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ORIGINAL ARTICLE

MODIFICATIONS OF ARTHROMETRIC TEST WITH KT-1000 IN ASSESSING PATIENTS AFTER ACL INJURY

MODYFIKACJE BADANIA ARTROMETRYCZNEGO Z UŻYCIEM KT-1000 W OCENIE OSÓB Z USZKODZENIEM ACL

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ABSTRACT

Introduction

The aim of this study was to validate the reliability of the KT-1000 modified arthrometer with hand-held dynamometer in active and passive condition of the knee joint stabilization. Performing the test in active conditions may give reliable information that can be used in patient follow-up with an injuried ACL.

Materials and methods

Two groups was examined: 21 patients with diagnosed anterior cruciate ligament rupture and 16 healthy controls. The modification of the KT-1000 was done by adding a dynamometer to allow the therapist to measure the strength used in the arthrometric test. The difference in the results was also evaluated according to the measurement conditions.

Results

Intraclass correlation coefficient (ICC) was performed to examine the reliability of measurements and passive ICC values were 0.97 and ICC = 0.89 under active conditions. Significant differences in the parameters tested in passive conditions also allowed for the determination of ROC curves with reliable cut-off points for both translation and stiffness coefficient.

Discussion

Modification of the KT-1000 with hand-held dynamometer allowed to obtained data to allow for joint stiffness to be observed which could provide opportunities for monitoring the influence of different forms of therapy on the mechanism of active knee stabilization.

Conclusion

The KT-1000 hand-held dynamometer modification is a sensitive tool for diagnosing knee instability and may be an alternative device in clinical practice. Also, a change in the condition of testing sagittal knee translation in the form of active muscle stabilization results in significantly differential outcomes.

Keywords: KT-1000 arthrometer, anterior cruciate ligament, arthrometry, knee stability

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STRESZCZENIE

Wstęp

Celem badania była walidacja zmodyfikowanego artrometru KT-1000 uzupełnionego o dyanamomter ręczny. Pomiar artrometryczny wykonywano w warunkach czynnej i biernej stabilizacji stawu kolanowego. Przeprowadzenie testu w warunkach aktywnych może uzupełnić informacje kliniczne, które można wykorzystać w monitorowaniu pacjentów z uszkodzonym więzadłem krzyżowym przednim podczas rehabilitacji.

Materiały i metody

Zbadano dwie grupy: 21 pacjentów ze zdiagnozowanym zerwaniem więzadła krzyżowego przedniego i 16 zdrowych osób kontrolnych. Modyfikację KT-1000 przeprowadzono poprzez dodanie dynamometru, aby umożliwić pomiar siły użytej w teście artrometrycznym. Różnicę w wynikach oceniono również w zależności od warunków pomiaru.

Wyniki

W celu zbadania niezawodności pomiarów wykonano współczynnik korelacji wewnątrzklasowej (ICC), a wartości ICC biernego wynosiły 0,97, a ICC = 0,89 w warunkach aktywnych. Istotne różnice w parametrach testowanych w warunkach biernych pozwoliły również na wyznaczenie krzywych ROC z wiarygodnymi punktami odcięcia zarówno dla współczynnika translacji, jak i sztywności.

Dyskusja

Modyfikacja KT-1000 za pomocą ręcznego dynamometru pozwoliła na uzyskanie danych umożliwiających obserwację sztywności stawów, co może dać możliwości monitorowania wpływu różnych form terapii na mechanizm aktywnej stabilizacji kolana.

Wnioski

Modyfikacja ręcznego dynamometru KT-1000 czułego narzędzia do diagnozowania niestabilności kolana i może być efektywnym urządzeniem w praktyce klinicznej. Ponadto zmiana warunków badania translacji strzałkowej kolana w przy aktywnej stabilizacji mięśniowej skutkuje istotnie zróżnicowanymi wynikami i daje informację na temat skuteczności stabilizacji mięśniowej. Dodatkowo testem ROC uzyskano wartości graniczne translacji oraz współczynnika sztywności.

Słowa kluczowe: artrometr KT-1000, więzadło krzyżowe przednie, artrometria, stabilność stawu kolanowego

Introduction

Anterior cruciate ligament (ACL) tear is one of the most common knee injuries. Acute torsion of the knee can lead to complete ACL rupture (Magnussen *et al.,* 2013, Behrens *et al.,* 2013). Arthrometry using a non-invasive arthrometer is in addition to the clinical examination of ACL function. One of the most popular and used clinically is the KT-1000 arthrometer (MedMetric, San Diego, CA, USA). The KT-1000 is as reliable as more sophisticated arthrometers (eg RSA) and advanced measuring methods such as computerized navigation systems used during ACL reconstruction (Tyler *et al.,* 1999, Monaco *et al.,* 2009, Isber *et al.,* 2006). It is a reliable tool used for examining stability in sagittal plane both before and after surgery. One of advantages is the simplicity of use and the possibility of performing it during

the appointment without special adjustment of the office (Forster *et al.,* 1989, Arneja *et al.,* 2009). When measuring undamaged or ruptured ACL, the KT-1000 was more accurate than the Rolimeter which is also economical and easy to use (Balasch *et al.,* 1999, Ganko *et al.,* 2000). For the accuracy of the results obtained in the KT-1000 arthrometric test it does not matter whether the patient is anesthetized or not. However, the investigator's experience has a significant influence on accuracy of the KT-1000 results (Ballantyne *et al.,* 1995, Berry *et al.,* 1999, Sernert *et al.,* 2001). The results of the test also depend on factors such as the angle of flexion in the joint, strength used in the study, activation of the stabilizing muscles of the joint and sex of the examined person (Markolf *et al.,* 1981, Markolf *et al.,* 1984, Rangger *et al.,* 1993, Strand *et al.,* 1995, Torzilli *et al.,* 1991). Measurement in clinical practice using the KT-1000 is used in conditions of full muscle relaxation. The addition of the displacement measurement giving a quantitative result in milimeters, with the variable representing quantitative force F [N] used in the test, gives the possibility of calculating the stiffness coefficient k for deflection in response to forces acting on the elastic body $k = F/\Delta x$, where Δx is the elongation of the body, and F is a stretching force. The k value can be used to assess the stiffness of joint stabilizing tissues, which may be useful in the treatment of a patient after a traumatic injury to the mechanism of passive stabilization of the joint.

Material

The study group was consisted of 37 people (21 in G group and 16 in CG – control group). In group G there were 11 men and 10 women aged 21 to 60 years (34.2 ± 9.7), weighing 54 kg to 84 kg (68.9 ± 8.1) and body height from 159 cm to 182 cm (171.04 ± 7.6). In the CG group there were 9 men and 7 women aged 23 to 24 years (23.3 ± 0.6), body mass 54 to 84 kg (68.9 ± 9.6) and body height 158 to 183 cm (173.69 ± 8.4).

Inclusion and exclusion criteria

The study involved patients who had been either diagnosed by orthopaedist complete isolated anterior cruciate ligament rupture and full mobility in the knee joint. Exclusion criteria were damage to other anatomical structures in the knee joint which was diagnosed during clinical examination and also age below 18 years.

The CG group (control group) was comprised of active patients which did not report any knee afflictions and other injuries with joint instability in the past and in clinical examination. The research project was approved by the Bioethics Committee of the Academy of Physical Education in Katowice.

Methods

The test consisted of two parts. The first was a "classical" measurement of the forced translation of the crus in the sagittal plane at the patient's passive attitude at a knee flexion angle of 30 degrees. According to the instructions, the patient was instructed to "maximal knee relaxation". The investigator measured to the "hard endpoint".

The second measurement was the original proposal to modify this study. In an examination patient was instructed to "tighten the muscles and immobilize the knee," then the measurement was performed.

Each test was performed 3 times, and the mean values were analyzed statistically. The study was performed by one investigator – an experienced physiotherapist.

Tool

Arthrometric examination of the knee was performed with a modified device KT-1000. The modification consisted in adding to the KT-1000 the spring dynamometer for measuring tensile forces [N] denoted by the number 92/14. The dynamometer has been checked at the Department of Precision Mechanics, obtaining a certificate of verification number 133/14.

Results

In order to verify the reliability of the test tool as the modified KT-1000, the intraclass correlation coefficient (ICC) values for the displacement variable (x) and stiffness (k) were determined. The ICC values for these variables under passive and active conditions in the group G and CG are presented below.

The repeatability of the results obtained with the modified KT-1000 is in the interval of excellent scores. The Mann-Whitney U test was used to verify the significance of the difference in results according to measurement conditions and group.

The results of displacement as well as stiffness differ significantly from one another depending on the measurement conditions (Table 1, Table 2). Measurement in active conditions may give other important information in the diagnosis and treatment in anterior instability of the knee.

Comparing the results obtained in the G and CG groups of the x and k parameters a statistically significant difference was achieved which indicates that measurement in passive conditions is a differentiation study of ACL damage (Table 1, Table 2).

For the results obtained during the study under active conditions, the differences between G and CG groups are not statistically significant for any parameter (Table 4). This modification cannot differentiate classification of ACL damages. However, the results indicate a statistical tendency pointing to a higher translation and less stiffness of the knee in patients.

The ROC curves were determined to provide reliable cut-off points and to diversify ACL patients from healthy subjects and provide area under curve (AUC) values for x and k parameters under passive and active conditions (Figure 1, Figure 2). AUC is in the range of <0; 1>.

