A close-up of a person

Description automatically generated

**MACHINE LEARNING AND CONTENT ANALYTICS**

**2023**

A logo with blue and white text

Description automatically generated

*MuraMed: A new approach to X-Rays*

**Team Members:**

|  |  |
| --- | --- |
| **Name** | **A.M.** |
| **Dimitra Diamanti** | **f2822209** |
| **Dimitrios Matsanganis** | **f2822212** |
| **Foteini Nefeli Nouskali** | **f2822213** |
| **Hegla Ruci** | **f2822219** |

**September 2023, Athens**

# Abstract

# Contents

[Abstract 2](#_Toc144844937)

[Contents 2](#_Toc144844938)

[Table of Figures 2](#_Toc144844939)

[B. Technical Implementation 16](#_Toc144844940)

[Technical Implementation Plan: A Detailed Roadmap 16](#_Toc144844941)

[A. Data Architecture 17](#_Toc144844942)

[Get to know the MURA Dataset 17](#_Toc144844943)

[B. Algorithm Development 18](#_Toc144844944)

[Optimization Procedures 18](#_Toc144844945)

[Justification for the Choice of Convolutional Neural Networks (CNNs) 19](#_Toc144844946)

[Why CNNs Are Preferable 20](#_Toc144844947)

[Additional Decisions/Procedures Followed 21](#_Toc144844948)

[C. Software Integration 22](#_Toc144844949)

[D. Quality Assurance 22](#_Toc144844950)

[E. Deployment 22](#_Toc144844951)

[Bibliography 23](#_Toc144844952)

# Table of Figures

***No table of figures entries found.***

**MuraMed Application Fields & Industries:**

**Introduction: Transforming Medical Diagnostics with AI**

In today's complex healthcare landscape, precise and timely diagnostics are of utmost importance. MuraMed, a leading healthcare technology company, is poised to revolutionize the medical field by addressing the critical need for accurate and efficient diagnosis. Our focus is on radiographs (images produced using X-Rays), which play a pivotal role in diagnosing and monitoring various medical conditions. However, interpreting these images can be challenging, potentially leading to misdiagnoses and inappropriate treatment plans.

**Specialization in Bone Abnormality Detection**

At MuraMed, we specialize in the detection of bone abnormalities. Our team has developed an AI-powered diagnostic system tailored to assist radiologists and healthcare professionals in identifying irregularities in bone X-ray images. Our primary objective is to enhance the accuracy, efficiency, and speed of diagnosing musculoskeletal issues, ultimately leading to improved patient well-being.

**AI-Powered Radiology Revolution**

We recognize that adopting cutting-edge technologies is crucial for optimizing patient care and operational efficiency. By utilizing the capabilities of Artificial Intelligence (AI), MuraMed is at the forefront of revolutionizing radiology and X-ray imaging. One of the significant challenges faced by healthcare facilities, radiologists, and orthopedic doctors is the timely and precise identification of issues in X-ray images. Conventional methods, though effective, can be slow and prone to human errors. Our AI-driven solution not only speeds up the diagnosis process but also enhances its accuracy. This empowers healthcare providers to make well-informed decisions swiftly, ensuring the best possible patient care.

**Versatility for All Healthcare Providers**

MuraMed's application is designed with versatility in mind. It caters not only to seasoned medical professionals but also to individuals outside the traditional medical realm. We understand the critical importance of early detection and intervention. Our platform seamlessly integrates into various environments and can be used by athletes, teachers, physiotherapists, and other non-medical personnel. This accessibility facilitates quicker identification of potential bone abnormalities, even in settings where immediate medical expertise might not be readily available. By democratizing the diagnostic process, MuraMed extends the benefits of our innovative technology beyond hospitals and clinics, promoting a proactive approach to health and well-being in diverse communities.

**Mura Datasets: Powered by Stanford University**

**A red rectangular sign with white text

Description automatically generated**

In our pursuit of these objectives, MuraMed relies on extensive datasets established by Stanford University, collectively known as the MURA datasets. These datasets encompass a vast collection of musculoskeletal radiographs, constituting a comprehensive library of bone X-rays specifically focusing on different body parts like the wrist, shoulder, elbow, hand, finger, forearm, and humerus. Radiologists have manually reviewed and labeled each study as either 'Normal' or 'Abnormal.'

A diagram of the bones of the arm

Description automatically generated

Currently, our algorithms are designed to focus on the aforementioned body parts. Their primary task is to determine whether an X-ray study of these areas exhibits normal or abnormal characteristics. In the near future, we plan to expand our AI capabilities to involve a broader spectrum of anatomical regions , further enhancing our diagnostic capabilities.

