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Content

Weronika Julia Gura, MSc. Eng. – 1st Prize of the XVIII Ed. PTIB Competition (2024)

MULTIFUNCTIONAL CHITOSAN-BASED HYDROGELS ENRICHED WITH BIOLOGICALLY ACTIVE SUBSTANCES

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Keywords: hydrogel, chitosan, bioactive glass, Schiff's base crosslinking, retinol, resveratrol

Abstract:

Motivation and Aim: Modern biomedical engineering continuously strives to develop innovative materials that can be applied in regenerative medicine and tissue engineering. Hydrogels based on biopolymers such as chitosan exhibit promising potential as biomaterials supporting tissue regeneration. The combination of chitosan with bioactive glass and the addition of biologically active substances such as retinol and resveratrol may further enhance their therapeutic properties. The aim of this study was to design and manufacture hydrogel materials based on chitosan and whey protein isolate, crosslinked with functionalized dextran and enriched with high-calcium bioactive glass, retinol, and resveratrol. The research focuses on assessing the impact of these components on mechanical properties, bioactivity, and the ability to release active substances, contributing to the development of advanced regenerative therapies.

Novelty: This study presents novel hydrogel materials based on chitosan and whey protein isolate, crosslinked with oxidized dextran and enriched with bioactive glass, retinol, and resveratrol. For the first time, a detailed investigation into the impact of these components on bioactivity, mechanical properties, and the controlled release of biologically active substances has been conducted. The results indicate the possibility of precisely modifying biomaterial properties, which could contribute to the advancement of modern tissue engineering therapies.

Methods: The hydrogels were obtained by crosslinking chitosan and whey protein isolate with functionalized dextran. These materials were produced in two forms: injectable hydrogels and lyophilized, highly porous three-dimensional scaffolds. Structural analysis was performed using FTIR spectroscopy and SEM-EDS microscopy. Mechanical properties were evaluated through compression and rheological tests. The bioactivity of the materials was assessed by incubation in simulated body fluid (SBF), while the controlled release of biologically active substances was analyzed using UV-VIS spectroscopy. Antioxidant

properties were determined using the ABTS• assay, and cytotoxicity and metabolic activity effects on RAW 264.7 and N2a cell lines were examined.

Main results: The obtained hydrogels exhibited high bioactivity and the ability to support mineralization in SBF solution. Bioactive glass improved the mechanical properties and structural stability of the materials, while resveratrol enhanced their antioxidant properties. The release profile of active substances depended on their concentration in the material, with higher concentrations of resveratrol leading to intensified release, whereas the effect for retinol was the opposite. High concentrations of resveratrol demonstrated cytotoxicity toward the tested cell lines, while bioactive glass improved cell viability and metabolic activity.

Conclusion: The results showed that the introduction of bioactive glass and biologically active substances significantly improved the therapeutic properties of the hydrogels. The materials demonstrated the ability to promote tissue regeneration, which was confirmed through tests on cell lines. Physicochemical analyses indicated adequate stability and structure of the hydrogels, and mechanical tests confirmed their suitability for medical applications.

The conducted studies confirmed that the developed hydrogels have significant potential as biomaterials for tissue engineering, particularly in bone and cartilage regeneration. Bioactive glass improved the mechanical parameters and bioactivity of the materials, while resveratrol exhibited strong antioxidant effects. Optimizing the concentration of active substances may enable controlled drug release and the customization of biomaterials for specific medical applications.z

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Julia Wilk, MSc. Eng. – 2nd Prize of the XVIII Ed. PTIB Competition (2024)

DEVELOPMENT OF A NEURAL NETWORK-BASED METHOD FOR ANALYZING MUSCLE INTERACTIONS IN BIOMECHANICS AND MEDICAL FIELDS

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Keywords: neural networks, electromyography, muscle cooperation, biomechanical simulations, machine learning

Abstract:

Motivation and Aim: This publication introduces a new approach for analyzing muscle cooperation using neural networks in biomechanics and medical applications. Various neural network models, including Echo State Networks (ESN), Long Short-Term Memory (LSTM), and recurrent neural networks, were utilized with electromyographic (EMG), kinematic, and dynamic data. The objective was to assess individual muscle contributions to overall muscle force production. The methodology involved training and testing neural networks on datasets representing lower limb muscle activity, predicting force generation, and validating results against biomechanical simulations in OpenSim. The findings highlight the potential of neural networks for accurate muscle function modeling, with applications in rehabilitation and sports injury prevention. This interdisciplinary approach connects machine learning with biomechanics, creating new avenues for research and practical use.

