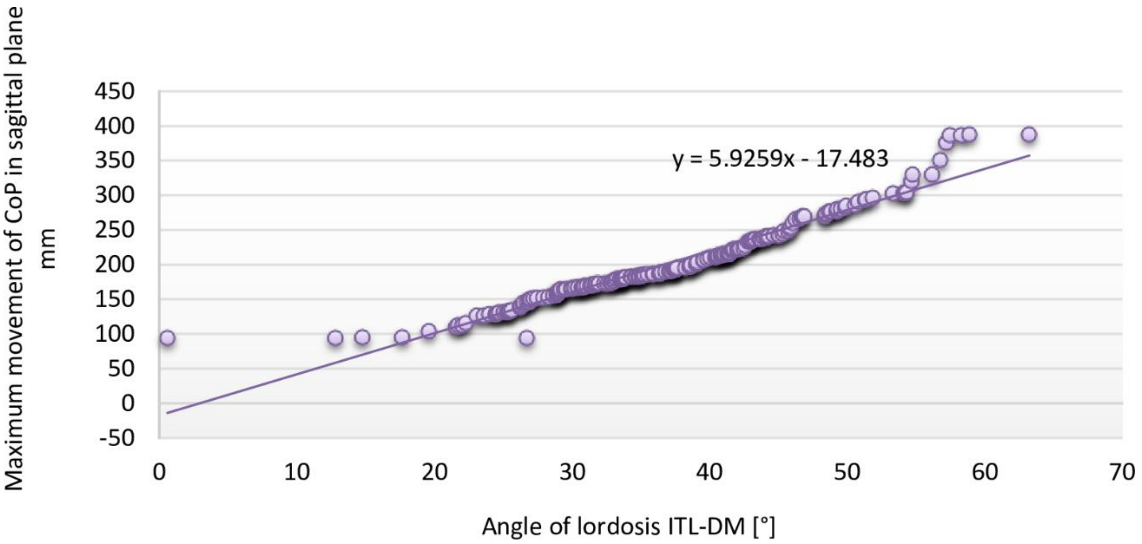
Ryc. 15 Changes in body posture parameters during the treatment of discopathy (Żurawski, Kiebzak 2019)

Effects of therapy on balance reactions in children with postural defects

The ability to maintain balance is a key component of proper postural control and body stabilisation, particularly in children with postural defects. Abnormal spinal alignment, including alterations in thoracic kyphosis and lumbar lordosis angles, may impair balance by affecting postural control mechanisms. Therefore, effective therapy should address not only biomechanical correction but also postural stability and balance reactions.

The study demonstrated that changes in thoracic kyphosis and lumbar lordosis angles have a significant influence on centre of pressure (CoP) displacement under both static and dynamic conditions. Analysis of balance parameters showed that children with greater postural deviations exhibited increased CoP displacement amplitudes, indicating reduced efficiency of compensatory mechanisms. Following therapy aimed at correcting spinal curvatures, a reduction in CoP displacement in both the frontal and sagittal planes was observed, reflecting an improvement in postural stability (Żurawski & Kiebzak, 2020).

The use of the DIERS Formetric 4D system in combination with stabilometric platform-based motion analysis enabled objective evaluation of changes in balance strategies. The results confirm that therapy focused on correcting spinal alignment improves not only static posture but also dynamic balance control mechanisms, which may contribute to a reduced risk of falls and improved motor function in children with postural defects.



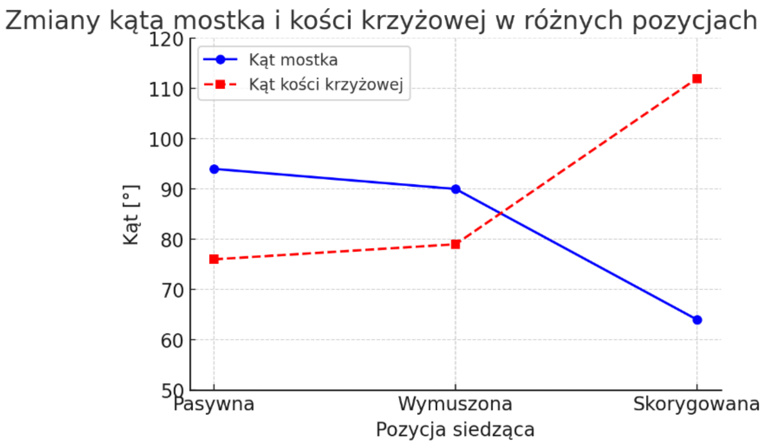
Ryc. 16 Correlation of the magnitude of lumbar lordosis and the deflection of the center of gravity projection in the sagittal plane (Żurawski, Kiebzak 2020)

Influence of the sitting position on the development of spinal curvatures in children

The contemporary lifestyle, characterised by prolonged sitting, has a substantial impact on the development of postural defects in children. Incorrect sitting posture may lead to biomechanical disturbances that adversely affect the formation of physiological spinal curvatures. In particular, the alignment of the sternum in relation to the sacrum plays a key role in postural stabilisation and may determine appropriate movement patterns in the sitting position.

Studies have demonstrated that the angle between the sternum and the sacrum is an important marker of sitting posture correction. Maintaining an optimal angle supports better postural control, reduces static loading of the spine and prevents the development of compensatory changes in the thoracic and lumbar regions. Analysis conducted in a group of children showed that positioning the sternum at an angle of approximately 64° relative to the body axis promotes maintenance of physiological lumbar lordosis and thoracic kyphosis (Kiebzak et al., 2022).

The use of DIERS Formetric 4D technology in combination with digital inclinometry enabled objective determination of the effects of different sitting postures on body alignment. The results confirmed that children who applied conscious postural correction by controlling the position of the sternum and the sacrum achieved better spinal stabilisation parameters and reduced trunk muscle tension.



Ryc. 17 Changes in the angle of the sternum and sacrum in different sitting positions (own material by Kiebzak, Żurawski)

Association between spinal shape and linea alba width in children aged 6–9 years

Postural defects in children are increasingly observed, particularly in the sagittal plane, and may lead to disturbances in muscle tone throughout the body. One factor that may contribute to such disturbances is diastasis of the rectus abdominis muscles, which can result in reduced spinal stabilisation and impaired body statics. Proper abdominal muscle tension plays a key role in maintaining correct organ positioning and in generating adequate support for the lumbar spine, thereby preventing excessive lumbar lordosis and increased anterior pelvic tilt.

A study conducted by Zmyślna, Kiebzak and Żurawski aimed to evaluate the relationship between spinal shape and the width of the linea alba in children aged 6–9 years. The study included 61 children, who were divided into two groups according to linea alba width: a study group (width >10 mm) and a control group (width ≤10 mm). Spinal shape was assessed using the DIERS Formetric 4D system, which enables non-invasive surface analysis of the back and spine.

The results demonstrated a statistically significant difference in trunk inclination between the study and control groups. In the study group, a negative trunk inclination was observed, indicating posterior displacement of the spinal axis beyond the vertical line. Moreover, weak but statistically significant correlations were found between linea alba width and trunk inclination, the position of the apex of lumbar lordosis, and the depth of the lumbar lordosis angle. No significant associations were identified between linea alba width and pelvic or spinal alignment in the frontal and transverse planes.

The authors suggest that there is an association between linea alba width and spinal shape in the sagittal plane, which may have clinical relevance for the prevention and treatment of postural defects in children. They also emphasise the need for further research to better understand the mechanisms underlying these relationships.

Influence of sternum and sacral alignment on sitting posture in children

Correct sitting posture is essential for spinal health, particularly in school-aged children who spend a substantial portion of the day seated. Inappropriate sitting habits may lead to alterations in spinal curvatures, such as excessive thoracic kyphosis or lumbar lordosis. Evidence indicates that the alignment of the sternum and the sacrum plays an important role in shaping these curvatures during sitting.

In a study conducted by Kiebzak and colleagues (2022), 113 children aged 9–13 years participated. The relationship between the inclination angles of the sternal body and the sacrum and changes in thoracic and lumbar spinal curvatures was analysed. Measurements were performed in two sitting positions: passive (relaxed) and corrected (active). A digital inclinometer was used to assess the inclination angles of the sternum and the sacrum, and the DIERS Formetric 4D system was used to analyse spinal curvatures.

The results showed that in the corrected sitting position, characterised by elevation of the sternum to an angle of approximately 64° relative to the body axis, normalisation of spinal curvatures occurred. A reduction in both thoracic kyphosis and lumbar lordosis angles was observed, indicating a more balanced posture. In contrast, in the passive sitting position, the values of these angles were more variable, suggesting suboptimal postural control.

The authors conclude that controlling the inclination angles of the sternum and the sacrum may represent an effective tool in postural education for children, supporting maintenance of correct sitting posture and prevention of spinal deformities.

Ryc. 18 Patient undergoing photogrammetric measurement (Kiebzak et al. 2022)

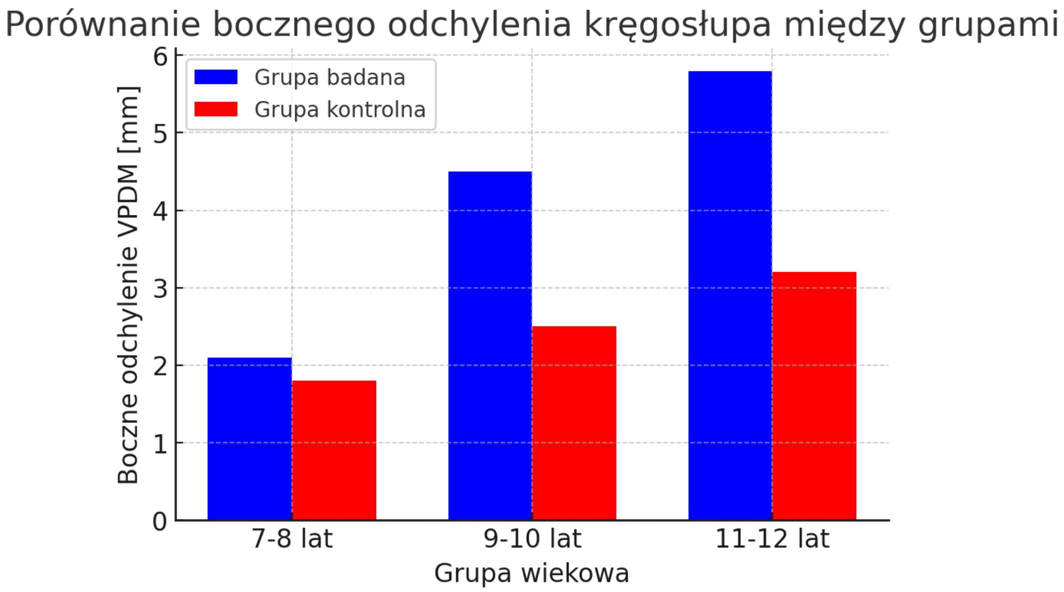
Assessment of body posture in children with chest pain

In recent years, an increasing number of children have been reporting chest pain. Although a cardiac origin is often initially suspected, research indicates that in the majority of cases these symptoms are not related to cardiovascular pathology. Growing evidence suggests that musculoskeletal disorders, including abnormal body posture, may constitute an important cause of such complaints.