**Our Μission: Global Impact and Enhanced Healthcare Access**

Musculoskeletal conditions affect over 1.7 billion people worldwide, often leading to severe, long-term pain and disability. This results in approximately 30 million emergency department visits annually, a number that's on the rise. Our mission is to utilize our dataset to drive significant progress in medical imaging technologies, enabling expert-level. This, in turn, will help improve healthcare access in regions where skilled radiologists are in short supply.

With MuraMed's AI-powered diagnostic system and our commitment to advancing medical diagnostics, we aim to make a meaningful impact on healthcare, enhancing patient outcomes, and promoting better well-being across the globe.

**Our Vision: Expanding Radiological Excellence for All**

At MuraMed, our vision is to make advanced radiological diagnostics accessible to healthcare facilities of all sizes, from large hospitals to smaller clinics. Moreover, our target audience extends beyond medical professionals, encompassing teaching personnel, fitness centers, athletes, and workplaces. We extend our reach beyond medical professionals to include teaching personnel, fitness centers, athletes, and other relevant sectors. Our goal is to equip healthcare providers and individuals with AI tools that elevate their diagnostic capabilities, offering reliable support and ensuring precise and timely diagnoses, even in complex cases.

**Value of MuraMed's Research**

MuraMed's research holds immense value in several key areas, bringing significant benefits to healthcare, technology, business, and innovation. Here, we outline the fundamental aspects of how our research positively impacts these domains, showcasing our dedication to enhancing patient care, technological capabilities, business growth, and medical advancement.

**Clinical Excellence:**

1. **Improved Diagnostic Precision:** MuraMed's AI-driven approach enhances the accuracy of identifying musculoskeletal issues in X-ray images. This means more precise diagnoses, timely treatments, and better patient outcomes. Our technology can detect even subtle abnormalities, reducing the risk of misdiagnosis.
2. **Efficiency and Speed:** MuraMed speeds up the diagnostic process for healthcare professionals. This helps reduce patient waiting times and simplifies treatment planning. With our AI system, radiologists can review X-rays more quickly, ensuring patients receive timely care.
3. **Early Issue Identification:** MuraMed plays a crucial role in detecting problems at an early stage. This can prevent complications, lower treatment costs, and improve overall patient well-being. Timely identification of musculoskeletal issues allows for less invasive treatments and better recoveries.
4. **Tailored Treatment:** MuraMed provides insights that enable personalized treatment plans. This ensures that each patient receives the most suitable care and perosnalized recommendations based on individual conditions, facilitating targeted interventions.
5. **Resource Optimization:** Our system automates the initial screening of X-ray images, allowing radiologists to focus on more complex cases. This improves the efficiency of patient care by utilizing resources more effectively.

**Technological Advancements:**

1. **Accessible Diagnostics:** MuraMed's innovations overcome geographical barriers, providing top-tier musculoskeletal diagnostics via telehealth, even in remote areas. This ensures that patients in isolatedregions have access to high-quality medical expertise.
2. **Supporting Healthcare Professionals:** Our AI serves as a reliable decision-support tool for healthcare providers, boosting their confidence in diagnoses. MuraMed's AI offers suggestions and insights that aid healthcare providers in their decision-making process.
3. **Reliability and Precision:** MuraMed's deep learning models ensure reliable interpretations and minimize errors, especially in more complex cases. The consistency and precision of our AI-powered system lead to more dependable diagnoses.
4. **Scalability:** Once validated, MuraMed's model easily integrates into various healthcare systems, addressing gaps in medical services. Our technology can adapt effectively to different healthcare infrastructures, ensuring broader access to advanced diagnostics.

**Business Growth:**

1. **Competitive Edge:** Healthcare organizations that embrace MuraMed gain a technological advantage, setting new benchmarks in patient care. Our innovative solutions enhance their ability to provide high-quality healthcare services, giving them a competitive edge in the industry.
2. **Financial Strengthening:** MuraMed offers monetization opportunities such as subscription models and partnerships with corporations, which strengthen the financial position of healthcare institutions. These revenue streams enhance their financial resources for continued growth and investment.
3. **Streamlined Operations:** MuraMed effectively integrates with existing hospital systems, streamlining their healthcare operations. This integration optimizes the healthcare value chain, ensuring that processes run efficiently and resources are utilized effectively.
4. **Market Expansion:** Our versatile solutions extend beyond healthcare to sectors like sports and education, extending the reach of our technology. This expansion into diverse fields not only broadens market access but also fosters institutional growth and development.