Novelty: Human movement is complex due to the intricate interactions between muscles, joints, and neural inputs. Understanding muscle cooperation is crucial in fields such as biomechanics, rehabilitation, and sports science. Conventional methods for modeling muscle behavior often depend on simplified mathematical models, like Hill-based muscle models, which struggle to accurately represent nonlinear interactions [1]. This publication combines neural network technology with biomechanical data to introduce a new approach for modeling muscle cooperation. By utilizing electromyography (EMG), kinematic, and dynamic data, this method aims to predict the individual contributions of muscles to overall muscle force generation.

Methods: The dataset used in this study was sourced from an open-access biomechanical repository [2], containing EMG signals, kinematic, and dynamic data from eight lower limb muscles. Preprocessing involved filtering the EMG signals, normalizing the kinematic data, and splitting the dataset into training and testing sets. Five different neural network architectures were evaluated: Echo State Networks (ESN), Long Short-Term Memory (LSTM), support vector machines (SVM), random forests, and regression models [3]. Training and testing were performed in MATLAB, with validation through biomechanical simulations in OpenSim. Error analysis focused on the absolute and relative differences

between the predicted and simulated forces. To assess generalizability, models were also tested on movements not part of the training set, such as knee lifts and stair descents [4].

Main results: The neural networks demonstrated varying degrees of accuracy in predicting muscle forces. Recurrent and LSTM models performed the best, especially in capturing the nonlinear relationships between EMG signals and muscle forces. While SVM and random forest models delivered satisfactory results, they faced challenges in generalizing to untrained movements. Error analysis showed that recurrent models were particularly effective in predicting complex movements, while LSTM models provided computational efficiency for real-time applications. The findings underscore the potential of neural networks to improve biomechanical modeling by providing accurate, non-invasive estimates of muscle activity. However, limitations include the need for high-quality input data and difficulties in generalizing the results to different populations.

Conclusion: This study illustrates the potential of using neural networks to model muscle cooperation in biomechanics. By integrating EMG, kinematic, and dynamic data with machine learning, a strong framework is established for analyzing muscle contributions to movement. The proposed method has practical applications in rehabilitation, allowing for personalized therapy plans, and in sports, enhancing training programs and injury prevention strategies. Future research should aim to expand the dataset to include a wider range of subjects and movements, improve model robustness, and explore real-time implementation possibilities.

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Martyna Myszograj, MSc. Eng. – Distinction of the XVIII Ed. PTIB Competition (2024)

ANALYSIS OF THE INFLUENCE OF THE BASAL GEOMETRY OF THE AUXETIC LAYER IN THE INTERVERTEBRAL DISC ENDOPROSTHESIS ON THE DISTRIBUTION OF STRESS AND STRAIN IN THE LUMBAR SPINE STRUCTURES

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Keywords: spine, intervertebral disc endoprosthesis, FEA, auxetics

Abstract:

Motivation and Aim: Diseases and injuries of the spine are increasingly common, with many cases requiring surgical intervention involving implants. Dynamic intervertebral disc endoprostheses offer the potential to preserve mobility in the implanted segment, thereby reducing the risk of postoperative complications such as adjacent segment disease. This study aims to design and evaluate an intervertebral disc endoprosthesis incorporating auxetic structures to improve its mechanical performance and reduce stress on spinal structures.

Novelty: The research explores the use of auxetic structures with different geometries in intervertebral disc endoprostheses. Unlike the designs with conventional structures, the study investigates how auxetic properties can influence stress and strain distribution, potentially leading to improved implant longevity.

Methods: The study included a literature review of the mechanical properties and biomechanics of the lumbar spine, the current state-of-the-art in auxetic structures, and experimental and numerical studies of auxetic structures used in biomedical engineering. In the design and research part, the design of an intervertebral disc endoprosthesis using auxetic structures with different basic geometries was proposed and numerical studies were carried out on the effect of the used geometry on the distribution of stresses and strains in the endoprosthesis structure and lumbar spine structures.