A study conducted by Zmyślna, Kiebzak and Żurawski aimed to assess body posture in children with chest pain using the DIERS Formetric 4D system. The study included 184 children aged 7–12 years, of whom 64 formed the symptomatic group with chest pain and 120 constituted a control group without such complaints. The analysis revealed statistically significant differences in postural parameters between the two groups.

In particular, children in the symptomatic group demonstrated greater lateral spinal deviation (lateral deviation of VPDM) compared with the control group. These differences were most pronounced in the 9–10 and 11–12 year age groups. Moreover, in children aged 9–10 years, significant abnormalities in trunk balance and pelvic asymmetry were observed.

The authors suggest that postural abnormalities may represent an important contributing factor to the occurrence of chest pain in children. They emphasise the importance of preventive measures and postural correction in order to reduce the risk of such complaints. Further studies are also recommended to develop effective rehabilitation programmes for children experiencing chest pain.



Ryc. 19 Comparison of lateral deviation of the spine (VPDM) between the study and control groups in different age groups (own material by Kiebzak, Żurawski)

Application of the Vojta method in the treatment of developmental dysplasia of the hip

Developmental dysplasia of the hip (DDH) is a condition characterised by abnormal formation of the acetabulum, which may lead to instability, subluxation or dislocation of the femoral head. Early detection and treatment of DDH are crucial to ensure normal development of the hip joint and to prevent later orthopaedic complications.

The Vojta method, developed by the Czech neurologist Václav Vojta, is a therapeutic approach based on stimulation of specific zones on the patient's body in order to elicit reflex locomotor patterns. It is widely used in the rehabilitation of children with neurological disorders; however, its application in the treatment of DDH is less well known.

A published case report described the use of the Vojta method in an infant with developmental dysplasia of the hip. The patient, a 3-month-old girl, was diagnosed with DDH on the basis of clinical examination and ultrasonography. Therapy using the Vojta method was implemented, consisting of regular stimulation of selected body zones to evoke reflex motor patterns supporting appropriate hip joint development.

After six weeks of therapy, a marked improvement in hip joint stability and normalisation of joint morphology were observed, as confirmed by ultrasound examination. The authors suggest that the Vojta method may be an effective treatment option for DDH, particularly when the condition is detected early, and may serve as an alternative or an adjunct to conventional treatments such as orthopaedic harnesses or surgical procedures.

It should be emphasised, however, that this report describes a single clinical case, and the effectiveness of the Vojta method in the treatment of DDH requires further investigation in larger patient cohorts. Early diagnosis and early intervention remain fundamental for successful management of DDH, and the Vojta method may represent a promising addition to the therapeutic repertoire.

Figure 3 X-ray of dysplastic hip joints (August 2. 2014).

Figure 5 X-ray of hip joints (October 12. 2014).

Ryc. 20 X-ray image showing the effectiveness of the intervention (own material by Kiebzak, Żurawski)

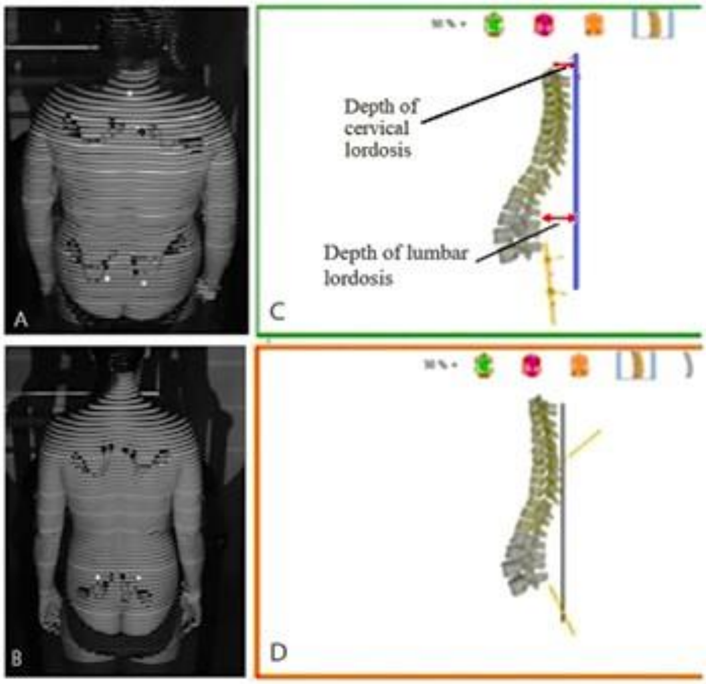
The effect of targeted motor control with emphasis on sternal position on spinal alignment in pregnant women at risk of preterm birth with low back pain

Lumbopelvic pain (LBP) is a common problem among pregnant women, affecting approximately 50–70% of this population. Its aetiology is multifactorial and includes hormonal, biomechanical and postural changes associated with pregnancy. Increased secretion of relaxin leads to ligamentous laxity and greater joint mobility, which may result in pelvic instability and pain in the lumbar region. In addition, an anterior shift of the body's centre of mass, together with increased lumbar lordosis and anterior pelvic tilt, imposes additional mechanical load on spinal structures.

In the study conducted by Żurawski and Kiebzak (2024), the effect of targeted motor control focused on the positioning of the sternum and the sacrum on spinal alignment, pain intensity and muscle activity was evaluated in pregnant women at risk of preterm birth presenting with LBP. The study included 32 women between 28 and 32 weeks of gestation who were hospitalised due to the risk of preterm delivery. The intervention consisted of motor control–oriented exercises aimed at optimising the position of the sternum and the sacrum.

After the intervention, statistically significant improvements were observed in spinal alignment parameters, including reductions in the sternal angle, sacral angle, cervical and lumbar lordosis depth, thoracic kyphosis angle and pelvic inclination. Pain intensity decreased significantly, while activity of the rhomboid muscles increased and was correlated with improvement in thoracic kyphosis. At the same time, activity of the serratus anterior muscle was reduced.

The authors concluded that targeted motor control with emphasis on sternal positioning effectively improves spinal alignment and reduces pain in pregnant women at risk of preterm birth with LBP. This intervention represents a safe, non-invasive and practical approach to the management of pregnancy-related musculoskeletal disorders. Further studies are recommended to confirm these findings in different populations and to investigate long-term outcomes and broader clinical applications.



Ryc. 21 Therapeutic effect in one of the study participants (own material by Kiebzak, Żurawski)

Conclusions

The presented studies clearly indicate that neurophysiological therapy is an effective corrective tool in the treatment of postural disorders, pain syndromes and other musculoskeletal dysfunctions in children, adolescents and adults. The combination of methods such as PNF, the Vojta method, the McKenzie method and targeted motor control leads to significant improvement in spinal biomechanical parameters, postural stability and pain reduction.

The studies confirm that the use of the DIERS Formetric 4D system enables precise, objective and repeatable assessment of postural changes and monitoring of therapeutic outcomes. Three-dimensional diagnostics allows for detailed analysis of kyphosis and lordosis angles, vertebral rotation and pelvic asymmetry, making it a key tool in evaluating the effectiveness of therapy.

Moreover, investigations of balance reactions demonstrated a strong relationship between improvements in postural parameters and the efficiency of the body's compensatory mechanisms. Therapy aimed at correcting spinal alignment contributes to a reduction in centre of pressure (CoP) displacement, which enhances postural stability and reduces the risk of balance impairments.

An important component of therapy is control of the position of the sternum in relation to the sacrum, which plays a crucial role in the correction of both sitting posture and dynamic posture. This control influences the formation of physiological spinal curvatures, which has been confirmed in both children and pregnant women with spinal pain.

In addition, beneficial effects of the Vojta method were observed in the treatment of developmental dysplasia of the hip (DDH), suggesting that this approach may serve as an alternative or an adjunct to conventional orthopaedic treatment.

In conclusion, an interdisciplinary and holistic therapeutic approach focused on postural correction, improvement of motor control and enhancement of postural stability enables effective management of musculoskeletal disorders in different patient populations. Future research should focus on the long-term effects of such interventions and on their application in diverse clinical groups.

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Practical Part

DIERS

Introduction

Rasterstereography is a modern, non-invasive method for three-dimensional analysis of body posture and spinal shape, based on the principle of optical projection. In the DIERS system, a dedicated projector emits a pattern of light stripes onto the patient's back. A camera records the deformation of these lines on the skin surface, and specialised software subsequently converts the data into a three-dimensional image. This enables a detailed reconstruction of the dorsal surface topography and an indirect assessment of spinal alignment in the sagittal, frontal and transverse planes, without the use of X-ray radiation.

Postural assessment is of key importance both in the diagnosis of postural defects in children and adolescents and in monitoring rehabilitation processes in patients with spinal disorders. Analysis of trunk and pelvic geometry enables early detection of asymmetries, axial deviations and abnormalities of physiological spinal curvatures. In clinical practice, rasterstereography is used in the diagnosis of scoliosis, hyperkyphosis and hyperlordosis, as well as in the evaluation of conservative and surgical treatment outcomes.

The main advantage of this method is its radiation-free nature, which allows repeated and serial examinations without exposing the patient to ionising radiation. In addition, the measurement is fast (a few seconds), non-invasive and objective, and the results can be immediately analysed and archived in electronic form. The DIERS system also enables dynamic (4D) examinations, which increases its diagnostic value in functional assessment.