**Research and Innovation:**

1. **Advancing Medical Science:** MuraMed's efforts have the potential to drive technological progress in radiology and deep learning, contributing to advancements in medical diagnostics. Our commitment to research and innovation leads to improved healthcare solutions and better patient outcomes.
2. **Collaborative Innovation:** Collaboration among data experts, engineers, and clinicians at MuraMed promotes a multidisciplinary approach. This collaborative environment paves the way for future innovations, where insights from various fields come together to create groundbreaking solutions.
3. **Continuous Improvement:** MuraMed remains dedicated to ongoing research and development. Our focus on continuous improvement ensures that our solutions remain innovative, delivering benefits to both healthcare providers and patients.
4. **Enhanced Data Security:** With a strong emphasis on data security and privacy, MuraMed continually innovates to protect patient information. Our robust data security measures set industry standards for safeguarding sensitive medical data.
5. **Global Impact:** MuraMed's commitment to innovation has strong potential to extend globally, encouraging international collaboration and the exchange of medical insights. This global perspective contributes to a more comprehensive understanding of healthcare challenges and solutions.

**Key Pillars:**

MuraMed is built upon a foundation of three key pillars that define its scope and impact in the specialized field of musculoskeletal radiograph analysis. These pillars represent diverse domains, each with its unique set of challenges and opportunities for analyzing musculoskeletal radiographs of the hand, elbow, and shoulder. Together, they form the core focus areas of MuraMed's application and illustrate its versatility in addressing the diagnostic needs of various sectors within the realm of musculoskeletal healthcare.

These key pillars encompass the realms of:

1. **Healthcare (Medicine/Hospitals)**
2. **Sports Organizations & Schools**
3. **Workplace (Private Organizations for employees' health)**

showcasing MuraMed's commitment to revolutionizing musculoskeletal healthcare across multiple industries while emphasizing its specialization in hand-related radiograph analysis.

**MuraMed: Healthcare Edition, an AI-Assisted Musculoskeletal Radiograph Analysis Platform**

MuraMed's first pillar encompasses the world of traditional medicine and healthcare facilities, focusing exclusively on musculoskeletal radiograph analysis of the hand, elbow, and shoulder. By leveraging advanced deep learning techniques, this solution offers an unparalleled diagnostic tool for radiologists and orthopedic doctors, ensuring timely, accurate, and efficient detection of musculoskeletal abnormalities. Here, MuraMed provides invaluable support to radiologists and orthopedic professionals, offering an AI-backed second opinion that enhances diagnostic accuracy within these specific areas. Its seamless integration with hospital systems ensures that diagnostic services are optimized, enabling timely and accurate detection of musculoskeletal abnormalities within the medical domain.

**Key Features**MuraMed's key features empower musculoskeletal health analysis with a comprehensive suite of capabilities:

* **Diagnostic Support:** MuraMed offers professionals an invaluable AI-backed second opinion, significantly enhancing diagnostic accuracy. It does so by carefully spotlighting potential areas of concern in radiographs, providing crucial insights for healthcare providers.
* **Telemedicine Capabilities:** In regions where specialized radiologists may be scarce, MuraMed steps in with its telemedicine capabilities. This functionality ensures that diagnostic services can extend their reach even to the most remote corners, guaranteeing access to essential healthcare resources.
* **Seamless PACS Integration:** MuraMed's integration with existing hospital systems is seamless and efficient. Upon radiograph upload, it delivers instantaneous analysis, optimizing the diagnostic process and minimizing delays in patient care.
* **Adaptive Learning:** With each deployment, MuraMed evolves and adapts. Drawing from diverse datasets, it refines its diagnostic capabilities continually. This commitment to adaptive learning ensures that MuraMed maintains and improves its accuracy and reliability in musculoskeletal health analysis, providing state-of-the-art diagnostic support.

**Monetization Strategies for Sustainable Healthcare**

In line with our commitment to revolutionizing musculoskeletal healthcare through MuraMed's Healthcare Edition, we have devised a set of monetization strategies designed for sustainability. These strategies ensure that healthcare professionals, clinics, and institutions can access MuraMed's cutting-edge AI-assisted musculoskeletal radiograph analysis platform effectively and efficiently. Below, we outline our structured approaches:

* **Diverse Subscription Models:** MuraMed offers a versatile range of subscription options, each thorough tailored to meet the specific needs of hospitals, clinics, and individual healthcare practitioners. These subscription plans guarantee unfettered access to MuraMed's robust AI diagnostic capabilities. Whether you're a large medical facility or a solo practitioner, our flexible subscription models ensure accessibility and affordability.
* **Pay-Per-Use Convenience:** For those seeking a more flexible arrangement, MuraMed provides a pay-per-use model, perfect for occasional or smaller healthcare establishments. This pay-as-you-go approach allows you to harness MuraMed's diagnostic power precisely when needed, without any long-term commitment.
* **Customized Model Training and Implementation:** MuraMed goes the extra mile by offering bespoke model training, fine-tuning, and implementation services. This tailored approach ensures that MuraMed's AI algorithms are precisely calibrated to match the unique demographics and equipment types of each user. The result? The most accurate and relevant diagnostic insights, making MuraMed an invaluable, adaptable, and cost-effective solution within the healthcare landscape.