Main results: The analysis revealed that the honeycomb-type auxetic structure placed in the insert, due to the accumulation of stresses, is destroyed and thus fails to fulfill its role in the intervertebral disc endoprosthesis. In contrast, the use of a star-type auxetic structure presents a potential solution to the problem of overloading the anatomical structures of the spine after the implantation of an intervertebral disc endoprosthesis. The maximum stress value was

found to be located on the insert, specifically on the auxetic layer. This contrasts with the conventional endoprostheses, where the maximum stress occurs on the spherical part of the insert. The maximum stress value on the endoprosthesis (442.12 MPa) is higher than the values reported by other researchers. Nevertheless, the stress values do not exceed the yield strength of the material (908 MPa). The maximum stresses on the anatomical structures of the spine were found to be smaller than those reported in studies.

Conclusion: In conclusion, the honeycomb-type auxetic structure in the insert is unsuccessful due to stress accumulation, while the star-type auxetic structure offers a potential solution to reduce overloading of the spine after implantation. The maximum stress is concentrated on the auxetic layer, in contrast to conventional implants where it occurs on the spherical component. The findings suggest that incorporating star-type auxetic structures in intervertebral disc endoprostheses may positively influence the stress and strain distribution, potentially improving the longevity and functionality of the implant. The maximum stress (442.12 MPa) remains below the material's yield strength (908 MPa), thereby ensuring structural integrity. Additionally, the stress on the spine's anatomical structures is lower, indicating an improvement in implant performance.

Barbara Szaflarska, MSc. Eng. – Distinction of the XVIII Ed. PTIB Competition (2024)

THE INFLUENCE OF SIMULATED MICROGRAVITY ON CELLS CULTURED ON POLYMERIC SCAFFOLDS AND MICROSPHERES

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Keywords: Microgravity, tissue engineering, polymeric scaffolds, microspheres, PLGA, bone tissue

Abstract:

Motivation and Aim: Spaceflight poses a variety of dangers to the human body, among them radiation and microgravity. Adaptation to this harsh environment can cause serious health problems. One of the most threatening issues that astronauts experience during space missions is bone tissue deterioration. It is thought to be caused by the dysregulation between bone formation and resorption, resulting in tissue density loss, however, the exact mechanisms are still not fully understood. To study those effects, microgravity-simulating devices have been developed, although each of them introduces certain artifacts to the experiment. The aim of this study was to establish a protocol for studying MG-63 osteoblast-like cells cultured on polymeric scaffolds and microspheres in simulated microgravity conditions and to characterize their behavior.

Novelty: Research on skeletal changes in space is complicated by inconsistencies between studies and the limitations of *in vitro* models of the isolated cells. Since extracellular matrix (ECM) influences cellular responses to microgravity, incorporating scaffolds mimicking bone tissue can provide more accurate insights into bone adaptation in space.

Methods: The study includes preparation of the scaffolds and microspheres made from poly(L-lactide-coglycolide)(PLGA), characterization of their properties, and experiments on osteoblast-like MG-63 cells in simulated microgravity conditions on a random positioning machine (RPM) in terms of their morphology, viability, and proliferation. Cell morphology was examined using scanning electron microscopy (SEM), while cell viability was evaluated using the Alamar Blue assay and live/dead fluorescence staining. Moreover, the cytotoxicity of the system was assessed by measuring lactate dehydrogenase (LDH) release. Additionally, pH of the culture medium was measured as a function of culture time.

Main results: Three experiments were performed and, as a result, a protocol for culturing MG-63 osteoblast-like cells on PLGA biomaterials on the RPM was successfully established. The study showed that cells remained viable up to 7 days of culture in simulated microgravity conditions, both on scaffolds and microspheres. Cells cultured on the microspheres exhibited weak adhesion to their surfaces but preferentially formed spheroids. Moreover, cells in the samples exposed to the RPM demonstrated increased metabolic activity; although, these conditions also resulted in higher cytotoxicity. This finding suggests greater cell activity and proliferation under RPM conditions.

Conclusion: The study demonstrated that the development of material-cell constructs based on PLGA scaffolds and osteoblast-like cells can serve as a research model for assessing the impact of microgravity on bone tissue.