In the case of passive measurement, the results allow to set 7 mm as the cut-off point. For the k factor in passive conditions the cut-off point is 17222.22 N/m. In passive tests AUC values are very close to 1 for both x and k, which means very high power of the model (Table 5, Table 6).

In case of active conditions, the results allow to determine the 3 mm value as the cut-off point. For k in passive conditions the cut-off point is 40000 N/m.

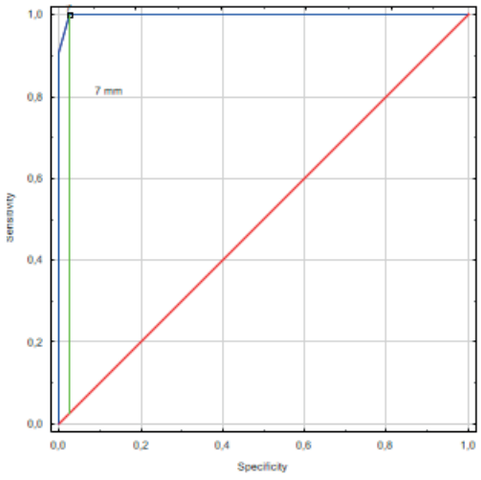

Figure 1. Area under curve (AUC) values for x and k parameters under passive conditions

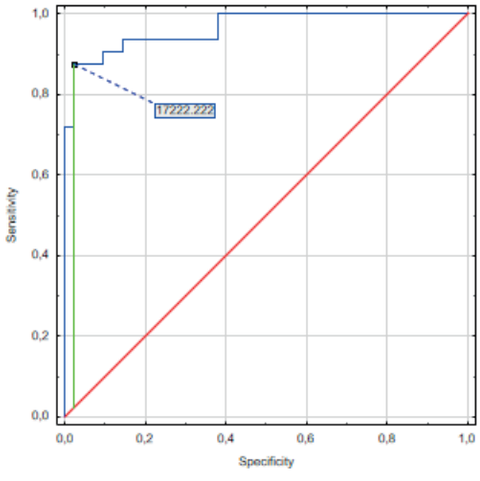

Figure 2. Area under curve (AUC) values for x and k parameters under active conditions

Table 1. ICC for translation (x).

Variable	Test Conditions	ICC	Group
x	passive	Total	0.97
		Group G	0.93
		Group CG	0.93
	active	Total	0.89
		Group G	0.89
		Group CG	0.91
	passive and active	Total	0.97

Table 2. ICC for the stiffness coefficient (k).

Variable	Test Conditions	ICC	Group
x	passive	Total	0.97
		Group G	0.93
		Group CG	0.93
	active	Total	0.89
		Group G	0.89
		Group CG	0.91
	passive and active	Total	0.97

Adopted ranges for intraclass correlation:

1. Less than 0.40 – weak
2. Between 0.40 and 0.59 – sufficient
3. Between 0.60 and 0.74 – good
4. Between 0.75 and 1.00 – excellent.

Table 3. Measurement results in active and passive conditions.

Variable	n	Averages in passive conditions	Standard deviation in passive conditions	Averages in active conditions	Standard deviation in active conditions	U	p
x [mm]	37	7.7	1.92	3.31	0.75	4.50	0.00
k [N/m]	37	17881.23	5849.69	43997.75	17293.29	32.00	0.00

Table 4. Measurements in group G and CG in passive and active conditions.

Variable	Passive (0)/ Active (1)	n CG	n important G	Averages CG	Standard deviation in CG	Averages G	Standard deviation in G	U	p
x [mm]	0	16	21	5.79	0.59	9.14	1.11	0.00	0.00
k [N/m]	0	16	21	22880.46	5192.32	14072.30	2479.27	15.00	0.00
x [mm]	1	16	21	3.04	0.79	3.51	0.67	106.50	0.058
k [N/m]	1	16	21	46010.10	34813.49	30588.89	4299.40	107.50	0.067

Table 5. AUC for translation and stiffness in passive conditions.

	for passive conditions					
	AUC	SE	AUC lower 95%	AUC upper 95%	z	p
variable (x)	0.999	0.002	0.996	1	292.345	0.0000
variable (k)	0.965	0.019	0.927	1	24.262	0.0000

Table 6. AUC for translation and stiffness in active conditions.

	for active conditions					
	AUC	**SE**	**AUC lower 95%**	**AUC upper 95%**	**z**	**p**
variable (x)	0.743	0.059	0.628	0.858	4.136	0.0000
variable (k)	0.751	0.057	0.638	0.864	4.368	0.0000

Discussion

There is no consensus on the reliability of the KT-1000 in the published literature. Wiertsema indicates low diagnostic value of the device (Witersma *et al.,* 2008). In the study 20 people participated and the measurement was performed with 89 N force by 2 investigators. Also Jardin signalizes that the results of lighter measurements using KT-1000 do not correlate with radiographic measurement using TELOS device (Jardin *et al.,* 1999). Hyder's studies show a lack of correlation between clinical trial and KT-1000 results (Hyder *et al.,* 1997). Forster demonstrated that the KT-1000 can provide reliable and statistically significant results by investigating using 67 N and 89 N by four investigators (Forster *et al.,* 1989). Our results show the excellent reliability of the KT-1000 modified instrument for both passive and active conditions. Modification of the device does not complicate the measurement process and its use in the office is as straightforward and economical as described by Ganko by comparing the KT-1000 with Rolimeter (Ganko *et al.,* 2000). Torzilli *et al.* found the best reproducibility of the results after using the maximum possible force on the KT-1000 during the test (Torzilli *et al.,* 1991). Strand results in a group of 42 patients show the highest efficacy with the use of maximal force during an arthrometric study using the KT-1000 in 37 cases of knee instability (Strand *et al.,* 1995). Also Ballantyne in a group of 22 subjects with a unilateral ACL lesion demonstrated a high ICC score of 0.88 with a maximum strength (Ballantyne *et al.,* 1995). Our study shows that measurements for tibial translation performed by one tester give ICC = 0.97 under passive conditions and 0.89 under active conditions. Performing the test in active conditions gives reliable information that can be used in patient follow-up with a ruptured ACL. Also, the introduction of the stiffness parameter into the patient observation process seems to be reasonable. The proposed measurement procedure is quick and easy and may give the opportunity to test for example the effect of exercise on the knee stability.

Conclusion

The results of the experiment show that the KT-1000 hand-held dynamometer modification is a sensitive tool for diagnosing knee instability and may be an alternative device in clinical practice. Also, a change in the condition of testing anterior translation of the tibia on the femur in the form of active muscle stabilization results in significantly differential outcomes and may be an important element in monitoring patient condition after knee injury during treatment and rehabilitation. Modification of the KT-1000 with hand-held dynamometer allowed to obtained data to allow for joint stiffness to be observed which could provide opportunities for monitoring the influence of different forms of therapy on the mechanism of active knee stabilization.

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TREATMENT OF DIABETIC FOOT SYNDROME: A COMPREHENSIVE REVIEW OF THERAPEUTIC APPROACHES

LECZENIE ZESPOŁU STOPY CUKRZYCOWEJ: KOMPLEKSOWY PRZEGLĄD METOD LECZENIA

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ABSTRACT

Introduction

Diabetic foot syndrome (DFS) is a severe complication of diabetes that increases the risk of limb amputation and significantly affects quality of life. Effective management requires a comprehensive approach, integrating advanced imaging, accurate microbiological diagnostics, targeted antibiotics, and innovative treatments. This review highlights the latest advancements and emphasizes the importance of an interdisciplinary approach in improving outcomes.

Aim

This review aims to analyze current strategies for diagnosing, evaluating infection severity, and treating DFS, including antibiotic therapy, surgery, and treatments like negative pressure and hyperbaric oxygen. It provides guidance for clinicians and researchers and identifies areas requiring further research.

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Material and methods
A literature review was conducted using the PubMed, ResearchGate, Web of Science, and Google Scholar databases, covering the years 1990–2023. Keywords related to the treatment of diabetic foot syndrome were used, including surgical methods, antibiotic therapy, and supportive treatments. Original and review articles published in Polish, English, German, and French were included. Non-peer-reviewed publications and those not addressing therapeutic aspects were excluded.

Results
Effective management of DFS depends on an integrated approach, combining advanced diagnostics, targeted antibiotic therapy, and innovative wound healing techniques. Surgical precision and a multidisciplinary team are essential to minimize complications and amputations.

Conclusions
An integrated approach involving early diagnosis, targeted therapy, advanced wound care, and surgical intervention significantly improves outcomes, reducing amputation rates and enhancing the quality of life for DFS patients.

Keywords: diabetic foot infection, surgical management of diabetic foot, supportive therapies in diabetic foot treatment

STRESZCZENIE
Wprowadzenie
Zespół stopy cukrzycowej (DFS) to poważne powikłanie cukrzycy, które zwiększa ryzyko amputacji kończyn i znacząco wpływa na jakość życia pacjentów. Skuteczne leczenie wymaga kompleksowego podejścia, obejmującego zaawansowaną diagnostykę obrazową, dokładne badania mikrobiologiczne, ukierunkowaną terapię antybiotykową oraz innowacyjne metody leczenia ran. Niniejszy przegląd przedstawia najnowsze osiągnięcia w tej dziedzinie i podkreśla znaczenie interdyscyplinarnego podejścia w poprawie wyników leczenia.