These monetization strategies empower healthcare providers with the flexibility to choose the most fitting plan, ultimately ensuring sustained access to MuraMed's advanced musculoskeletal radiograph analysis capabilities.

**Potential Challenges**

Navigating the healthcare tech landscape demands a methodical approach. Adhering to regulatory guidelines, ensuring robust data privacy measures, and fostering a close-knit collaboration with medical professionals are of prime importance. This ensures MuraMed is technologically robust while also catering to the practical needs of its user base. Additionally, a potential challenge lies in the fact that MuraMed's focus is solely on musculoskeletal radiograph analysis of the hand, elbow, and shoulder, limiting its scope to these specific areas and potentially necessitating collaboration with other solutions for radiographs of different body parts.

***Understanding PACS in the Context of MuraMed (subsection under PACS)***

Since MuraMed seeks to revolutionize the domain of musculoskeletal radiography. By harnessing the capabilities of cutting-edge deep learning methodologies, we present an unmatched diagnostic aid for radiologists and orthopedic specialists, ensuring prompt, precise, and efficient identification of musculoskeletal irregularities.

To be more precise, Picture Archiving and Communication System (PACS) is a medical imaging technology that provides economical storage and convenient access to images from various modalities. It's a synergy of hardware, software, and networking solutions that enables the capture, distribution, and display of medical images. PACS eradicates the need for tangible film, offering clinicians the advantage of remote access to view and diagnose from any location (*See the pictures below*).

A diagram of a computer

Description automatically generated

Figure X: The pathways of PACS: The foundational structure enabling MuraMed's seamless integration and rapid analysis within hospital systems.

A diagram of a computer system

Description automatically generated

Figure X: Streams of data flow: A visualization of the PACS network, channeling radiographic information to MuraMed for AI-assisted diagnostics.

**Additional Applications in Healthcare Landscape**

Beyond its primary applications, MuraMed's Healthcare Edition extends its versatile capabilities to a range of additional healthcare settings, redefining musculoskeletal health management across diverse healthcare landscapes:

**Primary Care Clinics**

MuraMed can be integrated into primary care settings, enabling general practitioners to identify potential musculoskeletal issues, especially those concerning the hand, elbow, and shoulder, and provide appropriate referrals to specialists. This capability ensures that patients presenting with hand-related discomfort or injuries can receive timely and accurate assessments, leading to swift referrals to orthopedic specialists or radiologists for further evaluation and treatment planning.

The application of MuraMed in this context revolves around its assistance to general practitioners in identifying potential musculoskeletal abnormalities during routine check-ups. The reason for this integration is clear: early detection is pivotal. It leads to timely referrals to specialists, ensuring that patients, especially those with hand-related issues, receive the comprehensive care they need. This proactive approach enhances the healthcare experience, offering patients timely access to the expertise of orthopedic specialists and radiologists, ultimately contributing to better musculoskeletal health and overall well-being.

**Elderly Care Facilities**

As the elderly population grows, MuraMed can play a vital role in detecting musculoskeletal issues, including hand injuries, in geriatric patients, aiding in early intervention and improving their quality of life. This capability is especially significant in addressing the unique healthcare needs of elderly individuals, where musculoskeletal concerns, such as hand injuries, can have a substantial impact on their daily lives and mobility**[**[**13**](#_44sinio)**]**. By incorporating MuraMed into the healthcare protocols of elderly care facilities, healthcare providers can ensure that geriatric patients receive timely attention and tailored care plans, ultimately enhancing their well-being and maintaining their independence.

MuraMed finds a valuable application in elderly care facilities through regular musculoskeletal screenings for elderly residents, aiming to detect issues like hand fractures, shoulder joint degeneration, or elbow osteoporosis. The reason behind this application is clear: early detection leads to prompt treatment and interventions. By identifying these musculoskeletal concerns at their nascent stages, healthcare providers can proactively prevent falls and other related accidents, ultimately leading to an improved overall quality of life for the elderly residents. This approach not only enhances their well-being but also contributes to the safety and comfort of the care facility as a whole.

**Physical Therapy Centers**

MuraMed's utility extends beyond diagnostics, providing an essential tool for physical therapists working with patients recovering from hand and shoulder injuries. As referenced in studies addressing the prognosis and treatment of shoulder pain[[14](#_44sinio)], the challenges in managing shoulder conditions have been well-documented. With MuraMed's focus on musculoskeletal radiograph analysis of the hand, shoulder, and elbow, physical therapists can leverage real-time insights to track patients' progress during therapy. This not only aligns with the need for more efficient targeting of shoulder pain treatments but also allows therapists to modify treatment plans and exercises promptly, optimizing rehabilitation outcomes[[15](#_44sinio)] and improving patient care.