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Malwina Furgała, MSc. Eng. – Distinction of the XVIII Ed. PTIB Competition (2024)

MULTIFUNCTIONAL ALGINATE-BASED CAPSULES FOR THERANOSTIC APPLICATIONS

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Keywords: theranostics, hollow hydrogel capsules, silver nanoparticles, magnetic-core particles, cancer treatment

Abstract:

Motivation and Aim: Cancer remains one of the leading causes of death worldwide, and the therapy of this disease has been a significant challenge [1]. Conventional treatment methods, such as chemotherapy and radiotherapy, often lack specificity, leading to side effects and damage to non-cancerous tissues. Therefore, there is a pressing need for more specific and efficient therapeutic approaches. Theranostics represents a new paradigm that integrates therapeutic and diagnostic modalities within a single system, providing an appealing alternative [2]. The aim of the research was to develop, synthesize, and assess innovative multifunctional particles with potential theranostic applications. Two types of materials were researched in this study: hollow hydrogel capsules and magnetic-core nanoparticles, both functionalized with metal nanoparticles to enhance therapeutic efficacy.

Novelty: This work presents the fabrication of silver or copper alginate multifunctional hydrogel capsules through a template-assisted synthesis pathway utilizing calcium carbonate particles. Furthermore, iron oxide nanoparticles were synthesized and subsequently coated with silver or copper alginate, achieving a novel integration of diagnostic and therapeutic capabilities. In comparison to traditional drug delivery systems, these materials facilitated controlled release, improved targeting, and potential imaging in the future, positioning themselves as promising candidates for next-generation cancer treatments.

Methods: Multifunctional alginate-based capsules were synthesized using calcium carbonate templates and further modified with silver or copper (*Fig.1*). Moreover, iron oxide nanoparticles were developed and coated with either silver or copper alginate. The obtained materials were characterized through scanning electron microscopy (SEM), transmission electron microscopy (TEM), and Fourier-transform infrared spectroscopy (FTIR). *In vitro* cytotoxicity studies were performed to assess their biocompatibility and anticancer properties.