Cel
Celem tego przeglądu jest przedstawienie kompleksowej analizy obecnych strategii diagnozowania, oceny nasilenia infekcji i leczenia zespołu stopy cukrzycowej, w tym terapii antybiotykowej, interwencji chirurgicznych oraz zastosowania terapii podciśnieniowej i tlenoterapii hiperbarycznej. Przegląd dostarcza cennych wskazówek dla klinicystów i badaczy, a także wskazuje obszary wymagające dalszych badań.

Materiał i metody
Przegląd literatury przeprowadzono w bazach: PubMed, ResearchGate, Web of Science oraz Google Scholar, obejmując lata 1990–2023. Zastosowano słowa kluczowe związane z leczeniem zespołu stopy cukrzycowej, w tym metodami chirurgicznymi, antybiotykoterapią oraz terapiami wspomagającymi. Włączono prace oryginalne i przeglądowe w językach: polskim, angielskim, niemieckim i francuskim. Wykluczono publikacje nierecenzowane oraz niezwiązane z tematyką terapeutyczną.

Wyniki
Skuteczne leczenie zespołu stopy cukrzycowej opiera się na zintegrowanym podejściu, łączącym zaawansowaną diagnostykę, ukierunkowaną terapię antybiotykową oraz innowacyjne

techniki leczenia ran. Precyzyjne techniki chirurgiczne i zespół multidyscyplinarny są niezbędne do minimalizacji powikłań i amputacji.

Wnioski
Zintegrowane podejście, obejmujące wczesną diagnozę, ukierunkowaną terapię antybiotykową, zaawansowaną pielęgnację ran i interwencje chirurgiczne, może znacząco poprawić rokowania pacjentów z zespołem stopy cukrzycowej, zmniejszając wskaźnik amputacji i poprawiając jakość życia.

Słowa kluczowe: infekcja stopy cukrzycowej, chirurgiczne leczenie stopy cukrzycowej, terapie wspomagające w leczeniu stopy cukrzycowej

Introduction
Infections of the foot, especially in diabetic individuals, are frequently associated with ulcerations that can progress to serious infections such as osteomyelitis. In advanced cases, such conditions can necessitate limb amputation. Impaired perception in diabetics increases the risk of unnoticed skin trauma, including abrasions, blisters, and foreign bodies. The primary objective in managing an infected diabetic foot is to inhibit the progression of osteomyelitis and systemic infections while minimizing the risk of limb amputation. The treatment of diabetic foot ulcers (DFU) is a multidimensional approach encompassing antibiotic therapy, surgical debridement, optimization of glycemic control, and interventions aimed at enhancing peripheral blood circulation (Graninger, 2006).

Aim
This review discusses current diagnostic and treatment strategies for infected diabetic foot syndrome, including antibiotic therapy, surgery, negative pressure wound therapy, and hyperbaric oxygen therapy. It emphasizes early diagnosis and interdisciplinary care to prevent complications.

Metarial and methods
This review examines the literature published between 1990 and 2023 from PubMed, Google Scholar, Web of Science, and ResearchGate. Keywords included diabetic foot infection, antibiotic therapy, surgical treatment, and wound therapies. The review emphasizes peer-reviewed studies, evidence-based clinical guidelines, and recent developments in treating infected diabetic foot syndrome, highlighting the clinical value of multidisciplinary approaches in improving treatment outcomes.

Results
Diagnosis and assessment of infection severity in diabetic foot
Early and accurate diagnosis of infection is crucial for assessing the severity of the condition, selecting an appropriate antibiotic therapy regimen, and planning necessary interventions, including hospitalization or amputation (Lavery *et al.,* 2007). The diagnosis of infection relies on classic symptoms (pain, erythema, swelling, purulent discharge), as well as secondary features, which may be crucial when symptoms are masked by peripheral neuropathy or ischemia (Lipsky, 2007; Miyan *et al.,* 2017). Alterations in wound odor, such as putrid, acidic, or saccharine characteristics, may serve as clinical indicators of infection (Gardner *et al.,* 2009). In cases of deep contagions, systemic symptoms, such as fever, may indicate a more advanced or severe infection (Pittet *et al.,* 1999). Specimens collected through scraping the ulcer base with a scalpel, or through wound or bone biopsy, are more reliable than wound swabs, which may be contaminated by commensal flora (Dinh *et al.,* 2008). Bacterial culture confirms the

diagnosis, but the obtained results are associated with a 50% risk of errors (Graninger, 2006). Among imaging studies, conventional radiography has limited sensitivity (54%) in detecting osteomyelitis (Dinh *et al.,* 2008). MRI is characterized by high sensitivity (90–100%) but lower specificity (<80%) for this purpose. SPECT/MRI scanning and hybrid techniques (e.g., combined with computed tomography) enhance diagnostic efficacy (Zavadovskaya *et al.,* 2015). Aseptic aspiration of pus or tissue fluid using a needle is an alternative diagnostic method that allows for pathogen identification and precise selection of targeted treatment. Furthermore, in cases where imaging cannot be performed due to patient contraindications or lack of appropriate equipment, it may be the only diagnostic option (Chakraborti *et al.,* 2010; Senneville *et al.,* 2006). Specimens should be collected before the initiation of antibiotic therapy or at least 10 days after its discontinuation (Lipsky *et al.,* 2012).

Antibiotic therapy

In mild foot infections, the most common pathogens are aerobic Gram-positive bacteria, primarily Staphylococcus aureus and β-hemolytic streptococci (group B). Moderate and severe infections are more often polymicrobial, including Gram-positive cocci (*S. aureus*), Gram-negative rods (*E. coli*, *Proteus mirabilis*, *Klebsiella* spp.), and non-fermenting Gram-negative rods (*Pseudomonas aeruginosa*). Osteomyelitis is most commonly caused by *S. aureus*, both in monomicrobial and polymicrobial infections (Zanella *et al.,* 2016). Local wound treatment and prior use of antibiotics select for resistant strains, such as MRSA, cephalosporin-resistant enterococci, and anaerobes (e.g., *Bacteroides*, *Clostridium*, *Peptococcus*, *Peptostreptococcus*) in wounds with necrosis and deep tissue damage (Day and Armstrong, 1997; Lipsky *et al.,* 1990; Lipsky, 1999). Factors that increase the risk of antibiotic resistance include the overuse of antibiotics, their prophylactic use in non-infected wounds, and suboptimal treatment choices. Therapy should be directed based on culture results and microorganism susceptibility testing.

Treatment of infections in diabetic foot should be targeted towards a narrow spectrum of pathogens based on microbiological test results (Lipsky *et al.,* 2016). The use of antibiotic therapy in non-infected wounds is not supported by evidence, as it does not enhance healing or reduce infection risk. Excessive use of antibiotics increases the risk of microbial resistance (Abbas *et al.,* 2015).

Empirical antibiotic therapy is typically required before culture results are available, especially in severe or rapidly progressing infections. It should cover *S. aureus*, and in cases of moderate or severe infections, also include Gram-negative bacteria (Lipsky *et al.,* 2012; Lipsky *et al.,* 2016). In warm regions of the world, as well as in cases of sepsis or severe infections, coverage of Gram-negative bacteria and potentially anaerobes is essential. In patients at risk of MRSA infection, empirical antibiotic regimens targeting these strains should be considered (Chargui *et al.,* 2014). For mild infections, oral antibiotics can be used, while severe infections or systemic conditions initially require parenteral treatment, which can be continued orally once the patient's condition stabilizes. The transition from parenteral to oral therapy depends on the severity of the infection and the patient's condition, typically lasting from several days to a few weeks (Bader, 2008).

If clinical improvement is observed, empirical antibiotic therapy may be continued, although culture results indicating resistance should prompt careful reassessment. A lack of response to treatment requires modification of the therapy to include broader-spectrum agents, targeting all isolated organisms. Recurrent ulcers may require microbiome screening from nasal, perineal, or oropharyngeal sites (Lavery *et al.,* 2014). In cases of treatment failure, it is crucial to evaluate the adequacy of serum drug levels, absorption, or metabolism of the prescribed medications, as well as to

determine whether surgical intervention may be required (Lipsky *et al.,* 2016).

Osteomyelitis may affect up to 80% of diabetic foot infections (DFI), particularly in the case of extensive and deep ulcers. The most reliable diagnostic method is bone biopsy, since surface samples demonstrate only around 50% concordance with bone biopsy findings (Ha Van, 2019). Laboratory tests, such as the erythrocyte sedimentation rate (ESR) (>70 mm/h), may support the suspicion of infection but have limited sensitivity (Newman *et al.,* 1991). Conventional radiography has low sensitivity (54%) and is primarily used for monitoring changes over time (Dinh *et al.,* 2008). Histological analysis of bone is crucial in distinguishing Charcot neuroarthropathy from infection. A predominance of osteoclasts over osteoblasts suggests neuroarthropathy (Ertugrul *et al.,* 2013). The treatment should include *S. aureus* and be tailored to the chronic nature of the infection (Lipsky, 1999). The recommended duration of therapy is approximately 6 weeks, according to the IDSA (2012) and IWGDF (2016) guidelines (Abbas *et al.,* 2015). Limited antibiotic penetration into bone tissue may reduce their effectiveness. Antibiotics are classified by their bone-to-blood concentration ratios as having good (>0.3; e.g., clindamycin, fluoroquinolones), moderate (0.1–0.3; e.g., β-lactams, macrolides), or poor (<0.1; e.g., aminoglycosides, vancomycin) bone penetration (Ha Van, 2019). The definitive method for treating chronic osteomyelitis is the removal of infected bone through debridement, resection, or amputation (Lipsky, 1999).