Integrating MuraMed's AI into physical therapy sessions serves as a groundbreaking approach to shoulder and hand injury management. Real-time insights offered by MuraMed enable therapists to closely monitor patients' progress and tailor treatment plans specifically to their unique needs, as recommended by recent studies [[14](#_44sinio)], [[15](#_44sinio)]. This dynamic adjustment of rehabilitation strategies, based on accurate and real-time diagnostic information, not only aligns with the evolving landscape of musculoskeletal healthcare but also promises to significantly enhance the quality of rehabilitation and patient outcomes.

**Chiropractic Clinics with a Specialization in Hand Care**

Chiropractic professionals specializing in hand, elbow, and shoulder care can harness MuraMed's insights to offer highly tailored treatment plans for their patients. The specificity of MuraMed's diagnostic capabilities aligns seamlessly with the intricate nature of musculoskeletal issues within these areas. Chiropractors can utilize MuraMed's AI-backed analysis to precisely identify and understand patients' conditions, facilitating targeted chiropractic adjustments and treatments [[16](#_44sinio)], [[17](#_44sinio)]. This specialized approach ensures that patients receive personalized care based on accurate diagnostic information, optimizing their musculoskeletal health in the context of hand, elbow, and shoulder-related concerns.

The integration of MuraMed's insights into chiropractic clinics specializing in hand, elbow, and shoulder care enhances the quality of patient treatments. By utilizing MuraMed's AI, chiropractors can tailor adjustments and treatment plans specifically to the unique musculoskeletal issues in these areas. This personalized approach, based on precise diagnostic information, results in more effective treatments, aligning with the overarching goal of chiropractic care – to improve musculoskeletal health and overall well-being for patients experiencing hand, elbow, and shoulder discomfort or injuries.

**Fitness Centers**

MuraMed's versatility extends to fitness centers, where trainers can harness its capabilities to evaluate clients' musculoskeletal health comprehensively, with a particular focus on the health of their hands, elbows, and shoulders. By incorporating musculoskeletal screenings into their assessment process, fitness professionals can gain valuable insights into clients' fitness readiness, especially regarding the condition of their hands. This data-driven approach ensures that personalized workout routines are not only effective but also aligned with each client's specific musculoskeletal condition, including potential hand-related issues [[13], [14](#_44sinio)]. This tailored approach plays a pivotal role in injury prevention during exercise, creating a safer and more productive fitness environment.

Incorporating musculoskeletal screenings using MuraMed to assess clients' fitness readiness, with specific attention to hand health, presents a proactive strategy in fitness center operations. The primary reason for implementing this approach is to prevent exercise-related injuries effectively, including those related to the hands. Through these screenings, trainers can identify potential vulnerabilities in the upper body's musculoskeletal system, particularly in the hands, elbows, and shoulders. Armed with this knowledge, fitness professionals can craft workout plans that are finely tuned to individual needs, mitigating the risk of hand-related injuries and promoting long-term physical well-being. This synergy between technology and fitness is a testament to MuraMed's potential impact on the health and safety of fitness enthusiasts.

**Pharmaceutical Research**

Within the realm of pharmaceutical research, particularly in clinical trials assessing medications targeting musculoskeletal disorders, MuraMed stands as a valuable asset for tracking patients' responses to treatment and potential side effects. Moreover, when pharmaceutical companies develop products like hand ointments or treatments with specific relevance to hand-related musculoskeletal conditions, MuraMed proves instrumental. By integrating MuraMed into these clinical trials, researchers can accurately evaluate patients' musculoskeletal responses, including the effects of products designed for hand usage. This application ensures precise assessment, contributing significantly to understanding treatment efficacy and identifying any potential side effects associated with these specialized products.

The utilization of MuraMed in pharmaceutical research for evaluating patients' musculoskeletal responses in clinical trials, particularly concerning products like hand ointments, emerges from the necessity for precision and thoroughness. It's vital to comprehensively assess the performance of medications and products tailored for hand-related musculoskeletal conditions, ensuring that they meet the desired efficacy standards and safety profiles. MuraMed's integration in this context underscores its pivotal role in advancing pharmaceutical research, not only for traditional medications but also for specialized products like hand ointments, promising a more thorough understanding of treatment outcomes and their implications for patients.