The limitations of the method include the fact that rasterstereography evaluates only the surface of the back and, on this basis, performs a mathematical reconstruction of the spinal position. Measurement accuracy may be affected by external factors such as body hair, tattoos, scars or an unstable standing posture. Moreover, the method does not replace imaging techniques such as X-ray or MRI, especially in the diagnosis of structural changes within the spinal canal.

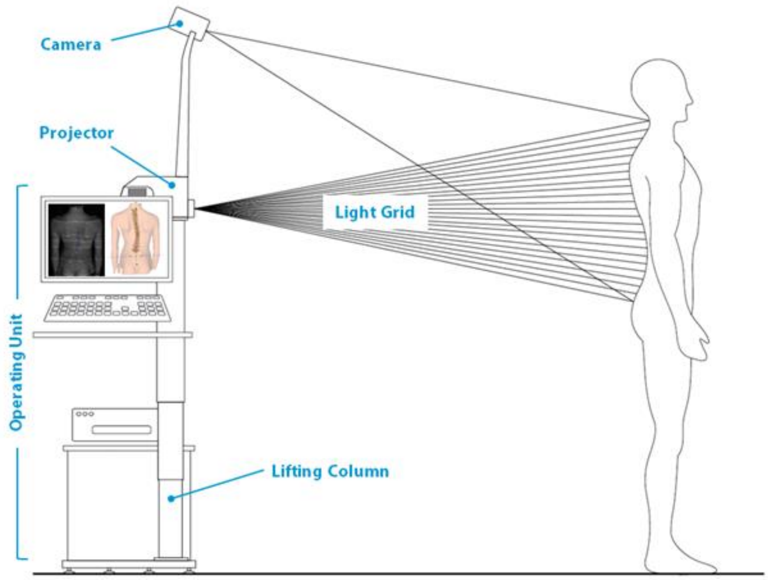
Hardware and software

The DIERS Formetric 4D system and its extended version, 4D Motion, are integrated devices designed for radiation-free assessment of body posture and the spine. Their operation is based on rasterstereography – projection of light stripes onto the patient's back surface and registration of their deformation by a camera.

The system consists of:

- **High-resolution camera** – used to record the image of deformed light lines on the surface of the back. The camera is capable of acquiring image sequences, enabling both static and dynamic analyses (movement, functional tests).

- **Light-stripe projector** – generates a high-contrast grid of lines projected onto the patient's skin. Deformations of this pattern constitute the basis for algorithmic three-dimensional reconstruction of the back surface.
- **Tripod and mounting system** – ensure stable positioning of the equipment relative to the patient and minimise the risk of measurement errors.
- **Computer with DIERS DICAM 3 software** – the central component of the system, responsible for 3D/4D reconstruction, geometric analysis and report generation. The software also allows comparison of consecutive examinations, monitoring of changes over time, and export of results to databases and medical documentation systems.



The DICAM 3 software includes modules that enable:

- analysis of static and dynamic posture,
- reconstruction of the spinal axis and calculation of angular parameters (e.g. thoracic kyphosis, lumbar lordosis, pelvic angle),
- assessment of symmetry of the shoulders, scapulae and pelvis,
- generation of clinical and scientific reports.

Integration with other DIERS modules increases the functionality of the system:

- **Pedoscan** – enables analysis of plantar pressure distribution in a static position, allowing the relationship between postural geometry and foot support to be assessed.

- **Pedogait** – a system for dynamic assessment of plantar pressure distribution during gait, combining postural analysis with locomotor biomechanics.
- **myoMotion** – a system of inertial measurement units (IMUs) that allows recording of three-dimensional movements of individual body segments and integration with postural data from Formetric 4D. This enables comprehensive biomechanical analysis of the spine, limbs and movement patterns.

Such a system configuration enables a holistic assessment of posture and musculoskeletal function. Thanks to the integration of DIERS modules, postural diagnostics can be combined with gait analysis, plantar load assessment and movement analysis.

Patient preparation

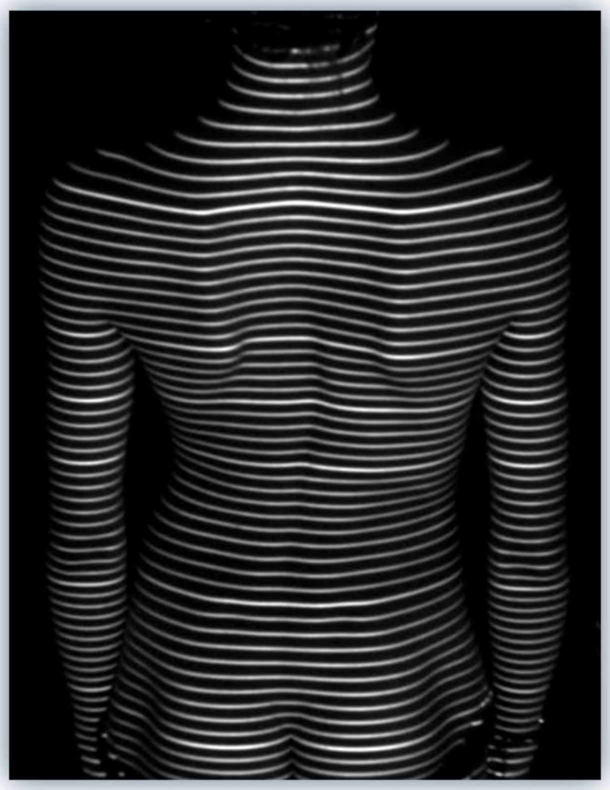
Proper patient preparation for rasterstereographic examination using the DIERS Formetric 4D / 4D Motion system is essential to obtain reliable and reproducible results.

Environmental conditions

- The examination room should be appropriately illuminated; additional light sources directed at the patient's back should be avoided in order to prevent interference with the projected light stripes.
- The room temperature should be comfortable (approximately 21–23°C) to allow the patient to stand freely without cold-induced muscle tension.
- The distance between the patient and the device is standardised and is usually 2 metres, in accordance with the system settings.

Exposure of the back

- The patient's back must be fully exposed; the examination is performed without clothing covering the trunk.
- Long hair should be tied up or lifted so that it does not cover the neck or the upper back, as this may interfere with the recording of the projected light pattern.
- The skin should be clean and dry, without sweat, lotions or creams, as these may cause light reflections and artefacts.



Standard patient position

- The feet are placed on the floor markers built into the system platform, which ensures standardisation of the position and enables comparison of results between successive examinations.
- The arms should hang freely along the trunk.
- The patient should stand in a natural upright posture, without any forced postural correction.
- Breathing should be calm and regular – the patient should not hold their breath or tense the muscles during the measurement.

Instructions for the patient

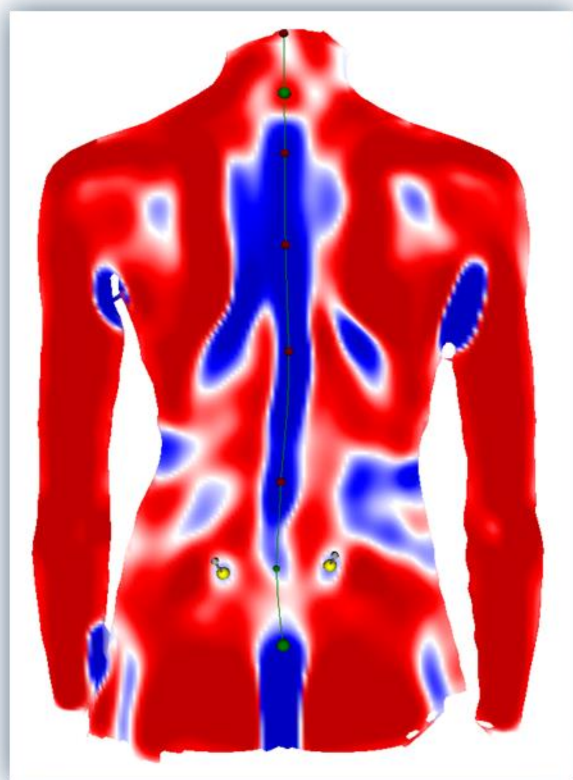
- The patient should be informed that the examination lasts only a few seconds and that they must remain still during this time.

- The patient should not consciously correct their posture or "straighten the back", because the purpose of the examination is to assess the natural alignment of the spine and pelvis.
- In the case of dynamic measurements (4D Motion), the patient receives instructions concerning calm walking, performing functional tests, or executing movements prescribed by the examiner.

Such preparation minimises measurement artefacts and ensures high repeatability of results, which is crucial when monitoring postural changes during rehabilitation and therapy.

Markers and anatomical landmarks

The use of anatomical markers in the DIERS Formetric 4D / 4D Motion system is a key element in ensuring high accuracy and reliability of the three-dimensional reconstruction of the spine and the entire body posture.
Correct placement of the markers enables precise identification of pelvic orientation, the angle of spinal curvature, and the spatial relationships between individual body segments.



Standard reference landmarks

- **C7 (spinous process of the C7 cervical vertebra)** – the superior landmark defining the starting point for reconstruction of the spinal axis. It is relatively easy to locate by palpation and allows stable identification of the cervicothoracic contour.
- **S1 (spinous process of the first sacral vertebra)** – the inferior reference landmark, essential for the assessment of pelvic alignment and the global sagittal curvature of the spine.
- **PSIS (posterior superior iliac spines – right and left)** – used to determine pelvic rotation and pelvic tilt, as well as to assess pelvic asymmetry.
- **Inferior angles of the scapulae** – used as control points for evaluating trunk rotation, shoulder girdle symmetry and postural balance.

Marker placement for specialised measurements

- In dynamic measurements (4D Motion) or functional tests (e.g. trunk flexion, gait), additional markers may be placed on selected body segments to enable precise motion tracking.
- These may include the iliac crest, acromial processes, and landmarks on the lower limbs, allowing global kinematic analysis.
- During gait assessment (Pedogait module), lower-limb markers enable correlation between spinal and pelvic alignment and ground reaction force distribution.

Importance of correct marker placement

- Precise and reproducible placement of markers is a prerequisite for reliable results. Incorrect localisation may lead to distortion of the 3D reconstruction and, consequently, erroneous interpretation of postural parameters.
- Standardisation of marker application (use of the same anatomical landmarks and palpation techniques) is particularly important in follow-up examinations, where postural changes over time are compared.