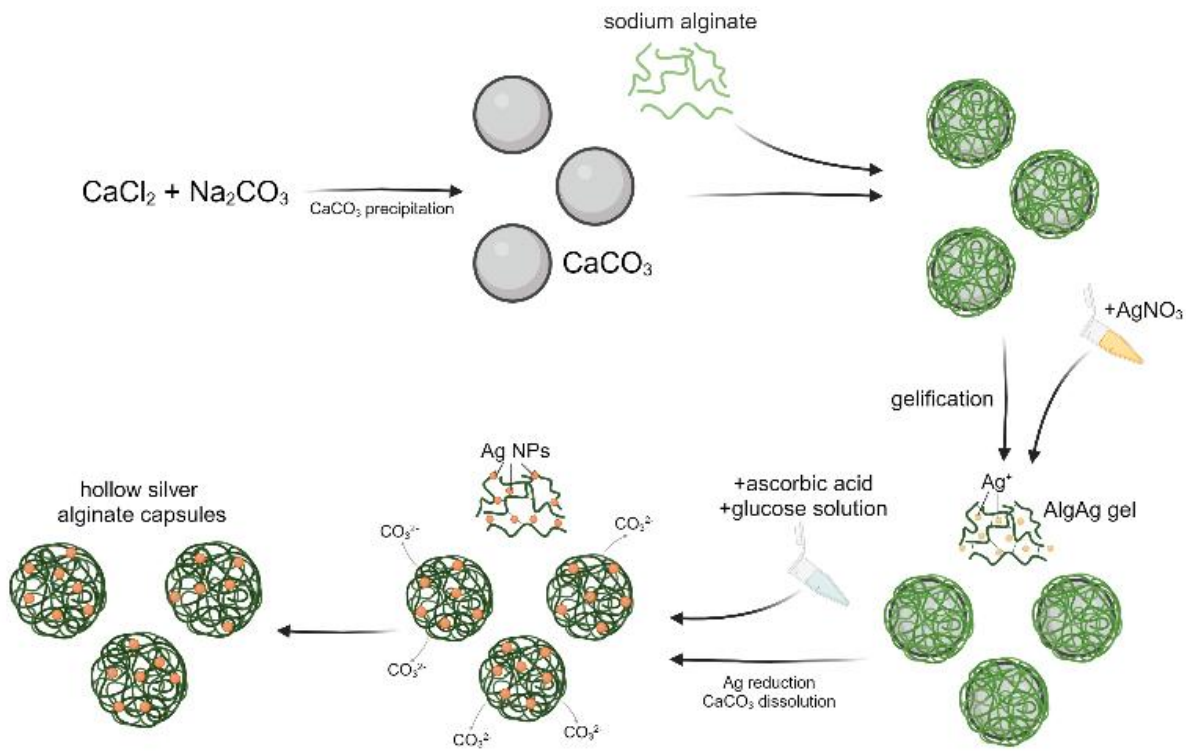

Fig.1 Fabrication process of silver alginate hydrogel capsules

Main results: The structural and physicochemical characterization confirmed the successful fabrication of hydrogel capsules and hydrogel-coated iron oxide nanoparticles. The capsule size was controlled by adjusting the size of the calcium carbonate sacrificial templates, which were produced either by regular mixing or ultrasonication. Metal-alginate hybrid structures were formed through reduction of silver nitrate/copper sulfate with the use of ascorbic acid. Silver alginate hydrogel capsules demonstrated the highest anticancer efficacy. Magnetic-core nanoparticles coated with copper alginate also exhibited promising results, suggesting their potential for further investigation in theranostic applications.

Conclusion: The present study demonstrated the potential of multifunctional hydrogel capsules and magnetic-core nanoparticles as effective theranostic agents for cancer treatment. Among the tested materials, silver alginate hydrogel capsules emerged as the most promising candidate. Nevertheless, copper alginate-coated magnetic-core nanoparticles also revealed considerable potential, and therefore additional studies aimed at optimization and *in vitro* validation are justified.

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Kamil Kwarciak, MSc. Eng. – Distinction of the XVIII Ed. PTIB Competition (2024)

UNSUPERVISED SEGMENTATION OF DEFECTIVE SKULLS IN VOLUMETRIC DATA BY USING DEEP NETWORKS DEDICATED TO MODALITY TRANSFER

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Keywords: Generative artificial intelligence, Deep learning, Modality translation, Synthetic data

Abstract:

Motivation and Aim: Skull segmentation from MR images is a crucial yet challenging task in modern computational medicine. MRI primarily focuses on soft tissues rather than bone structures, making direct skull segmentation difficult. While CT imaging provides well-established skull segmentation techniques, its radiation exposure poses health risks, highlighting the need for an MRI-based approach. This study aims to develop an unsupervised skull segmentation methodology by leveraging modality translation techniques. By converting MR images into synthetic CT representations, this approach enables effective skull segmentation without requiring labeled MR data, addressing both clinical and computational challenges.

Novelty: This study introduces a novel approach to MRI-based skull segmentation by transforming the problem into a modality translation task, followed by CT-based segmentation. Unlike traditional supervised methods that rely on annotated MRI datasets, presented method leverages deep generative models such as generative adversarial networks, denoising diffusion models, and contrastive learning techniques to achieve unsupervised segmentation. Additionally, integration of the super-resolution strategy addresses the lower resolution of MRI compared to CT, ensuring high-quality segmentation results. This methodology not only surpasses existing supervised methods but also outperforms a cutting-edge foundation medical segmentation model and other modality translation techniques.

Methods: This study employs an unsupervised skull segmentation pipeline that leverages modality translation techniques to convert MR images into synthetic representations. A diverse set of deep generative models is explored, including generative adversarial networks (GANs), denoising diffusion models, and contrastive learning methods. Once MR images are transformed into their CT counterparts, well-established CT-based segmentation techniques are applied. Additionally, a super-resolution approach is integrated to compensate for the lower resolution of MRI data, ensuring high-quality segmentation suitable for clinical applications.

Main results: The proposed methodology outperforms traditional supervised segmentation methods, demonstrating superior accuracy and robustness in MRI-based skull segmentation. It also surpasses a state-of-the-art foundation medical segmentation model and outperforms existing modality translation techniques. The integration of super-resolution further enhances the quality of segmentation, addressing the limitations of MRI's lower resolution. Additionally, ablation studies highlight the effectiveness of MR-to-CT translation for unsupervised skull segmentation, showcasing its potential in applications such as infant skull imaging and defective skull reconstruction. These results establish the proposed approach as a significant advancement over conventional segmentation techniques.

Conclusion: This study presents a novel unsupervised approach to MRI-based skull segmentation by leveraging modality translation techniques, transforming the problem into a more manageable CT-based segmentation task. The proposed methodology outperforms traditional supervised methods and state-of-the-art segmentation models while maintaining fast inference for volumetric data. Additionally, the integration of super-resolution ensures high-quality segmentation, addressing the resolution gap between MRI and CT. The results demonstrate the potential of MR-to-CT translation for broader applications, such as infant skull imaging and defective skull reconstruction, opening new research area in computational medical imaging.