**Hospital/Patient Health Portal**

MuraMed's application in the Hospital/Patient Health Portal brings advanced musculoskeletal radiograph analysis directly to the hands of patients and healthcare providers. Through seamless integration, patients can access their radiograph results and analyses conveniently, fostering a deeper understanding of their musculoskeletal health. This user-friendly interface allows for easy retrieval of diagnostic information, empowering patients to engage actively in their care journey. Moreover, healthcare providers benefit from MuraMed's expertise by receiving comprehensive insights into patients' musculoskeletal conditions, ultimately leading to more informed treatment decisions.

The inclusion of MuraMed's musculoskeletal radiograph analysis within the Hospital/Patient Health Portal serves as a catalyst for patient engagement and well-informed decision-making. By providing patients with direct access to their radiograph results and analyses, they become active participants in their healthcare, promoting a sense of ownership over their musculoskeletal well-being. Healthcare providers, on the other hand, gain a powerful tool to aid in accurate diagnoses and treatment planning. This collaborative approach between patients and providers not only enhances the quality of care but also contributes to better health outcomes, emphasizing the significance of integrating MuraMed's capabilities into the Hospital/Patient Health Portal within the broader healthcare landscape.

***In Summary:***

As the medical field continues to evolve, the potential applications of MuraMed's AI-driven solution are vast. The focus on accurate, efficient, and timely musculoskeletal diagnostics aligns with numerous healthcare sectors, contributing to improved patient care and outcomes. Each application demonstrates how MuraMed's AI-driven solution can be tailored to address specific challenges and opportunities in various sectors, ultimately leading to improved patient care and well-being.

**MuraMed: School & Sports Organization Edition**

MuraMed for School & Sports Organization is a cutting-edge solution that bridges the gap in musculoskeletal healthcare for young athletes and students. This innovative platform is not confined to the drawing board; it can be readily applied across various sports where hand injuries are particularly prevalent. For instance, in basketball, studies have indicated that hand and wrist injuries account for a substantial portion of injuries among players, ranging from fractures to sprains. Similarly, in sports like volleyball and handball, athletes are susceptible to various hand-related injuries due to the dynamic nature of the game and the frequent use of the hands for striking and blocking. By offering real-time, accurate detection of musculoskeletal abnormalities, MuraMed can play a transformative role in preventing and addressing these common injuries among young athletes. With its potential to enhance the health and performance of students and athletes in these sports, MuraMed is poised to make a significant impact on the field.

**Business Propositions and Objectives**

In the subsequent sections, we delve deeper into the distinct propositions and objectives that underpin our dedication to improving the health and well-being of the Sports and Education sectors:

**Early Injury Detection for Athletes**

In the realm of sports, where every move and play matters, early injury detection becomes paramount. MuraMed steps into this arena with its unparalleled capability to swiftly identify musculoskeletal issues in athletes, with a specific focus on the hand, elbow, and shoulder. The process begins at the start and end of each sports season, where schools and sports teams harness the power of MuraMed to conduct comprehensive scans. These scans are vital in the early detection of any potential musculoskeletal abnormalities that might have arisen due to intense sports activities. Within this rigorous process, the hand, being a vital player in many sports, receives particular attention. The reason behind this early detection protocol is clear: swift identification allows for prompt treatment, ensuring that athletes' long-term health and performance, especially in contexts where hand injuries are common, remain uncompromised.

The significance of early detection cannot be overstated, especially when it comes to athletes and the intricate biomechanics of their hands. Timely identification of musculoskeletal issues in the hand is a game-changer. It not only ensures that athletes receive the necessary medical attention but also contributes significantly to their overall well-being. The early detection process, driven by MuraMed's advanced AI capabilities, empowers athletes, schools, and sports teams to make informed decisions that prioritize health and performance. By keeping a watchful eye on the hand, athletes can address issues before they escalate, ultimately leading to safer and more productive sporting experiences. [[18] - [21](#_44sinio)]

**Post-Injury Rehabilitation Monitoring**

When athletes face injuries, particularly concerning their hands, the road to recovery can be intricate. In these scenarios, MuraMed's post-injury rehabilitation monitoring process plays a pivotal role. Focused on athletes' hand injuries, this process involves regular scans aimed at closely tracking the healing journey. The hand, being a crucial component in many sports, requires special attention. These scans are not only designed to monitor the healing process but also to detect any potential complications that might arise during recovery. The reason behind this rigorous monitoring is clear: athletes should only return to their respective games when they are fully healed, especially in cases involving hand injuries. By adhering to this stringent monitoring process, athletes can significantly reduce the risk of re-injury, protecting the long-term health and performance of their hands and allowing them to confidently resume their sporting endeavors.