- Markers also serve as orientation points for the DICAM 3 software, enabling accurate fitting of the reconstruction grid to the individual anatomy of the patient.

Thanks to the use of anatomical markers, the DIERS system provides objective, reproducible and high-quality assessment of posture in both static and dynamic conditions.

Examination methodology

A properly conducted examination protocol using the DIERS Formetric 4D / 4D Motion system is essential to obtain reliable and reproducible results. It includes both static and dynamic measurements, standardisation of the number of acquisitions, and a defined data analysis procedure.

Static measurement procedure

- The examination is performed in a standing position, with the patient placing the feet on dedicated floor markers to ensure repeatability of positioning.
- The patient’s back must be fully exposed, with no elements interfering with the projection of the light stripes.
- It is recommended to perform several acquisitions (at least 2–3) in order to minimise the influence of transient disturbances (e.g. respiratory movements, postural micromovements).
- In the DICAM software, the recording that best reflects the patient’s natural posture is selected; if required, mean values can also be analysed.

Dynamic measurement procedure

- In the 4D Motion mode, postural changes over time are recorded, for example during forward bending, trunk extension or functional tests (such as arm elevation or squatting).
- In addition, the system enables gait assessment using the DIERS Pedogait module, which allows simultaneous analysis of gait parameters and changes in spinal and pelvic alignment.
- Dynamic measurements enable assessment of motor control, postural compensations and segmental coordination under movement conditions.

Examination time and number of acquisitions per series

- A standard static measurement takes only a few seconds and consists of a single 3D acquisition.
- Dynamic examinations usually last between 10 and 30 seconds, depending on the protocol and the type of task.
- In follow-up examinations, it is recommended to perform a series of recordings (e.g. three repetitions of the same task) in order to improve the reliability of longitudinal comparisons.

Acquisition of 2D/3D images and processing in the DICAM system

- The DIERS system records the back surface as a grid of projected light stripes, which are then processed by the DICAM 3 software into a three-dimensional spatial model.
- The analysis includes both linear parameters (e.g. distances, angles, rotations) and surface-based parameters (shape of curvatures, symmetry of the shoulders and pelvis).
- DICAM also enables generation of comparative reports that present changes over time, which is of key importance for monitoring therapeutic outcomes.
- The 2D image serves a documentation purpose, whereas the 3D reconstruction constitutes the basis for diagnostic analysis.

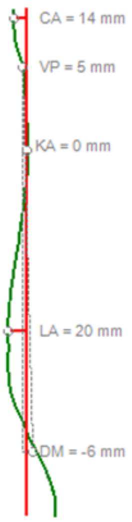
Analysis parameters

The DIERS Formetric 4D / 4D Motion system enables acquisition of a wide range of parameters describing spinal geometry and postural function in a three-dimensional, multi-planar approach. The analysis includes sagittal, frontal and rotational planes, as well as parameters related to the back surface and ground reaction forces.

Sagittal curvatures (sagittal plane)

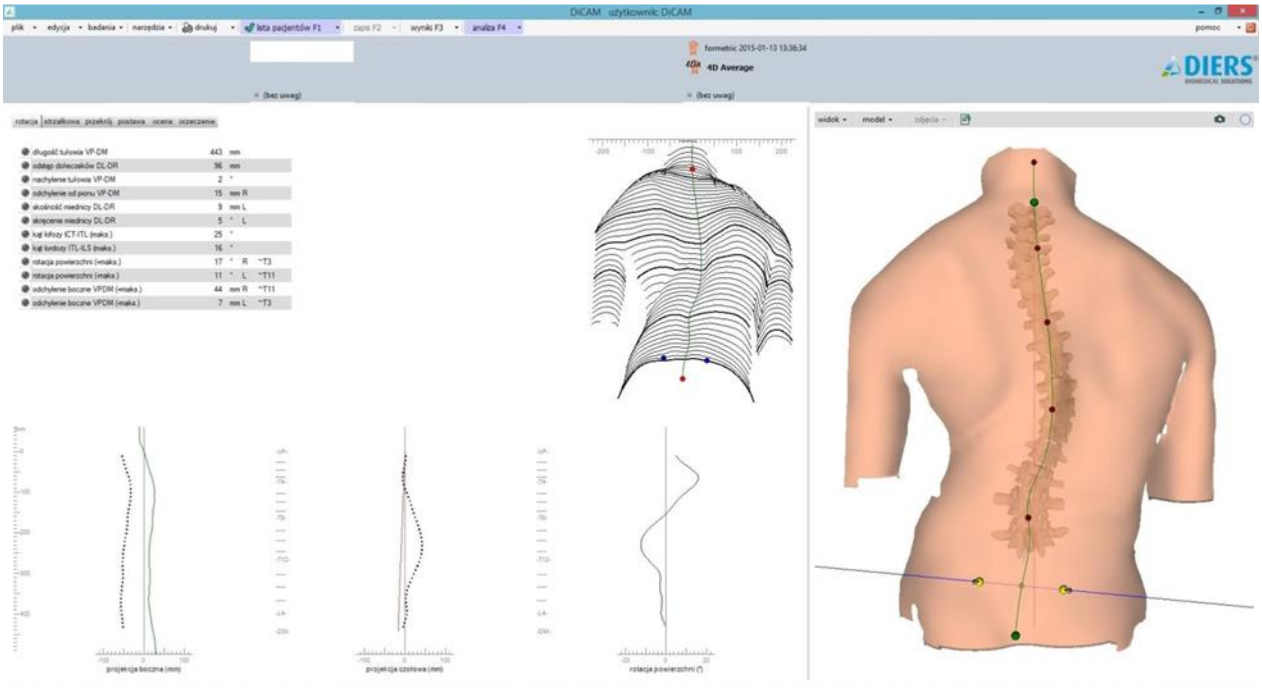
- **Thoracic kyphosis** – assessment of the angle and length of the thoracic curvature, most commonly between Th1 and Th12.
- **Lumbar lordosis** – measurement of the angle and length of the lumbar curvature, typically between L1 and S1.

- **Pelvic alignment (pelvic tilt / inclination)** – assessment of the pelvic tilt angle in the sagittal plane, which is essential for postural balance.



Parameters in the frontal plane

- **Shoulder asymmetry** – differences in the height and alignment of the shoulder girdle.
- **Pelvic asymmetry (pelvic obliquity)** – differences in the height and inclination of the iliac crests.
- **Scapular asymmetry** – the position of the inferior and medial borders of the scapulae in relation to the body midline.



Axial rotations and torsion

- **Axial rotation of the spine** – measurement of rotational deviations of individual spinal segments.
- **Torsion (twisting)** – assessment of global spinal torsion, particularly important in the evaluation of both functional and structural scoliosis.

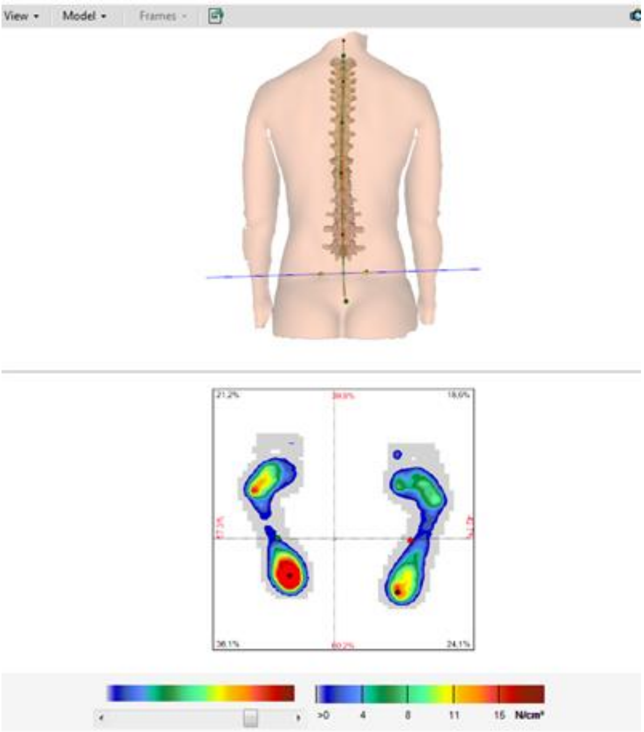
Back surface parameters

- **Scoliotic Index (Surface Rotation / Scoliotic Index)** – an indicator of back surface asymmetry, used as an indirect marker of spinal curvature.
- **Contour symmetry** – assessment of differences between the right and left sides of the trunk (e.g. muscular prominence, thoracic deformities).

Integration with Pedoscan / Pedogait

- **Centre of pressure (COP) path** – analysis of the trajectory of the centre of pressure displacement during standing or walking.
- **Ground reaction force distribution** – assessment of asymmetrical loading of the lower limbs, which is relevant for postural compensation mechanisms.

- **Combined posture and gait analysis** – integration of data from the spine, pelvis and feet allows a more comprehensive evaluation of stabilisation strategies and balance control.



Standardisation and measurement reliability

Repeatability (reliability)

Studies using the **DIERS Formetric 4D** system have demonstrated high repeatability of measurements both **within a single session (intra-session)** and **between different sessions (inter-session)**.
The highest stability of results concerns **sagittal spinal parameters** (thoracic kyphosis and lumbar lordosis) as well as **pelvic alignment**.
Lower repeatability is typically reported for **scapular asymmetry** and **axial rotations**, which is related to greater anatomical variability and the influence of respiration and muscle tone.

Disturbing factors

Measurement quality and reliability may be affected by several technical and environmental factors:

- **Patient movement** – even slight trunk displacement or changes in foot position may disturb the 3D reconstruction.
- **Body hair** – may interfere with reflection of the projected light stripes and generate image artefacts.
- **Tattoos and skin lesions** – may locally disturb stripe projection, leading to reconstruction errors.
- **External lighting** – excessive ambient light (e.g. sunlight) reduces stripe contrast and hampers image processing.
- **Clothing** – any garments covering the back (e.g. underwear, medical dressings) are not acceptable during the examination.