The duration of antibiotic therapy depends on the severity of the infection, ranging from 1 week for mild infections to several weeks for severe infections and bone or bone marrow infections (Grayson *et al.,* 1994; Lipsky, 1997). Aiming to shorten the duration of therapy reduces the risk of resistance development, minimizes side effects, and lowers costs. Antibiotics can be discontinued once the symptoms of infection resolve, rather than continuing until complete wound healing (Aragón-Sánchez, 2011).

Surgery

Surgical intervention plays a critical role in the management of diabetic foot, especially in advanced cases involving tissue necrosis or deep infections. It involves various strategies aimed at effectively controlling the infection, preserving the limb, and restoring its function.

Effective treatment of diabetic foot syndrome (DFS) requires a multidisciplinary team, including surgeons, infectious disease specialists, and nursing professionals, working together to optimize care and treatment outcomes (Fisher *et al.,* 2010; Zgonis *et al.,* 2008). The fragile health of patients with diabetes and comorbid conditions (e.g., heart disease, chronic kidney failure) increases the risk of surgical complications.

Surgical treatment is tailored to the form of DFS (neuropathic or neuroischemic), with an emphasis on preserving as much of the foot and its function as possible. In neuropathic DFS, changes are primarily due to peripheral nerve damage, leading to loss of sensation, foot deformities, and the formation of ulcers, while maintaining good tissue perfusion that facilitates healing. In neuroischemic DFS, ischemia is caused by macro- and microangiopathy, often in combination with neuropathy. These differences define the surgical approach in each case. In neuropathic DFS, treatment is focused on structural protection of the foot and involves procedures aimed at reducing deformity and selective amputations limited to necrotic tissue. Treatment of neuroischemic DFS, however, is focused on restoring perfusion through endovascular methods, endarterectomy, or extensive amputations to prevent the spread of gangrene (Liapis *et al.,* 2001). The stepwise approach includes initial aggressive debridement to control the infection, assessment of vascular status and potential revascularization to improve tissue perfusion, followed by soft tissue and skeletal reconstruction

to close the wound and salvage the limb (Lyakhovsky *et al.,* 2023; Zgonis *et al.,* 2008).

Initial surgical management typically involves extensive and thorough debridement, which is considered a critical step in infection control. This involves the removal of all necrotic tissue and drainage of abscesses to reduce the bacterial load and support the healing process (Ivanusa *et al.,* 2023).

After surgical debridement, a thorough assessment of the vascular status is essential. This may include vascular surgery or endovascular interventions to improve blood flow and support the healing process (Fisher *et al.,* 2010; Rauwerda, 2004).

Once infection is controlled and circulation optimized, reconstruction of tissues follows. The primary objective is to achieve wound closure and limb preservation, a process that frequently necessitates multiple staged surgical interventions (Fisher *et al.,* 2010; Zgonis *et al.,* 2008). Various wound cleaning methods, irrigation, and lavage are employed, followed by techniques for final closure. The use of modern hydrocolloid dressings and biomaterials is also recommended for ulcer closure (Okroyan *et al.,* 2018). Modern methods for treating deep tissue infections, which reduce tissue damage and improve outcomes, include endoscopic-assisted drainage support, cavitation using ultrasound waves to remove necrotic tissue and enhance the healing process, negative pressure wound therapy to assist drainage and accelerate tissue regeneration, and the use of the bactericidal and regenerative properties of ozone in infection treatment (Ivanusa *et al.,* 2023). Despite promising treatment outcomes, there is a lack of sufficient high-quality evidence to support the routine use of adjunctive therapies (Marson *et al.,* 2018).

Effective surgical treatment of DFS is complex and involves a varied, stepwise approach tailored to the specific characteristics of the infection and the patient's condition. The ultimate goal is not only to stop the progression of DFS but also to improve the patient's quality of life.

Negative Pressure Wound Therapy

Negative Pressure Wound Therapy (NPWT) is a widely used approach in the treatment of diabetic foot wounds, including ulcers and post-amputation sites. This technique applies regulated negative pressure to the targeted area, facilitating wound healing by actively extracting excess fluid (exudate), thereby maintaining a clean environment, lowering infection risk, and improving circulation by reducing edema.

NPWT offers significant benefits in treating DFU, primarily by accelerating healing compared to traditional moist wound dressings. NPWT creates a controlled environment that reduces edema, supports angiogenesis, and enhances granulation tissue formation, which promotes wound closure (Armstrong *et al.,* 2005; Chen *et al.,* 2021). Studies consistently show that wounds treated with NPWT have a higher likelihood of achieving complete healing compared to those managed with traditional dressings, providing patients with faster and more durable outcomes (Liu *et al.,* 2017; Liu *et al.,* 2018; Zhang *et al.,* 2014).

Due to its ability to modulate inflammatory processes, NPWT represents an effective therapeutic option that promotes faster and more efficient wound healing, particularly in the case of chronic ulcers, where excessive inflammatory response can hinder regeneration. This mechanism is associated with the regulation of signaling pathways and the reduction of inflammatory marker levels. The MAPK-JNK pathway, which plays a crucial role in regulating inflammatory processes and tissue damage response, is suppressed during the application of NPWT. The reduction in levels of inflammatory markers, such as interleukin-6 (IL-6) and tumor necrosis factor-alpha (TNF-α), also limits the intensity of the inflammatory response (Wang *et al.,* 2019).

Studies suggest that NPWT can significantly improve the prognosis of patients with DFS, helping them avoid amputation and enhancing their quality of life. NPWT

has been shown to reduce the incidence of major (above-ankle) amputations, highlighting its therapeutic relevance in advanced DFU management. The impact of NPWT on the frequency of minor amputations, such as toe amputations, remains less clear and requires further research (Liu *et al.,* 2017; Liu *et al.,* 2018; Zhang *et al.,* 2014).

Although NPWT has higher initial costs, it is more cost-effective over the long term. Faster wound healing reduces the overall treatment time, leading to lower hospitalization costs. NPWT requires less frequent dressing changes compared to traditional methods, which reduces material and healthcare staff labor costs. Due to its more effective wound healing, NPWT reduces the risk of complications that may require rehospitalization. The reduced risk of amputation lowers long-term costs associated with rehabilitation, prosthetics, and loss of productivity. As a result, NPWT not only improves clinical outcomes but also leads to significant savings for both patients and the healthcare system (Bogucka *et al.,* 2023; Liu *et al.,* 2017).

NPWT is generally safe, but requires monitoring for complications. Improper application or lack of adequate monitoring may lead to the development of infections at the wound site. In patients with coagulation disorders or improper use of NPWT, there is a risk of excessive bleeding. Incorrect patient selection or improper use of the device can result in tissue necrosis. It is crucial to strictly follow the guidelines for NPWT application, continuously monitor the wound and device status, and carefully select patients, including a thorough analysis of the indications for the proposed treatment approach (Ji *et al.,* 2021; Seidel *et al.,* 2020). NPWT has a safety profile comparable to standard wound care, with no significant increase in adverse events, provided it is used correctly and regularly monitored (Chen *et al.,* 2021; Liu *et al.,* 2017; Zhang *et al.,* 2014).

The effectiveness of NPWT largely depends on the application technique and adherence to standardized treatment protocols. International consensus recommends regular training of medical staff in the application of NPWT and monitoring therapy outcomes to minimize the risk of complications such as infections or damage to surrounding tissues, ultimately leading to better treatment outcomes. Guidelines include detailed instructions on wound preparation, device selection, pressure level, and dressing change frequency. The success of NPWT largely depends on its customization to the individual patient's needs, including the wound's size and depth, the degree of exudate, and the presence of infection (Ji *et al.,* 2021).

Hyperbaric Oxygen Therapy

Hyperbaric Oxygen Therapy (HBOT) aids wound healing through several mechanisms, including enhancing oxygen delivery, promoting angiogenesis, reducing inflammation, and modulating growth factors and reactive oxygen species.

The Hyperbaric Oxygen Therapy in Diabetics with Chronic Foot Ulcers (HODFU) study demonstrated that HBOT significantly increases the rate of complete ulcer healing compared to placebo (52% vs. 29%) (Löndahl *et al.,* 2010). Meta-analyses have confirmed that HBOT increases the healing rate of DFU (relative risk: 1.901) and reduces the frequency of major amputations (relative risk: 0.518) (Zhang *et al.,* 2022). However, studies did not show significant differences in the impact on minor amputations (Brouwer *et al.,* 2020).

HBOT stimulates neovascularization by increasing the expression of markers such as EGF, VEGF, PDGF, FGF-2, and CXCL10. This process is regulated through the activation of growth factors such as HIF-1α, which controls the proliferation and migration of endothelial cells and fibroblasts (Dhamodharan *et al.,* 2019; Huang *et al.,* 2020). By elevating the oxygen partial pressure within tissues, it improves oxygen delivery to the wound, meeting the energy requirements essential for tissue regeneration (Kranke *et al.,* 2015; Tejada *et al.,* 2019). Oxidative stress constitutes

a key regulatory mechanism in the wound healing cascade, and HBOT has shown the ability to modulate it, thereby supporting the regeneration process. HBOT reduces the levels of pro-inflammatory mediators such as TNF-α and IL-1β, thereby contributing to the reduction of oxidative stress and inflammation. The antioxidant response is also crucial in controlling oxidative stress. Enzymes like catalase, superoxide dismutase (SOD), and glutathione peroxidase (GPx) are critical in mitigating oxidative damage (Capó *et al.,* 2023; Paprocki *et al.,* 2020). Reactive oxygen species (ROS) and nitrogen species generated during HBOT exhibit bactericidal effects and enhance the antimicrobial activity of the immune system by influencing processes such as cell recruitment and chemotaxis (Fosen and Thom, 2014; Thom, 2009; Thom, 2011; Zhou *et al.,* 2023). HBOT influences signaling pathways, including ROS/MAPK/MMP, thereby supporting the healing of ischemic wounds by reducing tissue degeneration (Zhang and Gould, 2014).