The reasoning behind such detailed hand rehabilitation monitoring is simple yet profound. Athletes depend on the optimal functioning of their hands for precision, strength, and agility. Even minor complications during the healing process can have lasting consequences, especially for the hand. Therefore, it is essential to ensure that athletes regain full strength, dexterity, and functionality in their hands before they re-enter the arena. MuraMed's regular scans serve as a critical tool in this journey, offering insights into the healing trajectory of hand injuries. By adhering to this strategy, sports teams and medical professionals can ensure that athletes only rejoin their respective sports when they are fully recovered, significantly reducing the risk of exacerbating hand injuries and securing the athlete's long-term well-being and sporting potential. [[22](#_44sinio)], [[23](#_44sinio)]

**Physical Education Class Health Check**

In the realm of physical education classes, ensuring students' musculoskeletal health is crucial. Here, MuraMed offers a transformative process that schools can leverage to promote the well-being of their students, with particular emphasis on the hand, elbow, and shoulder. By incorporating MuraMed into physical education classes, schools can conduct routine health checks to guarantee that students are in optimal musculoskeletal condition. This proactive approach is not only about ensuring their immediate fitness but also about safeguarding their long-term health. Among its many advantages, this process can detect early signs of conditions like scoliosis in students, a condition that, when left untreated, can significantly impact their musculoskeletal health. By integrating hand health assessments into these checks, schools can comprehensively evaluate students' physical well-being, allowing for early interventions when needed. This ensures that students can continue their physical education journeys with confidence, knowing that their musculoskeletal health is a priority.[[34](#_44sinio)], [[35](#_44sinio)]

The inclusion of hand health assessments within these health checks is particularly pertinent, given the role of hands in various physical activities. Early detection of hand-related musculoskeletal issues, such as strains, sprains, or joint problems, is vital to prevent their escalation and ensure that students can fully participate in physical education without discomfort or limitations. MuraMed's advanced AI capabilities make this process efficient and accurate, further enhancing the overall health and safety of students engaged in physical education classes.

**Integration with Sports Biomechanics**

The integration of MuraMed with sports biomechanics is a groundbreaking process that can significantly impact athletes' performance and health, including those cases where hand injuries are prevalent. This process brings together the world of radiography and biomechanics to provide a comprehensive view of an athlete's well-being, focusing on their hand, elbow, and shoulder. By synchronizing athletes' movement patterns with radiographic findings, this process allows for a deep understanding of how an athlete's movements, including those involving the hand, may be contributing to musculoskeletal issues. The hand, with its intricate movements and dexterity, plays a vital role in many sports, making its assessment within this process particularly significant.

The reason behind this integration is clear: optimizing an athlete's performance and minimizing the risk of injuries, especially those involving the hand, requires a holistic approach. By combining data from radiographic assessments with biomechanical insights, coaches and sports professionals can tailor training regimens to address specific musculoskeletal concerns. For example, in sports where hand injuries are common, such as basketball or volleyball, the integration of hand health assessments into sports biomechanics becomes invaluable. It helps identify potential areas of improvement or modification in an athlete's technique, ultimately contributing to enhanced performance and reduced injury risks. This seamless fusion of technology is at the forefront of musculoskeletal healthcare, offering athletes a data-driven path to excellence while safeguarding their hand health. [[24](#_44sinio)], [[25](#_44sinio)]

**Athlete's Health Passport**

The development of an Athlete's Health Passport marks a significant stride in optimizing athlete care and performance, with a specific focus on the hand, elbow, and shoulder. This innovative process involves creating a digital repository where an athlete's radiographs, AI analyses, and doctor's notes are accurately stored in chronological order. This comprehensive record offers a detailed and evolving account of the athlete's musculoskeletal health over time. Coaches, physiotherapists, and other medical professionals involved in an athlete's care can access this passport, gaining valuable insights into the athlete's condition. For sports where hand injuries are common, this passport allows for precise tracking of an athlete's hand health. Understanding the nuances of hand-related musculoskeletal issues through chronologically stored data empowers medical staff to make informed decisions regarding training regimens, injury prevention, and rehabilitation, all geared towards optimizing the athlete's performance while safeguarding their hand health.

Moreover, the Athlete's Health Passport is not limited to professional athletes but extends its benefits to students engaged in physical education classes. By using the passport to monitor the hand health of young athletes, schools can provide a safe and nurturing environment for students to develop their physical abilities. With a comprehensive view of an athlete's musculoskeletal health, this process ensures that every participant, from budding talents to elite athletes, receives the utmost care and attention, particularly when it comes to their hands. [[26](#_44sinio)] - [[28](#_44sinio)]

**Educational Workshops**

Educational workshops are a cornerstone of MuraMed's commitment to musculoskeletal health in sports and physical education, with a particular emphasis on the hand, elbow, and shoulder. This process entails offering informative sessions to physical education teachers, coaches, and sports team medical staff. These workshops cover a wide spectrum of topics, from understanding radiographs to highlighting the paramount importance of early detection and showcasing how to effectively utilize MuraMed. Hands-on workshops, where participants can interact with real-world examples involving the hand, further enhance the learning experience. The reason behind these workshops is simple but powerful: educated stakeholders can make more informed decisions for the health and well-being of students and athletes alike.