Manufacturer recommendations and literature standards

According to the DIERS manufacturer and validation studies reported in the literature, in order to ensure high measurement reliability the following should be observed:

- examinations should be performed under **controlled and constant lighting conditions**,
- **full exposure of the patient's back** must be ensured,
- measurements should be **repeated at least three times** to allow averaging and to minimise the effect of single disturbances,
- a **standardised patient position** should be maintained (feet on markers, arms along the trunk, natural upright posture),
- **anatomical markers** should be applied according to DIERS instructions and literature guidelines (C7, S1, PSIS, inferior scapular angles).

Implementation of these procedures enables a level of reliability comparable with conventional imaging methods (e.g. radiography), while preserving the major advantage of rasterstereography – its **radiation-free and repeatable** nature.

Clinical applications

Diagnosis of postural disorders

The DIERS Formetric 4D system is widely used in the diagnosis of postural abnormalities such as **thoracic hyperkyphosis, lumbar hyperlordosis and idiopathic scoliosis**.
Three-plane analysis allows rapid determination of the degree of deviation from normal values, shoulder and pelvic asymmetry, and rotational parameters, enabling accurate differentiation between postural disorders.

Assessment of conservative treatment outcomes

Rasterstereography is an effective tool for monitoring the effectiveness of conservative interventions, including **corrective exercise programmes, manual physiotherapy and core stabilisation programmes**.
Repeated measurements allow objective evaluation of progress and modification of the treatment plan based on quantitative data.

Monitoring brace treatment and postoperative management

The DIERS system allows follow-up of postural changes in patients undergoing **brace treatment for scoliosis** and after **spinal surgery**.
The 4D analysis enables safe documentation of therapeutic effects without exposing patients to ionising radiation, which is particularly important in children and adolescents requiring frequent follow-up examinations.

Screening in children and adolescents

Because of its speed, non-invasiveness and lack of radiation exposure, rasterstereography is recommended as a **screening tool in school-age children and adolescents**.
It enables early detection of postural abnormalities that may require further diagnostic procedures or therapeutic intervention. Regular screening using the DIERS system increases the likelihood of early intervention and limits the progression of more severe spinal deformities.

Development perspectives

Development of 4D techniques and dynamic motion analysis

Further development of the DIERS system focuses on improving **4D rasterstereography**, allowing not only static but also **real-time dynamic assessment** of posture and spinal motion. Analysis of kinematics during gait, functional tests and therapeutic exercises opens new possibilities for diagnostics and rehabilitation monitoring.

Integration of DIERS with ultrasound, sEMG and motion-capture systems

Integration of rasterstereography with other imaging and functional assessment methods, such as **ultrasound of deep muscles, surface electromyography (sEMG)** and **motion-capture systems**, enables comprehensive evaluation of patient biomechanics.
Combining information on structure, muscle function and movement patterns allows more precise treatment planning and monitoring of therapeutic outcomes.

Use of artificial intelligence (AI) for deformity prediction and personalised therapy

The application of **machine learning and artificial intelligence algorithms** to DIERS data analysis opens new perspectives for predicting spinal deformity progression (e.g. idiopathic scoliosis) and for personalising rehabilitation programmes.
Integration of large datasets with clinical practice may enable the development of predictive models and individualised therapeutic strategies tailored to each patient.

Summary

The **DIERS Formetric system** is a modern and comprehensive tool for the assessment of body posture and spinal curvatures, enabling non-invasive, rapid and objective measurements in both static and dynamic conditions.

Its high repeatability and clinically validated usefulness make it suitable for a wide range of applications, including diagnosis of postural disorders, monitoring the effects of conservative therapy, brace treatment and postoperative follow-up, as well as screening programmes in children and adolescents.

The main limitations of the method are related to the need for strict standardisation of examination conditions (lighting, patient positioning and back exposure) and to operator experience, which determines correct marker placement and appropriate interpretation of results.

Ultrasound (US)

Introduction

Ultrasonography (US) is a non-invasive and versatile imaging method widely used in the diagnosis of the musculoskeletal system. By using ultrasound waves, it allows real-time visualisation of soft tissues, enabling assessment of both their morphology and function. In clinical practice and research, ultrasonography has become a first-line tool for evaluating muscles, tendons, ligaments and nerves, as well as for monitoring the effects of therapy and rehabilitation.

The main advantages of ultrasound are its non-invasive character and the absence of ionising radiation, which makes repeated examinations safe for the patient. A key feature of ultrasonography is real-time imaging, allowing dynamic assessment of muscle function during movement or isometric contraction. In addition, ultrasound enables direct comparison of both sides of the body, which is particularly useful in the assessment of asymmetry and compensatory strategies.

Despite its many advantages, the method also has limitations. The most important is operator dependency – image quality and correctness of interpretation largely depend on the examiner's experience and skills. Additional difficulties are caused by ultrasound artefacts, such as anisotropy or acoustic shadowing, which may lead to misinterpretation. Another limitation is reduced penetration of deeper structures, which makes assessment of deep muscles, such as the multifidus or longus colli, more difficult and less precise.

In summary, ultrasonography is a valuable diagnostic tool in musculoskeletal assessment, combining safety, accessibility and dynamic imaging. However, its reliable clinical use requires standardised procedures, experienced operators and awareness of its potential limitations.

Basic principles of musculoskeletal ultrasound examination

The effectiveness and reliability of musculoskeletal ultrasound largely depend on adherence to technical principles and proper organisation of the examination. Appropriate probe selection, correct positioning of the patient and equipment, and awareness of potential sources of error are crucial for obtaining high-quality images and reliable measurements.

Probe selection

For assessment of muscles and superficial spinal stabilisers, high-frequency linear probes (7–12 MHz) are most commonly used. They provide high spatial resolution, necessary for precise evaluation of muscle thickness and structure. For deeper muscles (e.g. lumbar multifidus), lower-frequency probes (5–7.5 MHz) may be used to achieve greater penetration at the cost of image detail.

Proper positioning of the patient and the ultrasound system

Correct patient positioning is essential for standardisation. The subject should be in a comfortable, symmetrical position with maximal muscle relaxation, which reduces the risk of artefacts and interpretation errors. The position depends on the muscle examined – for example, for transversus abdominis assessment the patient lies supine with slightly flexed hips, whereas for multifidus assessment the patient lies prone. The ultrasound unit should be positioned to allow ergonomic probe handling and continuous real-time image observation.

Technical standards

Muscle ultrasound should be performed in two basic planes:

- **longitudinal plane** – to assess fibre orientation and adjacent structures,
- **transverse plane** – to measure muscle thickness and delineate muscle borders.

The probe orientation should be stable and the pressure gentle, in order to avoid tissue compression and artificial reduction of muscle thickness.

Factors affecting measurement reliability

Image quality and repeatability of measurements are influenced by:

- system settings (frequency, depth, focal zone),
- probe pressure – excessive compression reduces muscle thickness, especially at rest,

- environmental conditions – room temperature and time of day may influence muscle tone and tissue hydration,
- procedural repeatability – standardised probe placement, preferably with skin landmarks marked.

Artefacts and their reduction

Common artefacts in musculoskeletal ultrasound include:

- **anisotropy** – occurs when the ultrasound beam is not perpendicular to muscle fibres; reduced by changing the probe angle,
- **reverberation** – multiple reflections generating artificial echoes; reduced by optimising settings and maintaining stable probe contact,
- **acoustic shadowing** – behind highly reflective or absorptive structures (e.g. bone); expected and interpreted by comparison with adjacent sections.

Methods of muscle assessment using ultrasound

Real-time imaging makes ultrasonography one of the most important tools for analysing the structure and function of spinal stabilising muscles. Both quantitative and qualitative assessments are possible.

Muscle thickness measurement – rest vs. isometric contraction

Muscle thickness is measured in two conditions:

- **at rest** – baseline muscle size and side-to-side comparison,
- **during isometric contraction** – assessment of the muscle's ability to increase its thickness during activation.

The comparison of both conditions reflects activation capacity. The transversus abdominis (TrA), for example, shows a consistent and reproducible increase in thickness during correct activation and is therefore particularly suitable for monitoring.

Shape and echogenicity – tissue quality

Ultrasound enables evaluation of:

- **muscle shape** – detection of asymmetry, atrophy or anatomical abnormalities,
- **echogenicity** – healthy muscle is moderately hypoechoic and homogeneous; increased echogenicity indicates fatty or fibrotic infiltration and may reflect degeneration or weakness.

This is especially relevant for the multifidus muscles, which often show degenerative changes in chronic low back pain.

Functional activation – thickness change as a recruitment marker

The difference in muscle thickness between rest and isometric contraction is commonly used as an indicator of muscle activation. Ultrasound measures correlate well with surface EMG for selected deep muscles.

- **Transversus abdominis** – clear thickness increase, high repeatability.
- **Multifidus** – moderate reliability due to depth and overlapping structures.
- **Serratus anterior and longus muscles** – less clear response, requiring precise instructions and activation tasks.

Advanced techniques

Technological advances enable more detailed assessment:

- **M-mode** – records dynamic changes in muscle thickness over time, allowing evaluation of onset and timing of recruitment.
- **Elastography** – assesses muscle stiffness, providing information about muscle tone and biomechanical properties.
- **Harmonic imaging** – improves contrast and reduces noise, especially for deeper structures.

Standardisation and measurement reliability

Intra- and inter-rater reliability

- **Intra-rater reliability** refers to repeatability of measurements obtained by the same examiner at different time points.
- **Inter-rater reliability** refers to agreement between different examiners.

High repeatability is essential, because differences of only a few millimetres may influence interpretation of muscle activation and rehabilitation effects.

Statistical indicators: ICC, SEM, MDC

- **ICC (Intraclass Correlation Coefficient)** – values close to 1.0 indicate high agreement; >0.75 is considered good and >0.90 very good.
- **SEM (Standard Error of Measurement)** – reflects precision of a single measurement; lower values indicate higher accuracy.
- **MDC (Minimal Detectable Change)** – the smallest change that represents a real change beyond measurement error; crucial in monitoring therapy outcomes.

Evidence from own studies and the literature

Data from studies conducted at the Collegium Medicum of Jan Kochanowski University and from the literature indicate that reliability differs between muscles:

- **Transversus abdominis (TrA)** – highest reliability; ICC often >0.90, SEM <1 mm, MDC <3 mm.
- **Serratus anterior (SA)** – high reliability (ICC 0.80–0.95).
- **Multifidus (MF)** – moderate reliability; ICC 0.60–0.85, SEM >2 mm, MDC >6 mm.
- **Longus colli / longus capitis (LC)** – moderate reliability (ICC 0.52–0.89).