HBOT shows promising results in improving the healing of DFU and reducing the incidence of major limb amputations. However, the current evidence base is limited by methodological weaknesses, underscoring the need for larger, high-quality studies to validate its efficacy and cost-effectiveness (Barnes, 2006; Wunderlich *et al.,* 2000). Despite these challenges, HBOT remains a valuable adjunctive treatment for selected patients with DFS.

Conclusions

Diabetic Foot Syndrome (DFS) is a common complication of diabetes, often leading to infections, osteomyelitis, or amputations. Treatment includes prompt diagnosis, appropriate antibiotic therapy, surgical procedures, and adjunctive therapies. Diagnosis is based on clinical evaluation along with microbiological and imaging investigations. Antibiotics are prescribed according to culture results, with empirical treatment utilized for severe infections. Surgical management, including wound debridement and improving blood flow, plays a pivotal role in advanced stages. Negative Pressure Wound Therapy (NPWT) and Hyperbaric Oxygen Therapy (HBOT) contribute to healing by improving microcirculation and promoting tissue regeneration. A multidisciplinary, integrated care model may reduce the risk of amputation, optimize clinical outcomes, and enhance health-related quality of life. Ongoing monitoring and individualized treatment are vital for successful management.

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REVIEW ARTICLE

PROFESSOR ALEKSANDER BOGUSLAW KABSCH – LAUDATION

PROFESOR ALEKSANDER BOGUSŁAW KABSCH – LAUDACJA

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ABSTRACT

"A pioneer of basic and clinical research in the field of biomechanics, orthopaedics and neurophysiology, as well as rehabilitation, related to the diagnosis and treatment of patients with musculoskeletal disorders of various etiologies."

The laudation for Professor Aleksander Kabsch was delivered on the occasion of honoring him with the " Wiktor Dega Medal" as part of the International Day of Persons with Disabilities in December 2024. The medal was awarded by the Chapter of the Wiktor Dega Orthopedic and Rehabilitation Clinical Hospital of the Karol Marcinkowski University of Medical Sciences in Poznań after a unanimous motion of the Institute Council. The content of the laudation modestly outlines the outstanding scientific and organizational activity of the Professor in the national and international arena. This is an expression of respect for the contribution of Aleksander Kabsch to the development of science in basic and clinical research on the diagnosis and treatment of patients with disorders of the musculoskeletal system of various etiologies in the field of biomechanics, orthopedics, neuroanatomy and neurophysiology, as well as broadly understood rehabilitation.

Keywords: Aleksander Kabsch, laudation, biomechanics

STRESZCZENIE

„Pionier badań podstawowych i klinicznych w zakresie biomechaniki, ortopedii i neurofizjologii oraz rehabilitacji, związanych z diagnostyką i leczeniem chorych z dysfunkcjami narządu ruchu o różnej etiologii".

Laudacja dla Pana Profesora Aleksandra Kabscha została wygłoszona z okazji wręczenia mu „Medalu im. Wiktora Degi" w ramach Międzynarodowego Dnia Osób z Niepełnosprawnościami w grudniu 2024 roku. Medal został przyznany przez Kapitułę Ortopedyczno-Rehabilitacyjnego Szpitala Klinicznego im. Wiktora Degi Uniwersytetu Medycznego im. Karola Marcinkowskiego w Poznaniu po jednogłośnym wniosku Rady Instytutu. Treść laudacji skromnie nakreśla wybitną działalność naukową i organizacyjną Pana Profesora w środowisku ogólnopolskim oraz międzynarodowym. Jest to wyraz szacunku dla wkładu Aleksandra Kabscha w rozwój nauki w badaniach podstawowych i klinicznych nad diagnostyką i leczeniem chorych z dysfunkcjami narządu ruchu o różnej etiologii w zakresie biomechaniki, ortopedii, neuroanatomii i neurofizjologii oraz szeroko pojętej rehabilitacji.

Słowa kluczowe: Aleksander Kabsch, laudacja, biomechanika

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Aleksander Bogusław Antoni Kabsch was born in Śrem on January 21, 1928, in the family of Antonina, née Malińska, and Władysław Kabsch. He is the son, grandson, and nephew of Greater Poland Insurgents. After the World War II he attended the secondary school in Ostrów Wielkopolski, where he graduated in 1947. He is a physician by education, a specialist in orthopedics, a pioneering researcher of the biomechanics of the musculoskeletal system in normal and pathological conditions. In the years 1947–1952 he studied at the Faculty of Medicine of the Poznań Medical Academy, graduating a medical doctor's degree in August 1952 (Figure 1).

Figure 1. Aleksander Kabsch – M.D.

During his studying, he worked at the Poznań Medical Academy in the Department of Descriptive and Topographic Anatomy as a Junior Assistant (1949–1951), Assistant and Professor's Assistant (1952–1963) under the supervision of Józef Kołaczkowski. His interest in biomechanics resulted in PhD in medical sciences at the Faculty of Medicine of the Poznań Medical Academy in 1961 and Habilitation in 1967 in the field of medical sciences in orthopedics/biomechanics. He took over the management of the Department in 1969. In November 1977, he was appointed the Associate Professor, in 1989 the Titular Professor nominated by the President of the Republic of Poland, and in 1990 he received the Full Position of Professor.

Figure 2. Aleksander Kabsch – 1977

In 1952–1958 he also worked closely with the Orthopedic Clinic of the Medical Academy, specializing in the field of orthopedics and rehabilitation. A student and a co-worker of Professor Wiktor Dega, he was a direct collaborator of Professor Kazimiera Milanowska and Professor Janina Tomaszewska in the field of orthopedics and rehabilitation (Figure 3).

In 1968, he joined the Poznań College of Physical Education, where he began teaching biomechanics, which was included in the curriculum of studies at the Department of Biomechanics. His expert scientific knowledge of biomechanics and anatomy, as well as clinical specializations in the field of the musculoskeletal system in orthopedics and rehabilitation, as well as exceptional organizational skills, enabled him to create and manage the Department of Biomechanics (1969–1984) (Figure 4), the Department of Clinical Biomechanics (1984–2001) and the Department of Biomechanics and Kinesiotherapy (1990–2001).

Figure 3. Kazimiera Milanowska, Aleksander Kabsch, Wiktor Dega

Figure 4. The Teacher's Day in 1971, and meeting with the Rector of Academy of Physical Education in 1979

In 1969–1972 he was Vice-Dean of the Faculty of Physical Education. He also led to the establishment in 1972 of the Biomechanics Laboratory at the Academy of Physical Education branch in Gorzów Wielkopolski, where he also gave lectures and trained scientific staff. In 1970 he created a rehabilitation program in Mongolia as a World Health Organization expert. He was a co-founder and Director of the Institute of Rehabilitation at the Eugeniusz Piasecki Academy of Physical Education in Poznań (1993–1998) (Figure 5).

Figure 5. Inauguration of the academic year 1975–1976

Professor Aleksander Kabsch was democratically elected in 1981 to the honorable position of Rector of the Academy of Physical Education, which he held in the years 1981–1985. He outlined ambitious plans for the development of the Academy, including its opening to the world, modeling it on western universities, and introduced democratic forms of management.

Figure 6. Inauguration of the academic year 1983–1884 as the Rector of the Academy of Physical Education

He developed a plan for the construction of new sports and educational facilities, especially an athletics hall and a student residence in Gorzów Wielkopolski (Figure 7). He also made the first efforts to obtain the right to award the degree of habilitated doctor. The possibility

of holding the office of Rector lasted only four years. During his second term, for political reasons, standing in defense of democracy, he was dismissed from this function by the Minister of Education.

Figure 7. Unveiling of the plaque of Eugeniusz Piasecki, patron of the Academy of Physical Education in Poznań in 1982

It is difficult to list all of Professor Aleksander Kabsch versatile scientific interests, but the most important of them are:

- Biomechanics of human gait, especially in aspects of selected sports disciplines of disabled people, with particular emphasis on skiing in people with amputations,
- Biomechanics of gait in thigh prostheses,
- Issues of muscle function testing: measurement methods and techniques, also in specialist sports training,
- Diagnostics, prevention and treatment of human body overloads in professional work and in sports, also in an ergonomic approach.

The researches were carried out in cooperation with the Rehabilitation Commission of the Polish Academy of Sciences and other international organizations of rehabilitation and sports. He is the author of over 190 scientific publications, 6 books and patents.

In the field of training of scientific staff, Professor Aleksander Kabsch was the supervisor of 18 doctoral dissertations in the field of medical sciences and physical culture sciences. Four direct collaborators under the patronage of the Professor Aleksander Kabsch obtained post-doctoral degrees.