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Anna Maria Berent, MSc. Eng. – Distinction of the XVIII Ed. PTIB Competition (2024)

COMPUTER METHODS TO SUPPORT DIAGNOSIS AND THERAPY OF SCOLIOSIS USING SPINAL RADIOGRAMS AND CLINICAL DATA

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Keywords: adolescent idiopathic scoliosis (AIS), diagnosis support, treatment support, Cobb angle, mobile app, radiogram, deep neural networks

Abstract:

Motivation and Aim: This work focuses on supporting the diagnosis and treatment of scoliosis. The motivation for choosing this topic stems from the author's personal experience with adolescent idiopathic scoliosis (AIS) and interest in technological solutions that support medicine. AIS affects 2-3% of the population and accounts for 80% of all scoliosis cases. It is a three-dimensional deformity of the spine, characterized by a lateral curvature greater than 10 degrees, often accompanied by vertebral rotation. The progression of the disease is typically assessed through Cobb angle measurements on radiographs. Since these measurements form the basis for diagnosis and treatment decisions, including invasive scoliosis correction surgery, they should be as reliable and efficient as possible.

This study challenges the assumption that Cobb angle measurement is the most critical factor in scoliosis diagnosis and treatment. The goal was to develop an effective support system for scoliosis patients by addressing broader needs beyond Cobb angle measurement, focusing on improving communication and access to reliable information.

Novelty: A literature review highlighted the need for increased accuracy and repeatability of Cobb angle measurements. However, it also revealed a lack of access to databases that could facilitate the verification and improvement of measurement methods. While many studies emphasize the importance of Cobb angle measurement, this work identifies a gap in understanding its practical significance in clinical settings.

Interviews with doctors who regularly perform Cobb angle measurements revealed that, in practice, the accuracy of this measurement is not the primary concern. Instead, it is just one of several important factors considered when assessing scoliosis, alongside body balance and the overall clinical evaluation. A physiotherapist specializing in scoliosis treatment confirmed these findings, emphasizing that X-ray examinations should be viewed as part of a broader treatment process.

To incorporate the perspectives of patients and their families, a pilot survey was conducted among 23 individuals affected by scoliosis (18 patients and 5 parents). The results indicated that the most significant area requiring support is communication – both between patients and specialists and among patients themselves. Additionally, access to reliable information about scoliosis emerged as a key concern.

This study ultimately concludes that the most critical aspect of scoliosis diagnosis and treatment is not just improving Cobb angle measurement accuracy but rather enhancing communication and access to trustworthy information for patients.

Methods: To address these identified needs, a comprehensive approach was taken. The study involved: **a literature review** to examine existing methods and their limitations, particularly regarding Cobb angle measurement; **interviews with specialists**, including doctors and physiotherapists, to understand the real-world importance of Cobb angle measurement and the broader diagnostic and therapeutic proces; **a pilot survey** conducted with scoliosis patients and their families to determine their primary concerns and needs.

Based on these findings, a **mobile application concept** was developed to comprehensively support scoliosis patients by improving access to information and communication with specialists.

Main results: As a response to the identified needs, a mobile application named **"SKOLIOŻApka"** was designed. The app serves as a comprehensive support tool for scoliosis patients by offering: reliable information about scoliosis, a database of specialists recommended by patients, personal stories from other patients to provide emotional suport, tools to help patients accept their appearance, a platform for improved communication between patients and specialists, as well as among patients themselves.

Additionally, the app is planned to include **automatic Cobb angle measurement** with accuracy comparable to manual methods and will allow a smartphone to function as a scoliometer.

Conclusion: The paper confirms that while improving Cobb angle measurement accuracy is important, a more pressing need exists in supporting patient-specialist communication and access to reliable scoliosis-related information. The findings justify the development and implementation of the proposed mobile application, which aligns with the needs identified through literature analysis, specialist interviews, and patient surveys.

If the application is to be further developed, enhancements will be necessary, including refining its graphical interface and adding additional functionalities. Collaboration between the app administrator, patients, and specialists will be crucial to ensure its effectiveness.

Future research should also explore **new solutions** that directly support medical professionals, such as: automating the analysis of X-ray images, including Cobb angle measurement and body balance parameters, developing more precise methods for assessing spinal curvature and establishing new clinical guidelines for scoliosis treatment.