Similar conclusions are reported by Whittaker et al. (2013) and Teyhen et al. (2005), indicating particularly high reliability for TrA and serratus anterior compared with deeper muscles.

Standardisation of patient positioning, system settings and probe placement is essential for repeatable ultrasound measurements. The highest reliability is observed for transversus abdominis and serratus anterior, whereas assessment of multifidus and deep cervical flexors shows greater variability. ICC, SEM and MDC allow objective evaluation of measurement quality and differentiation between true change and measurement error.

Characteristics of selected spinal stabilising muscles

Ultrasound enables non-invasive and repeatable assessment of both deep and tonic superficial muscles responsible for postural control.

Longus capitis / longus colli

Anatomical and functional role

The longus capitis and longus colli muscles are deep cervical flexors responsible for stabilisation of the cervical spine and control of flexion movements. Dysfunction of these muscles is associated with neck pain and postural disorders.

Patient position

Supine position, head in neutral alignment, arms along the trunk.

Probe placement

A linear probe (7.5–10 MHz) is placed transversely above the clavicle, medial to the sternocleidomastoid muscle. The probe may be slightly tilted towards the spine to improve visualisation.

Imaging parameters

Depth is set to visualise the anterior surfaces of the cervical vertebral bodies. Probe pressure should be minimal to avoid muscle compression.

Image interpretation

The muscle appears as a hypoechoic structure located directly on the vertebral bodies. Diagnostic difficulties may arise due to the proximity of the trachea and oesophagus, which generate acoustic artefacts.

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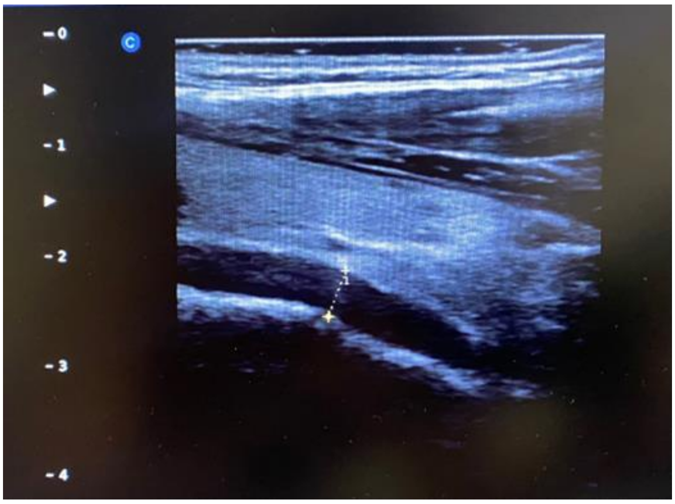

Serratus anterior muscle

- **Anatomical and functional role**
  The serratus anterior is responsible for scapular protraction and upward rotation. Proper function of this muscle is essential for scapular stability. Weakness may lead to scapular dyskinesis and impaired upper-limb function.
- **Patient position**
  The patient lies supine with the upper limb abducted to approximately 60°, which tensions the muscle and facilitates visualisation.
- **Probe placement**
  The probe is placed along the mid-axillary line at the level of the manubrium, perpendicular to the course of the ribs.
- **Imaging parameters**
  Linear probe 7.5–10 MHz; depth 4–5 cm. The image should include the rib surfaces where the muscle attaches.
- **Image interpretation**
  The serratus anterior is visualised as a hypoechoic layer lying directly over the ribs. Muscle thickness and symmetrical activation can be assessed during scapulothoracic movements.

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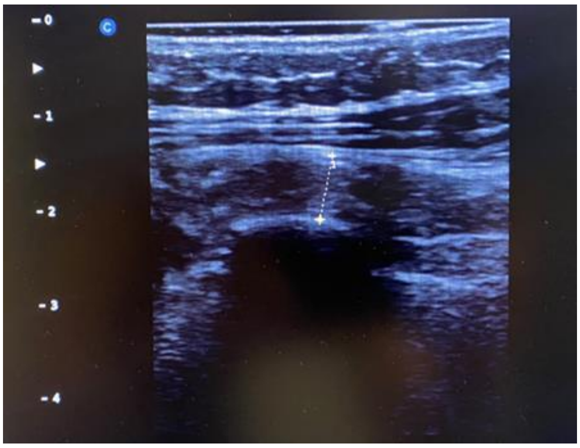


Transversus abdominis muscle (TrA)

- **Anatomical and functional role**

  The transversus abdominis acts as a stabilising "corset" of the trunk by regulating intra-abdominal pressure and increasing stiffness of the lumbar spine. It is regarded as a key muscle in core stability training and in the management of low back pain.

- **Patient position**

  The patient lies supine, with the hips flexed to approximately 60° and the feet supported on the surface.

- **Probe placement**

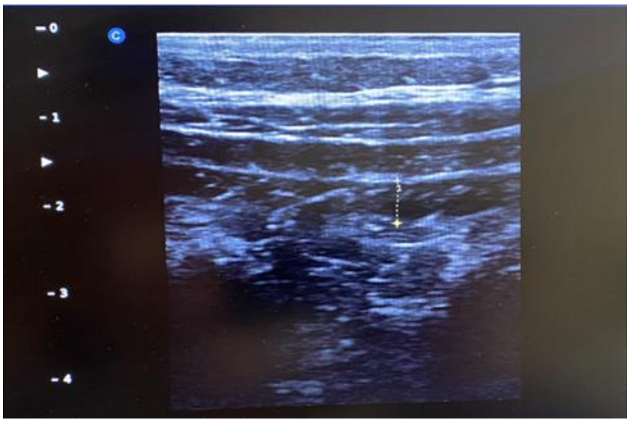
  A linear transducer (7.5–12 MHz) is positioned midway between the anterior superior iliac spine and the lower costal margin, along the mid-axillary line.

- **Imaging parameters**

  Imaging depth is set to approximately 5 cm. From superficial to deep, the following layers should be visible: external oblique, internal oblique, and the transversus abdominis as the deepest layer.

- **Image interpretation**

  At rest, the transversus abdominis appears as a thin hypoechoic layer. During isometric activation, its thickness increases clearly, which is considered a reliable marker of correct muscle recruitment. In research, TrA demonstrates the highest measurement reliability (ICC > 0.90, with low SEM and MDC).

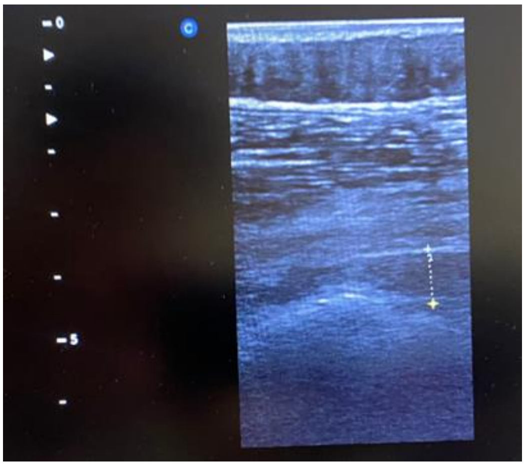


Multifidus muscle

Lumbar multifidus muscle (MF)

- **Anatomical and functional role**
  The multifidus stabilises individual segments of the lumbar spine and controls intersegmental (intervertebral) movements. Weakness and atrophy of this muscle are commonly reported in patients with chronic low back pain.
- **Patient position**
  The patient lies prone on the examination table, with the spine in a neutral position.
- **Probe placement**
  A linear transducer (7.5–10 MHz) is placed longitudinally along the axis of the spine at the L4–L5 level, lateral to the spinous processes. The probe should be slightly angled medially to visualise the muscle adjacent to the facet (zygapophyseal) joint.

- **Imaging parameters**
  Increased imaging depth (approximately 6–7 cm) is required to visualise the deeper structures.
- **Image interpretation**
  The muscle appears as a hypoechoic layer located beneath the transverse processes. Its assessment is challenging due to its deep location and substantial anatomical variability. In research, multifidus measurements show moderate reliability (ICC 0.60–0.85), which limits its usefulness for monitoring subtle changes over time.



Clinical applications

Functional ultrasonography is increasingly used in clinical practice by physiotherapists and rehabilitation physicians, both for diagnostic purposes and for monitoring the rehabilitation process. Real-time imaging enables assessment of both the structure and functional activation of muscles responsible for spinal stabilisation.

Diagnosis of postural dysfunctions

Ultrasound enables evaluation of deep muscles that play a key role in the stabilisation of the cervical and lumbar spine. Dysfunction of the deep cervical flexors (longus colli and longus capitis) is associated with neck pain and impaired postural control, whereas atrophy and asymmetry of the multifidus muscle are commonly linked to chronic low back pain. Ultrasonography allows objective documentation of these alterations and complements clinical examination.

Monitoring the effects of therapy and stabilisation training

Repeated measurements of muscle thickness and activation allow quantitative assessment of rehabilitation outcomes. Changes in the ability to activate the transversus abdominis and improvements in the symmetry of serratus anterior activity can be monitored objectively. The use of SEM and MDC indices makes it possible to distinguish true clinical change from measurement error.

Biofeedback in re-education of deep muscles

Ultrasound provides real-time visualisation of muscle activity and can therefore be used as biofeedback during training of selective activation of deep muscles (e.g. transversus abdominis, multifidus, deep cervical flexors). This form of feedback supports neuromuscular re-education and represents an important component of core stabilisation programmes.

Assessment of asymmetry and compensatory patterns

Ultrasound enables direct comparison between the right and left sides of the body. Differences in muscle thickness and activation patterns may indicate persistent compensatory strategies, particularly in patients after episodes of spinal pain and in athletes. These findings may have prognostic value with regard to the risk of symptom recurrence.

Limitations and future perspectives

Operator dependence

One of the main limitations of ultrasonography is its strong dependence on the examiner's experience. Correct probe positioning, accurate identification of anatomical structures and proper image interpretation require systematic training and the use of standardised examination protocols.