Professor Aleksander Kabsch officially finished his work at the Academy of Physical Education in Poznań at the age of 73 in 2001, but he has served other universities and institutions with his great experience and didactic, organizational and scientific knowledge, not only

in Poland but also abroad, also to this day, e.g. Medical University of Bydgoszcz, Collegium Medicum in Toruń, Higher School of Physiotherapy in Wrocław, Higher School of Education and Therapy in Poznań (Figure 8). He provided monograph lectures on social rehabilitation at the Faculty of Social Sciences of the Adam Mickiewicz University in Poznań and at Poznań University of Technology.

Figure 8. A lecture at the Conference organized by The Higher School of Education and Therapy in Poznań

I recall Professor Aleksander Kabsch first time when he hired me in 1981. He was the frontier organizer of the neuroanatomical and neurophysiological approach to the education of students at the Academy of Physical Education in Poznań; during his term as the Rector, the Department of Morphological and Functional Bases of Movement was created at the Eugeniusz Piasecki Academy of Physical Education, headed by Professor Kazimierz Grottel (Figure 9). This facility was later transformed into the Department of Neurobiology. Especially in the difficult period for Poland after 1981, together with Professor Kazimierz Grottel and Professor Jadwiga Koczocik-Przedpelska, he directed the role of clinical neurophysiology in the Poznań, as important in the assessment and determination of possible effects of treatment of patients with dysfunction of the musculoskeletal system.

Figure 9. 10th anniversary of the Department of Morphological and Functional Bases of Movement

Professor Aleksander Kabsch skillfully and pleasantly combines professional, scientific activity with social contacts, an example of which was the co-organization, together with Professor Kazimierz Grottel, of the cyclical Spring Neurobiology Colloquiums at meetings at the sport center in Chycina. This skill allowed the Poznań scientific community to establish contacts with world-class scientists from the Marceli Nencki Institute of the Polish Academy of Sciences in Warsaw, including Professors Elżbieta Jankowska, Teresa Górska, Urszula Sławińska, Maria Piotrkiewicz and Stefan Kasicki (Figure 10). With many of them, this resulted in joint projects and scientific works of international scope.

Figure 10. Photos from one of Spring Neurobiology Colloquium with scientists from the Marceli Nencki Institute of the Polish Academy of Sciences in Warsaw

In professional contacts, Professor Aleksander Kabsch uses nice, reliable argumentation with an admixture of factual, yet gentle persuasion, de facto... it is difficult ever to refuse his requests.

Professor Aleksander Kabsch is a co-founder, leader and elected member of many scientific societies and consulting institutions of national and international scope: Polish Medical Society, Voivodeship Consultant for Rehabilitation (1958–1975), Expert of the Physical Culture and Sports Committee, Polish Academy of Sciences – Committee for Rehabilitation and Social

Adaptation (1984–1999), Commission for Rehabilitation Engineering (since 1990), Committee for Physical Culture (1987–1999), Committee for Rehabilitation, Physical Culture and Social Adaptation of the Polish Academy of Sciences (since 1999), Commission for Medical Rehabilitation (since 2003), Ergonomics Committee (since 1987), Polish Rehabilitation Society (founder since 1970), Polish Biomechanics Society (founder since 1985), International Society of Biomechanics (since 1983), Polish Society for Combating Disability, Expert in Rehabilitation of the World Health Organization.

Professor Aleksander Kabsch is the winner of many awards, among which the ones dear to his heart should be singled out (Figure 11):

- 2018 – Winner of the medal "For Merit to the Eugeniusz Piasecki Academy of Physical Education in Poznań",
- 2021 – Winner of a special award in the third Plebiscite of the Polish Paralympic Committee "Guttmanny 2021".

Figure 11. Professor Aleksander Kabsch awarded the medal "For Merit to the Eugeniusz Piasecki Academy of Physical Education in Poznań" and a special award in the third Plebiscite of the Polish Paralympic Committee "Guttmanny 2021"

Prof. Aleksander Kabsch is the initiator and organizer of sports for the disabled and many cyclical conferences of national and international scope devoted to rehabilitation issues, including oncological and geriatric rehabilitation. As the creator and visionary of the Rehabilitation and Social Integration Commission of the Polish Academy of Sciences, and the first Editor-in-Chief of the Journal of Rehabilitation Promotion of the Polish Academy of Sciences in Poznań, he enabled the popularization of the content of these meetings in the form of monographs. Later, as an active Senior Editor of Issues of Rehabilitation, Orthopaedics, Neurophysiology and Sport Promotion – IRONS, he caused this journal to obtain a scoring rank on list of the Ministry of Science and Higher Education (40 points), currently also visible in the PubMed database (Figure 12).

Figure 12. Formers and Editorial Board of the Issues of Rehabilitation, Orthopaedics, Neurophysiology and Sport Promotion – IRONS

Dear Professor Aleksander Kabsch,

For us, your students and colleagues, you are not only a model researcher and promoter of scientific staff, but also an inspirer of the idea of orthopedic biomechanics, rehabilitation and neurobiology, indicating paths for practical, clinical use of research in translational medicine.

Please do not stop, as long as you have the strength, because we deeply believe that you will never lack the intention and enthusiasm.

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REVIEW ARTICLE

THE NEUROLOGICAL PHENOMENON OF ALICE IN WONDERLAND SYNDROME

NEUROLOGICZNE ZJAWISKO ZESPOŁU ALICJI W KRAINIE CZARÓW

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A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article

ABSTRACT

Introduction

Alice in Wonderland Syndrome (AIWS) is a rare neurological disorder characterized by distortions in the perception of size, time, and spatial relationships. Named after Lewis Carroll's novel, the condition has been known since the 1950s, yet its underlying mechanisms remain incompletely understood. AIWS is frequently associated with migraine, epilepsy, and viral infections.

Aim

The aim of this paper was to provide a comprehensive review of AIWS, including its pathophysiology, clinical manifestations, potential causes, diagnostic approaches, and treatment strategies.

Material and methods

This review is based on scientific literature, including 17 epidemiological studies and case reports. It also incorporates neuroimaging data and symptom assessment scales.

Results

The most common symptoms of AIWS include micropsia and macropsia, altered time perception, derealization, and depersonalization. Micropsia was reported in 73% of cases. The condition is more commonly diagnosed in children, with a mean onset age of 8.3 years. Migraines were present in 90% of patients. Treatment involves pharmacotherapy (e.g., triptans, antiepileptics, SSRIs) and non-pharmacological methods, such as cognitive-behavioral therapy.

Conclusions

AIWS is a complex disorder that requires further research to better understand its pathophysiology and optimize treatment strategies. Neuroimaging studies suggest the involvement of occipital and temporal lobes and dysregulation of neurotransmitter systems, including serotonin, dopamine, and GABA. Due to the variability and transient nature of symptoms, AIWS is often underdiagnosed. Effective management should address the underlying condition – most commonly migraine – and include psychological support when psychiatric comorbidities are present.

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Keywords: neuropsychology, migraine, Alice in Wonderland Syndrome, perceptual disturbances, micropsia

STRESZCZENIE

Wstęp

Zespół Alicji w Krainie Czarów (AIWS) to rzadkie zaburzenie neurologiczne objawiające się zniekształceniem percepcji wielkości, czasu i przestrzeni. Nazwa pochodzi od powieści Lewisa Carrolla. Choć zaburzenie to znane jest od lat 50., mechanizmy jego powstawania nadal nie są w pełni poznane. Zaburzenie często współwystępuje z migreną, padaczką oraz infekcjami wirusowymi.

Cel

Celem pracy było kompleksowe omówienie AIWS – jego patofizjologii, objawów klinicznych, możliwych przyczyn, diagnostyki oraz strategii leczenia.

Materiał i metody

W pracy dokonano przeglądu literatury naukowej, analizując wyniki 17 badań epidemiologicznych, studiów przypadków i artykułów. Uwzględniono także dane neuroobrazowe i wyniki skali oceny objawów.

Wyniki

Najczęstszymi objawami AIWS są mikropsje i makropsje (zaburzenia percepcji wielkości), zniekształcenia czasu, derealizacja i depersonalizacja. U 73% pacjentów stwierdzono mikropsję. AIWS częściej występuje u dzieci (średni wiek zachorowania: 8,3 lata). Najczęstszym czynnikiem etiologicznym są migreny (90% przypadków). W leczeniu stosuje się farmakoterapię (np. tryptany, leki przeciwpadaczkowe, SSRI) oraz podejścia niefarmakologiczne, jak terapia poznawczo-behawioralna.

Wnioski

AIWS to złożone zaburzenie wymagające dalszych badań w celu pełniejszego zrozumienia mechanizmów jego powstawania i opracowania skuteczniejszych metod terapii. Badania neuroobrazowe sugerują udział płatów potylicznych i skroniowych oraz zaburzenia w układach neuroprzekaźników, takich jak serotonina, dopamina czy GABA. Ze względu na różnorodność objawów i ich przejściowy charakter, AIWS bywa trudne do rozpoznania i często pozostaje niezdiagnozowane. Skuteczne leczenie wymaga identyfikacji i terapii choroby podstawowej – najczęściej migreny – oraz podejść psychoterapeutycznych w przypadku współistniejących zaburzeń lękowych lub depresyjnych.

Słowa kluczowe: migrena, neuropsychologia, zespół Alicji w Krainie Czarów, zaburzenia percepcji, mikropsja

Background

Alice in Wonderland Syndrome (AIWS) is a neurological condition characterized by distorted perception of size, time, and spatial relationships. Named after Lewis Carroll's novel, the syndrome can manifest in various ways, leading to significant impairment in daily functioning. This paper provides an extensive overview of AIWS, including its pathophysiology, clinical manifestations, potential etiologies, and management strategies. Quantitative data from various studies will be incorporated to highlight the syndrome's prevalence and demographic variations.

Introduction

Alice in Wonderland Syndrome (AIWS) is a complex neurological disorder characterized by transient perceptual distortions affecting sensory integration, body schema, and reality interpretation. First systematically described and named by John Todd in 1955 (Todd, 1955), the syndrome draws inspiration from Lewis Carroll's *Alice's Adventures in Wonderland*, whose protagonist experiences bodily and environmental size distortions mirroring patient reports. Carroll himself suffered from migraines with aura, suggesting potential personal insight into these phenomena (Podoll & Robinson, 1999; Blom, 2016). Earlier clinical observations of similar distortions, particularly in migraineurs, were documented by Lippman (1952).

Clinically, AIWS manifests through distinct symptom clusters: **Type A (Somaesthetic distortions)** including micro/macrosomatognosia (altered body part size), depersonalization, and altered time perception; **Type B (Visual distortions)** such as micro/macropsia (objects shrinking/enlarging), teleopsia/pelopsia (altered depth perception), and metamorphopsia (shape distortion); and **Type C** involving combined A and B symptoms (Lanska & Lanska, 2013; Mastria *et al.,* 2016). These episodes typically last minutes to hours, with a significant proportion (65.1%) reporting a temporal association with headaches (Liu *et al.,* 2014). While migraines are a frequent association, AIWS also arises from infections (notably Epstein-Barr virus, implicated in 68.4% of pediatric cases) (Abe *et al.,* 2018), epilepsy, strokes, or psychoactive substances (Blom, 2016). Neuroanatomically, dysfunction at the temporo-parieto-occipital junction (TPO-C), a critical hub for multisensory integration, is strongly implicated in symptom generation (Lanska & Lanska, 2013; Mastria *et al.,* 2016). Incidence remains difficult to ascertain due to diagnostic ambiguities and underreporting, but studies suggest a non-trivial prevalence: lifetime AIWS symptoms occur in 16.5% of migraine patients (Fitzek *et al.,* 2024) micropsia/macropsia specifically affect 6.5% of male and 7.3% of female adolescents (Weidenfeld & Borusiak, 2011), and only approximately 200 severe cases requiring medical intervention were documented between 1955 and 2016 (Blom, 2016).

Clinical manifestations

Symptomatology

The symptoms of AIWS can vary significantly among individuals, but commonly reported features include micropsia and macropsia – distortions in the perceived size of objects, leading to feelings of objects being smaller (micropsia) or larger (macropsia) than they actually are. A study by Fitzek *et al.,* (2024) found that 73% of patients reported micropsia as a primary symptom. Also, temporal distortion, which is altered perception of time, where time may feel accelerated or decelerated. This symptom is frequently reported in conjunction with visual distortions. The AIWS is characterised by derealization and depersonalization which often describe feelings of detachment from their environment or their own bodies, which can be distressing and contribute to anxiety. It is also worth mentioning other sensory distortions – individuals may experience altered perception of sound and touch, although these symptoms are less frequently reported.

The Mastria *et al.* (2016) classification system categorizes AIWS into three subtypes: Type A (somaesthetic distortions: 9% of cases), Type B (visual distortions: 75%), and Type C (mixed symptoms: 16%). This framework clarifies that visual distortions alone (Type B) represent the most common presentation, necessitating broader diagnostic criteria beyond somaesthetic symptoms. The numerical data they used came from previous studies (Lanska & Lanska, 2013).

Prevalence and demographics

There are no definitive prevalence estimates for Alice in Wonderland Syndrome (AIWS) in the general population reported in the current literature. However, one method of

approximation involves extrapolating from migraine data, as AIWS symptoms – particularly visual distortions such as micropsia and macropsia – are frequently associated with migraine, especially with aura. Migraine affects roughly 12% of the global population (Dong *et al.,* 2024). A recent large-scale study by Fitzek *et al.* (2024) reports a 16.5% lifetime prevalence of AIWS in adult migraine patients, with significantly higher rates in migraine-with-aura (19.5%) versus without aura (14.1%). Micropsia/telopsia (72.9%) and macrosomatognosia (49.6%) dominate symptom profiles, typically lasting ~30 minutes. Extrapolating from Fitzek *et al.* (2024), AIWS prevalence in migraineurs is 16.5%. Applied to the global migraine population (12%), this suggests a general population prevalence of ~2%, though true rates may differ significantly when other extrapolating approach is used. Considering that some publications report only 27% of AIWS cases involving migraines prior to diagnosis (Blom, 2016) (rather than 90% as in Mastria *et al.,* 2020), the higher estimate of the AIWS rates would be considered more likely. The condition is more commonly observed in children, particularly between the ages of 5 and 12 years. AIWS is likely underdiagnosed because patients (especially children) may fear stigma or lack vocabulary to describe bizarre symptoms. Clinicians might misinterpret symptoms as psychiatric (e.g., psychosis) without careful history-taking. This stresses the need for direct questioning about perceptual distortions (size, time, body image) in patients with migraines (especially with aura), epilepsy, or viral illnesses especially if accounting for Blom's finding that only 27% had prior migraine diagnosis.

Etiologies

Migraine-related AIWS

Migraine is the most common association with AIWS, with approximately 90% of patients reporting a history of migraine attacks (Mastria *et al.,* 2020). The mechanism underlying this association may involve shared neurobiological pathways, including cortical excitability and the modulation of neurotransmitter systems.

Other neurological conditions

AIWS can also occur in conjunction with other neurological disorders, for example epilepsy, which is shown in mentioned study that temporal lobe epilepsy has been linked to episodes of AIWS, particularly during ictal or postictal states (Matsudaira *et al.,* 2020).

Although primarily a neurological phenomenon, AIWS can coexist with psychiatric conditions, particularly anxiety and depression.

Stroke is an emerging etiology, with a 2025 case study linking macropsia to right parietal and left occipital chronic infarcts. Symptoms resolved with low-dose quetiapine, implicating vascular dysfunction in TPO-C pathways (Mbizvo *et al.,* 2025).

When it comes to neurodegenerative disorders, the first case of AIWS in dementia with Lewy bodies (DLB) (2025) reported object-size agnosia (micropsia) linked to right extrastriate cortex dysfunction, highlighting the role of visual associative areas in perception distortions (Demas, 2025).

Infections

Infectious diseases may also have an influence, because Conditions such as Epstein-Barr virus infections have been reported in some older cases of AIWS, suggesting a potential viral etiology (Ho *et al.,* 1992). More recently other infectious triggers were discovered. These include Zika virus and COVID-19, particularly in paediatric populations. These associations suggest viral-induced neuroinflammation disrupts TPO-C sensory integration (Brooks *et al.,* 2019; Hossain, 2020).

Implications for diagnostics

It is highly important to rule out acute neurological emergencies (e.g., stroke, encephalitis, brain tumours) and psychiatric conditions (e.g., schizophrenia, depersonalization-derealization disorder) using appropriate investigations (neuroimaging, EEG, labs) to avoid misdiagnosis. Certain features warrant urgent investigation.

These include: new-onset in adults, persistent/progressive symptoms, associated focal neurological deficits, altered consciousness or fever.

Pathophysiology

Neurological mechanisms

The pathophysiology of AIWS remains poorly elucidated, but several hypotheses have been proposed. Neuroimaging studies indicate that altered activity in the occipital and temporal lobes may contribute to the syndrome's symptoms. The visual processing areas, particularly the primary visual cortex (V1) and surrounding regions, are thought to be involved in the distorted perception of size and shape (Blom, 2016; Landais & Michelin, 2019).

Recent advances in neuroimaging (2020–2025) identify the temporoparietal-occipital carrefour (TPO-C) as a critical neural hub for AIWS. Hypoperfusion in this region – observed via SPECT and fMRI – disrupts multisensory integration, explaining the co-occurrence of dysmetropsia and body schema distortions (Mastria *et al.,* 2023; Mbizvo *et al.,* 2025). Cortical spreading depression (CSD), the mechanism underlying migraine aura, is directly linked to AIWS through biparietal hypoperfusion patterns during episodes, reinforcing shared pathophysiological pathways with migraine (Viganò *et al.,* 2020; Mastria *et al.,* 2023).

Cortical dysregulation

Alterations in cortical excitability, particularly in response to migraine-induced changes, have been observed. In individuals with migraines, there is evidence of increased cortical spreading depression, which may lead to transient disruptions in visual perception (Charles & Baca, 2013). The involvement of the temporal lobe is also significant, as this region is crucial for integrating sensory information.

Neurotransmitter systems

Several neurotransmitter systems may play a role in the manifestation of AIWS symptoms. Dopaminergic dysregulation has been implicated in perceptual disturbances, while serotonergic pathways may contribute to alterations in mood and cognition (Beh *et al.,* 2018). Additionally, disturbances in the gamma-aminobutyric acid (GABA) system may influence sensory processing and perception. Critically, dopaminergic/serotonergic dysregulation may modulate TPO-C excitability, potentiating CSD-induced perceptual disruptions (Beh *et al.,* 2018; Sprenger *et al.,* 2018).