Difficulties in the assessment of deep muscles

Assessment of deeply located muscles is associated with important technical limitations:

- in the case of the deep cervical flexors, visualisation is hampered by the trachea and oesophagus, which generate artefacts,
- the multifidus muscle shows greater measurement variability and lower reliability than more superficial muscles.

Results obtained for these muscles should therefore be interpreted with particular caution and, when necessary, supplemented with other functional assessment methods.

Development of imaging techniques

Advances in ultrasonography create new possibilities for functional muscle assessment:

- elastography enables evaluation of mechanical properties and muscle stiffness,
- 3D/4D imaging allows spatial assessment of muscle volume and dynamic behaviour,
- contrast-enhanced techniques open new perspectives for analysing muscle perfusion and metabolism in clinical and sports-medicine research.

Summary

Ultrasonography is a useful and objective tool for the assessment of muscles responsible for spinal stabilisation. It enables evaluation of both muscle structure and functional activation under clinical conditions.

The highest measurement reliability is observed for the transversus abdominis and the serratus anterior, which makes these muscles particularly suitable for monitoring therapeutic interventions and stabilisation training. In contrast, assessment of the deep cervical flexors and the multifidus is more demanding due to their deep location and the presence of neighbouring structures that generate artefacts.

When performed by a properly trained operator, ultrasonography serves not only as a diagnostic method but also as a therapeutic tool, providing biofeedback and supporting neuromuscular re-education, especially in patients with low back pain and neck pain syndromes.

sEMG

Introduction

Definition and clinical relevance of sEMG

Surface electromyography (sEMG) is a non-invasive method for recording the bioelectrical activity of muscles using electrodes placed on the skin surface. It enables the assessment of both the activity of individual muscles and the coordination of muscle groups during movement or postural tasks. In musculoskeletal diagnostics and rehabilitation, sEMG represents a valuable tool for functional analysis, evaluation of spinal stabilisation strategies, and monitoring of rehabilitation outcomes.

Advantages and limitations of the method

The main advantages of sEMG include its non-invasive character, the possibility of objective and quantitative assessment of muscle activity, and its use as a biofeedback tool, allowing patients to monitor and improve muscle activation in real time. sEMG can also be applied in dynamic conditions, which facilitates movement analysis and functional assessment.

The limitations of the method include a high susceptibility to artefacts (movement artefacts, skin–electrode interface issues, and electrical interference), strong dependence on the examiner’s technique and experience, and limited ability to record the activity of deep muscles (e.g. multifidus or longus colli). In such cases, the recorded signal may be contaminated by activity from superficial muscles (cross-talk).

Comparison of sEMG and ultrasound imaging (USG)

sEMG and ultrasonography (USG) should be regarded as complementary methods. sEMG provides information on muscle function and electrical activity, whereas USG enables assessment of muscle structure, thickness and real-time dynamic changes. Combining both techniques increases diagnostic validity—for example, USG can confirm muscle activation through changes in muscle thickness, while sEMG provides information on the timing of motor unit recruitment and the level of neural drive. This combined approach allows for more precise planning of therapeutic interventions and stabilisation training.

Equipment and measurement configuration

Noraxon system (16-channel)

Noraxon is one of the most widely used systems for sEMG signal acquisition in biomechanics and rehabilitation. The 16-channel version enables simultaneous recording of multiple muscles, allowing analysis of both local muscle function and inter-muscular coordination. The system consists of:

- a signal acquisition unit (portable recorder with wireless data transmission),
- disposable or reusable surface electrodes,
- MR3 software (Noraxon myoRESEARCH), which enables signal filtering, real-time visualisation, frequency analysis, signal normalisation and reporting.

The system can be integrated with other measurement tools (e.g. dynamometers, gait analysis systems and motion capture), which considerably broadens its application in both clinical practice and scientific research.

Types of surface electrodes and their properties

For sEMG recording, Ag/AgCl (silver/silver-chloride) electrodes are used, most commonly disposable, self-adhesive electrodes with a conductive gel layer. They are characterised by low skin–electrode contact impedance, which minimises noise and improves the signal-to-noise ratio (SNR).

An alternative is reusable electrodes, which require conductive gel and appropriate fixation and are used mainly in laboratory settings. Electrode spacing is of key importance—according to SENIAM (Surface EMG for Non-Invasive Assessment of Muscles) standards, the typical inter-electrode distance is 20 mm (centre-to-centre).

Channel configuration and sampling frequency selection

The measurement configuration depends on the number of muscles assessed and the purpose of the experiment. In a 16-channel system, simultaneous recording from multiple muscle groups is possible (e.g. trunk stabilising muscles: multifidus, erector spinae, rectus abdominis, obliques, serratus anterior).

The sampling frequency should be selected to faithfully represent the EMG signal spectrum. Commonly used values are:

- **1000–2000 Hz** – in scientific and clinical studies,
- **500–1000 Hz** – in training and biofeedback applications.

The signal should be band-pass filtered (typically **10–500 Hz**) to eliminate movement artefacts and electrical interference.

Patient and skin preparation

Skin preparation and hygiene

To obtain reliable sEMG recordings, proper skin preparation is essential:

- degreasing the skin with an isopropyl alcohol or 70% ethanol swab to reduce contact impedance and improve conductivity,
- removing hair at the electrode site to prevent electrode detachment and reduce noise,
- in the case of dry or calloused skin – gentle abrasion using medical skin-prep paper to improve electrode adhesion and reduce impedance.

Reduction of movement artefacts and electrical noise

Movement artefacts and electrical interference are among the main challenges in sEMG recording. To minimise them:

- electrodes should be firmly attached, without air bubbles under the gel,
- light and flexible cables should be used and fixed with tape to limit cable motion,

- the patient should be instructed to avoid unnecessary movements unrelated to the test task,
- special attention should be paid to power-line interference (50 Hz in Europe) – the Noraxon system is equipped with high-pass, low-pass and notch filters that effectively reduce such artefacts,
- measurements should be performed away from devices generating strong electromagnetic fields (e.g. fluorescent lamps, radio equipment).

Importance of standardisation of measurement conditions

To ensure repeatability and comparability of results, standardisation is essential:

- patient position should be reproduced across sessions (e.g. supine, sitting, functional position),
- ambient temperature should be stable (to avoid excessive sweating, which affects skin impedance),
- time of day – measurements should preferably be performed at a similar time, as physiological muscle properties may vary throughout the day (e.g. fatigue, hydration).

Electrode placement – practical guidelines

General placement rules (according to SENIAM and the Noraxon Muscle Chart)

Electrode placement is crucial for obtaining reliable sEMG signals. SENIAM guidelines and the Noraxon Muscle Chart are most commonly used to ensure standardisation:

- electrodes should be placed along the direction of muscle fibres, in the central part of the muscle belly,
- placement close to muscle insertions (tendons) should be avoided, as the signal is weaker and more contaminated,
- symmetry of placement should be maintained in bilateral measurements.

Inter-electrode distance and reference electrode (ground)

- the standard distance between two active electrodes is **20 mm (2 cm)**, providing an optimal signal-to-noise ratio,

- the reference (ground) electrode should be placed over a bony structure or an area with minimal muscle activity (e.g. a bony prominence, iliac crest, wrist),
- in multi-channel recordings (e.g. Noraxon 16-channel system), proper placement of reference electrodes is essential to avoid inter-channel interference.

Typical application errors and how to avoid them

1. **Too small inter-electrode distance** – leads to signal interference and low selectivity; maintain at least 20 mm.
2. **Placement over a tendon or near a joint** – results in distorted signals; move the electrodes towards the muscle belly.
3. **Inadequate skin preparation** – increases impedance and noise; proper cleaning and hair removal are required.
4. **Incorrect electrode orientation** – electrodes placed perpendicular to muscle fibres produce weaker signals; electrodes must be aligned parallel to fibres.
5. **Lack of cable fixation** – cable motion causes movement artefacts; cables should be secured with tape.
6. **Proximity of other active muscles (cross-talk)** – the signal may originate from neighbouring muscles; this can be reduced by placing electrodes centrally on the muscle belly and using appropriate filters.

Assessment of selected stabilising muscles

1. Multifidus muscle (L4–L5)

- **Function:** key segmental stabilisation of the lumbar spine, control of rotation and extension.
- **Patient position:** prone, neutral spinal position; assessment may also be performed in sitting during functional activation.
- **Electrode placement:** along the fibre direction, approximately 2–3 cm lateral to the L4/L5 spinous process; parallel to the spinal axis; reference electrode on the iliac crest.
- **Signal interpretation:** low-amplitude signal, high inter-individual variability; difficulty in eliminating cross-talk from the erector spinae. Activity increases during isometric extension and pelvic stabilisation.

2. Serratus anterior

- **Function:** scapular stabilisation, upward rotation and protraction; prevents scapular winging.
- **Patient position:** supine with the arm abducted to 90°, or in weight-bearing positions (e.g. push-up plus).
- **Electrode placement:** along the fibres at the mid-axillary line at the level of the 5th–7th rib; parallel to the ribs; reference electrode on the acromion.
- **Signal interpretation:** clear increase in amplitude during scapular protraction; possible interference from the external oblique – correct positioning is essential.

3. Abdominal oblique muscles (external and internal)

- **Function:** trunk rotation and stabilisation, regulation of intra-abdominal pressure, cooperation with transversus abdominis.
- **Patient position:** supine, hips and knees flexed (hook-lying); testing during trunk rotation tasks.
- **Electrode placement:**
  - *external oblique* – electrodes parallel to fibres, below the costal margin in the mid-axillary line, fibres directed inferomedially,
  - *internal oblique* – electrodes below the iliac crest, medial to the axillary line, parallel to fibres running superomedially.
- **Signal interpretation:** high activity during rotational tasks; careful differentiation between layers is required; possible cross-talk with transversus abdominis and rectus abdominis.

4. Erector spinae (various levels)

- **Function:** global spinal stabilisation, maintenance of upright posture, spinal extension.
- **Patient position:** prone or sitting; assessment during lumbar and thoracic extension.
- **Electrode placement:** 2–3 cm lateral to the spinous processes, along the muscle belly; most commonly at L3/L4 and Th10; reference electrode on the iliac crest.
- **Signal interpretation:** high-amplitude, easily obtainable signal; clear activation pattern during trunk extension; possible contamination from multifidus.