Quantitative analysis

Epidemiological studies

Based on 169 case descriptions Blom, J. D. (2016) revealed that approximately 27.1% of patients had a history of migraines. The mean age of symptom onset was found to be 15.5 years, with a male-to-female ratio of approximately 1.25 : 1. In terms of symptom frequency, 58.6% of patients experienced micropsia and 45.0% experienced macropsia, indicating that these were the most commonly reported perceptual distortions. Epidemiological surveys in non-clinical populations also suggested that up to 30.3% reported at least one AIWS-like symptom during their lifetime, with some studies documenting 6-month prevalence rates for specific symptoms ranging from 1.3% to 3.9% among adolescents. Most recently, Fitzek *et al.* (2024) identified micropsia/telopsia as the most prevalent visual distortion (72.9%), followed by macrosomatognosia (49.6%), with episodes averaging 30 minutes – suggesting transient but clinically impactful disruptions.

Correlations with migraines

Research suggests a strong association between Alice in Wonderland Syndrome (AIWS) and migraines. A study by Liu *et al.* (2014) found that paediatric patients with AIWS often experienced more frequent migraines, with some reporting perceptual distortions before or during attacks. Similarly, Lanska & Lanska (2013) noted that AIWS symptoms frequently co-occurred with migraines, supporting the idea of shared pathophysiological mechanisms. One proposed explanation involves Cortical Spreading Depression (CSD), a wave of neuronal depolarization linked to migraine

aura (Hadjikhani *et al.,* 2001). CSD may trigger transient perceptual disturbances resembling AIWS, while dysregulation in serotonin and dopamine pathways – known to influence migraines – could further contribute to these phenomena.

Diagnostic criteria

Clinical assessment

The diagnosis of AIWS is primarily clinical, relying on detailed patient history and symptomatology. Neurological examinations, including neuroimaging and electrophysiological studies, are often utilized to rule out other conditions.

Diagnostic tools

Standardized scales for measuring the severity and frequency of symptoms, such as the Migraine Disability Assessment Scale (MIDAS) (Stewart *et al.,* 2001) and the Hamilton Anxiety Rating Scale (HAM-A), can aid in assessing the impact of AIWS on daily functioning. For providing an example, the MIDAS is in in the form of a questionnaire – people are asked to fill out the paper and then their answers are summed up as follows:

Table 1. MIDAS scale (Stewart *et al*., 2001).

MIDAS grade	Level of disability	MIDAS score
First	Little or no disability	0–5
Second	Mild disability	6–10
Third	Moderate disability	11–20
Fourth	Severe disability	21+

If the MIDAS score is higher than 6, the person should visit a doctor.

Management strategies

Management is primarily targeted at the underlying cause (migraine prophylaxis, epilepsy control, treating infection). Success therein often resolves AIWS.

Tiered approach

Suggested is a practical framework to follow in the management of the condition:

1. Rule out serious pathology.
2. Identify and treat primary trigger (Through: migraine, epilepsy, infection and psychiatric causes).
3. Add symptom-specific support: Pharmacological (if linked to primary trigger and severe) and Non-pharmacological (CBT/mindfulness for anxiety/coping, patient/family education) as first-line for distress.

Pharmacological interventions

Pharmacological management of AIWS primarily focuses on treating underlying conditions, such as migraines. There are some common medications involved in AIWS treatment. Triptans are first-line treatment for migraines and cluster headaches (Lew & Punnapuzha, 2023). They are effective for acute migraine relief, these medications can reduce the frequency of AIWS episodes in migraine sufferers. People use antidepressants as well, such as selective serotonin reuptake inhibitors (SSRIs) and tricyclic antidepressants which may alleviate anxiety and mood disturbances associated with AIWS and antiepileptics meaning medications such as lamotrigine and topiramate have shown promise in managing both epilepsy and associated perceptual disturbances (Sprenger *et al.,* 2018). Lacosamide shows efficacy in AIWS triggered by cortical venous thrombosis, while low-dose quetiapine resolves macropsia in post-stroke cases (Mbizvo *et al.,* 2025).

Non-pharmacological approaches

Cognitive behavioural therapy (CBT) represents a valuable psychological intervention for managing the distress and perceptual abnormalities associated with Alice in Wonderland Syndrome (AIWS). While AIWS itself is not

life-threatening, the profound perceptual distortions frequently induce significant anxiety, confusion, and distress. CBT, a structured and goal-oriented psychotherapy, equips individuals with AIWS to reframe maladaptive thoughts and behaviours triggered by these distortions. Specifically, cognitive restructuring helps patients challenge catastrophic interpretations of their experiences, while exposure techniques facilitate gradual adaptation to altered perceptions (Blom, 2016; O'Toole & Modestino, 2017). By developing these coping strategies, CBT reduces the emotional impact of symptoms and enhances emotional resilience. Furthermore, CBT effectively addresses common comorbidities like anxiety disorders and migraines, which often exacerbate AIWS symptoms (Hamed, 2010; Losada-Del Pozo *et al.,* 2011). Although CBT cannot eliminate the core perceptual distortions, its capacity to significantly reduce distress and improve quality of life is particularly crucial given the current lack of specific pharmaceutical treatments for AIWS. Treatment typically involves regular sessions, homework for skill practice, and a focus on identifying and modifying dysfunctional cognitions. While further research is needed to establish its precise efficacy for AIWS specifically, evidence supporting CBT for analogous perceptual and anxiety disturbances underscores its promise for managing the psychological sequelae of this syndrome.

Functional impact and quality of life

Alice in Wonderland Syndrome (AIWS) imposes significant functional impairment and reduced quality of life. In paediatric populations, educational performance is frequently disrupted by micropsia (Fitzek *et al.,* 2024) and spatial distortions (Liu *et al.,* 2014), with children avoiding classroom activities due to distress. Adults report occupational disability, including diminished work efficiency and safety risks during driving or machinery operation (Mastria *et al.,* 2020). Psychosocial burden is profound: >80% of patients experience anxiety about symptom misinterpretation as psychiatric illness, leading to social withdrawal (Mastria *et al.,* 2020; Beh *et al.,* 2018). Physical safety is compromised by falls from distorted depth perception (Fitzek *et al.,* 2024) and sleep disruption from nocturnal derealization (Landais & Michelin, 2019). Diagnostic delays exacerbate distress, with patients reporting inadequate validation of experiences (Blom, 2016). Standardized metrics confirm severe disability: migraine-associated AIWS patients score >21 on the MIDAS (indicating "severe disability") (Stewart *et al.,* 2001), exceeding typical migraine disability due to compounded distress from both headache and reality distortion (Fitzek *et al.,* 2024), while comorbid depression (present in 31% of vestibular migraine-related cases) amplifies QoL erosion (Beh *et al.,* 2018). Non-pharmacological interventions like CBT show promise in mitigating anxiety (Curtiss *et al.,* 2021), yet residual functional deficits often persist despite pharmacological management of underlying etiologies (Sprenger *et al.,* 2018).

Conclusion

AIWS represents a critical intersection of neurology and psychiatry, where transient but distressing perceptual distortions significantly impair quality of life despite the syndrome's non-life-threatening nature. The condition demonstrates distinct etiological patterns across age groups, with migraines constituting a primary trigger in adults while infectious processes frequently precipitate paediatric cases (Blom, 2016; Mastria *et al.,* 2016). Neuroanatomically, dysfunction within the temporo-parieto-occipital junction (TPO-C) provides the most compelling explanation for the syndrome's heterogeneous manifestations – from somaesthetic illusions to environmental dysmetropsia – given this region's role in multisensory integration (Lanska & Lanska, 2013; Mastria *et al.,* 2016).

Therapeutic emphasis must prioritize cognitive-behavioural therapy (CBT) as a cornerstone intervention for mitigating AIWS-related distress. By targeting catastrophic misinterpretations of perceptual anomalies

(e.g., "my shrinking hand indicates neurological deterioration") and comorbid anxiety, CBT builds essential emotional resilience in the absence of syndrome-specific pharmacotherapies (O'Toole & Modestino, 2017; Blom, 2016). Exposure techniques promote habituation to distortions, while cognitive restructuring disrupts symptom-triggered panic cycles (O'Toole & Modestino, 2017). Nevertheless, the evidence base remains constrained by limited AIWS-specific CBT studies, underscoring the need for randomized controlled trials. Efficacy data for both pharmacological and non-pharmacological interventions remain disproportionately scarce in paediatric populations, warranting age-stratified clinical trials.

Critical priorities for advancing the field include: 1) **Standardizing diagnostic criteria** to reduce reliance on subjective clinical recognition (Blom, 2016; Mastria *et al.,* 2016); 2) **Validating neuroimaging biomarkers** (e.g., temporal lobe perfusion deficits) to objectivize diagnosis (Mastria *et al.,* 2016); and 3) **Designing integrated protocols** that concurrently address primary pathologies (e.g., migraines) and perceptual distress. As Mastria *et al.* (2016) observed, AIWS epitomizes how "pathologies of sensory integration" necessitate multidisciplinary collaboration – uniting neurology, psychology, and patient education to effectively demystify this complex condition.

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Acknowledgments

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Books:

Rang, H. P., Dale, M. M., Ritter, J. M., Moore, P. K. Pharmacology. 5th Ed. Edinburgh: Churchill Livingstone; 2003, Phillips, S. J., Whisnant, J. P. *Hypertension and stroke. In: Laragh JH, Brenner BM, Editors. Hypertension: pathophysiology, diagnosis, and management.* 2nd Ed. New York: Raven Press; 1995. pp. 465–478.

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