5. Rectus abdominis

- **Function:** trunk flexion, regulation of intra-abdominal pressure, contribution to postural stability.
- **Patient position:** supine, lower limbs flexed; activation during head or trunk lift.
- **Electrode placement:** parallel to the fibres, centrally on the muscle belly, 2–3 cm above the umbilicus; reference electrode on the sternum or iliac crest.
- **Signal interpretation:** high-amplitude signal; activity increases proportionally with trunk flexion effort; compensatory activity of the oblique muscles should be controlled.

Other muscles that can be assessed

In addition to the main trunk stabilisers, sEMG can be effectively used to assess many other muscles, both local (segmental stabilisers) and global muscles involved in large trunk and limb movements.

Additional locations according to the sEMG Muscle Chart

Trapezius (upper and lower parts)

- *Function:* scapular control and stabilisation, elevation and retraction of the shoulder.
- *Application:* assessment of shoulder girdle compensations in scapular dyskinesis and load tests.

Gluteus medius

- *Function:* frontal plane pelvic stabilisation, especially during stance phase of gait.
- *Application:* gait analysis and assessment of dysfunctions associated with low back pain.

Latissimus dorsi

- *Function:* global extensor and adductor of the shoulder, involved in trunk stabilisation.
- *Application:* evaluation of compensations during upper-limb tasks and functional training.

Rectus femoris

- *Function:* part of the quadriceps; knee extension and hip flexion.
- *Application:* assessment of pelvic control, gait and lower-limb training.

Application of sEMG in the assessment of global and local stabilisation strategies

- **Local strategies:** involve deep, segmental muscles (e.g. multifidus, transversus abdominis, gluteus medius). sEMG enables analysis of recruitment patterns and activation sequencing during stabilisation tasks.
- **Global strategies:** involve superficial and large muscle groups (e.g. erector spinae, rectus abdominis, trapezius, latissimus dorsi). sEMG allows assessment of compensations and excessive activity commonly associated with impaired postural control.
- **Integration of local and global measurements** provides a more comprehensive view of a patient's stabilisation strategy, which is highly relevant for both diagnostics and monitoring of rehabilitation or training effects.

Signal analysis parameters

sEMG signal analysis is based on three main domains: amplitude, frequency and muscular coordination. Each provides different but complementary information on muscle function and motor strategies.

Amplitude

- **RMS (root mean square)** – the most commonly used parameter, representing the averaged signal value over a defined time window; an indicator of muscle activation intensity.
- **Mean amplitude** – reflects the overall activation level during a task or movement period.
- **Peak amplitude** – indicates the maximal muscle activation during movement; useful for identifying moments of highest load.

- **Applications:** side-to-side comparisons, assessment of activation efficiency during functional tasks.

Frequency

- **Spectral analysis (FFT – Fast Fourier Transform)** – evaluates the frequency distribution of the sEMG signal and is relevant for analysing motor unit recruitment strategies.
- **Median frequency (MDF) and mean frequency (MNF)** – commonly used to assess muscle fatigue. A decrease in median frequency indicates increasing fatigue and changes in motor unit behaviour.
- **Applications:** monitoring training progression and identifying abnormal activation patterns associated with fatigue.

Muscular coordination

- **Co-activation analysis** – evaluation of simultaneous activity of agonist and antagonist muscles (e.g. trunk extensors vs. flexors). Excessive co-activation may indicate compensatory strategies or insufficient segmental stability.
- **Recruitment timing** – assessment of activation delays between muscles or relative to movement onset. This is particularly important for deep stabilising muscles (e.g. multifidus, transversus abdominis), which should activate prior to global movement.
- **Applications:** diagnosis of postural control disorders, monitoring of stabilisation therapy outcomes and evaluation of movement quality.

Standardisation and reliability

Standardising sEMG procedures is essential to obtain repeatable and reliable results. Inadequate patient preparation, inconsistent electrode placement, or insufficient control of environmental conditions can lead to high data variability and reduce clinical usefulness.

Measurement repeatability (intra-/inter-rater reliability)

- **Intra-rater reliability** refers to the agreement of results obtained by the same examiner across repeated measurements.
- **Inter-rater reliability** refers to the agreement of measurements performed by different examiners.
- Studies show that when **SENIAM recommendations** and standard **Noraxon protocols** are followed, reliability for **superficial muscles** (e.g., *rectus abdominis*, *erector spinae*) reaches high ICC values (**ICC > 0.85**).
- For **deeper muscles** (e.g., *multifidus*, *internal oblique*), repeatability is lower, mainly due to difficulty in precise electrode placement and the influence of adjacent muscle activity.

Factors influencing the recorded signal

1. **Skin impedance** – High impedance caused by hair, sweat, or inadequate skin preparation significantly reduces signal quality. Shaving and degreasing the skin with alcohol are recommended.
2. **Patient movement** – Motion artefacts, especially during rotational and dynamic tasks, can contaminate the recorded signal.
3. **Electrical interference** – External sources (e.g., 50 Hz mains noise) and internal sources (e.g., cross-talk from adjacent muscles) require appropriate filtering and correct electrode placement.
4. **Environmental conditions** – Temperature, time of day, and muscle fatigue can affect signal stability.

Reference values for selected muscles (based on the literature)

- **Rectus abdominis** – resting RMS: very low values (**<10 µV**); during maximal isometric contraction: **200–400 µV**.
- **Erector spinae** – activation in quiet standing: **20–50 µV**; during maximal trunk extension: **300–600 µV**.
- **Serratus anterior** – mean activation during arm elevation to 90°: **80–200 µV**; clinically relevant for scapular dyskinesis diagnostics.
- **External/internal oblique** – during trunk rotation: **100–250 µV**; side-to-side activation asynchrony may indicate impaired postural control.
- **Multifidus** – resting: **<15 µV**; during local activation (gentle extension or abdominal drawing-in manoeuvre): **50–150 µV**; low repeatability without strict standardisation of patient position.

Clinical applications

Surface electromyography (sEMG) is widely used in diagnosing, monitoring, and treating musculoskeletal dysfunctions. By providing an objective measure of muscle activity, it supports assessment of stabilisation strategies, asymmetries, and motor re-education.

Assessment of stabilisation dysfunctions (LBP, neck pain)

- In chronic low back pain (**LBP**), sEMG can detect impaired recruitment of key stabilisers such as **multifidus** and **transversus abdominis**, which are critical for segmental control.
- In neck pain, the method supports analysis of activation patterns of cervical flexors (e.g., **longus colli**) and extensors, which is relevant for identifying muscle imbalance and postural compensation.
- EMG signals often reveal characteristic patterns: delayed activation of stabilisers, excessive activation of global muscles, and left–right asymmetries.

Monitoring therapeutic and training effects (core stability, scapular control)

- sEMG is an effective tool to quantify changes in muscle activation before and after an intervention.
- In **core stability** training, it enables objective assessment of abdominal muscles (*rectus abdominis*, *external/internal oblique*, *transversus abdominis*) and back extensors.
- In scapular dyskinesis rehabilitation, recording activity of **serratus anterior** and **trapezius** helps track improvements in scapular motor control.
- In clinical research, sEMG is used as an objective outcome measure for the effectiveness of therapeutic protocols (neurological, orthopaedic, and sports physiotherapy).

Biofeedback for learning selective muscle activation

- Real-time signal visualisation provides immediate feedback on contraction quality and intensity.
- sEMG biofeedback is used to re-educate deep trunk muscles that are difficult to activate voluntarily (e.g., **transversus abdominis**, **multifidus**).
- It facilitates correction of compensatory movement patterns and improves motor control, increasing therapy effectiveness.
- The method is also widely used in sport as a training tool to optimise technique and improve movement economy.

Future directions

Development of sEMG technology is moving toward integration with other diagnostic methods and the use of advanced data-analysis approaches. As a result, sEMG is gaining importance not only in research, but especially in clinical practice, ergonomics, and sport.

Combining sEMG with ultrasound and motion capture (e.g., Noraxon myoMOTION)

- Multimodal systems combining sEMG with ultrasound imaging and 3D movement analysis are increasingly used.
- Linking bioelectrical activity with muscle structure (USG) improves understanding of stabilisation mechanisms and compensations.
- Integration with motion capture systems such as **Noraxon myoMOTION** enables comprehensive biomechanical analysis—from muscle activation, through joint kinematics, to postural control.

Advanced analytics (AI, big data, 3D/4D models)

- Artificial intelligence (**AI**) and machine learning are opening new possibilities for interpreting EMG signals.
- Big-data approaches support the creation of normative activation databases and detection of subtle clinically relevant deviations.
- 3D/4D visualisations integrating EMG, ultrasound, and kinematic data may allow more precise real-time mapping of motor strategies.

Applications in rehabilitation, ergonomics, and sport

- In rehabilitation, advances in sEMG support personalised therapy programmes based on objective data and biofeedback.
- In ergonomics, the method allows assessment of muscular workload in the workplace and supports safer workstation design.
- In sport, sEMG is increasingly used to optimise technique, prevent injuries, and improve muscular performance.
- Combining sEMG with wearable and mobile technologies may move the method from laboratories into routine clinical and training settings.

Summary

Surface electromyography (sEMG) is an objective and valuable tool for assessing the function of muscles stabilising the spine, enabling analysis of both individual muscle activation and inter-muscular coordination. Compared with clinical assessment based solely on observation or manual tests, sEMG provides measurable quantitative data that can be used in diagnostics, therapy monitoring, and research.

The method is particularly useful for muscles essential to trunk and shoulder girdle stability, such as:

- **erector spinae** – analysis of extension strategies and compensations in the lumbar and thoracic regions,
- **transversus/rectus abdominis (TrA/RA)** – assessment of deep vs. global muscle contributions to trunk control,
- **serratus anterior** – key for scapular stabilisation and movement control,
- **multifidus** – crucial for segmental spinal stability.

However, sEMG has limitations: the signal is susceptible to noise and artefacts, and results can vary depending on skin preparation, electrode placement, and device settings. Data interpretation requires operator experience and competence in bioelectrical signal analysis.

Despite these limitations, sEMG—especially when combined with ultrasound and movement analysis—forms a cornerstone of modern assessment and treatment of movement-system dysfunctions, supporting objective, data-driven, and personalised rehabilitation.