In sports where hand injuries are prevalent, such as basketball or volleyball, workshops using real-life examples involving the hand can be particularly enlightening. Participants gain insights into the specific musculoskeletal challenges associated with these sports, allowing them to tailor their training and coaching strategies accordingly. These educational initiatives contribute to a safer and more productive sports environment, ensuring that coaches and medical staff possess the knowledge and skills necessary to protect and optimize the hand health of their athletes. [[29](#_44sinio)] - [[31](#_44sinio)]

**Collaboration with Sports Equipment Manufacturers**

Collaborating with sports equipment manufacturers stands as a pivotal process within MuraMed's mission to enhance the safety and performance of athletes, with a specific focus on the hand, elbow, and shoulder. This strategic partnership involves a thorough analysis of various types of sports equipment, including hand gear, elastic bandages, elbow guards, upper arm protectors, and general protective equipment. The objective is to investigate if certain equipment contributes to musculoskeletal issues, especially those affecting the hand and upper extremities. For sports like rugby, where shoulder and chest protection is essential, the evaluation extends to materials like high-density foam padding, with a consideration for alternatives to traditional outer hard shells. This in-depth analysis ensures that athletes are equipped with gear that not only maximizes their safety but also minimizes the risk of musculoskeletal injuries.[[32](#_44sinio)], [[33](#_44sinio)]

The reason behind this collaboration is clear: it paves the way for the design and development of superior sports equipment that actively mitigates the risk of injury. By scrutinizing the impact of different gear on musculoskeletal health, manufacturers can refine their products to provide athletes with enhanced protection. For instance, when focusing on hand gear, the process may reveal design improvements that offer better support and impact absorption for hand-related sports injuries. This collaborative effort strives to create a new generation of sports equipment that not only optimizes performance but also prioritizes the preservation of athletes' hand health. Through this synergy between medical insights and manufacturing expertise, athletes can engage in their chosen sports with greater confidence, knowing that their equipment is designed to minimize the risk of musculoskeletal injuries, particularly those affecting the hand, elbow, and shoulder.

**Athlete Health Portal**

The Athlete Health Portal in MuraMed's School & Sports Organization Edition serves as a centralized hub for athletes, coaches, and healthcare providers. Athletes can securely access their musculoskeletal health data, including radiograph results and AI-backed analyses, offering them valuable insights into their physical condition. Coaches and medical staff can monitor the progress of athletes, ensuring their well-being throughout the sports season. Through the portal, radiographs and other relevant information are readily available, streamlining communication and coordination among all stakeholders involved in an athlete's care.

The Athlete Health Portal in MuraMed's School & Sports Organization Edition is pivotal in fostering a collaborative and informed approach to athlete care. By providing athletes access to their musculoskeletal health data, they become active participants in their own well-being, which can contribute to early injury prevention and better long-term health. Coaches and medical staff benefit from real-time insights into athletes' conditions, allowing for prompt interventions when needed and the development of tailored training and rehabilitation plans. In essence, the Athlete Health Portal promotes a holistic and data-driven approach to athlete health management, enhancing overall sports performance and athlete satisfaction within schools and sports organizations.

**Monetization Strategies for Sustainable Sports and Education Health**

In our unwavering commitment to promoting the well-being of students and athletes through MuraMed's Schools and Sports Organization Edition, we've crafted a set of monetization strategies geared toward long-term sustainability. These strategies are designed to ensure that musculoskeletal health management remains effective, benefiting educational institutions, sports teams, and the broader sports industry. Below, we provide an extensive overview of our structured approaches:

* **Tailored Package Deals:** MuraMed extends the convenience of tailored package deals to schools and sports organizations, enabling them to scan multiple students or athletes cost-effectively. These deals provide competitive rates, making it accessible for educational institutions and sports teams to proactively manage the musculoskeletal health of their students and athletes.
* **Flexible Subscription Model:** Our flexible subscription model empowers educational institutions and sports academies to select from a range of plans customized to their specific requirements. By subscribing annually, these organizations enjoy uninterrupted access to MuraMed's monitoring services, AI analyses, and the dedicated health portal. This approach fosters ongoing musculoskeletal health management while accommodating budget considerations.
* **Enhanced Education Workshops:** MuraMed offers specialized education workshops, charging fees for these enlightening sessions aimed at deepening stakeholders' comprehension of radiographs and the critical importance of early detection. These workshops can be precisely tailored to address the unique challenges faced by educational and sports sectors, nurturing a culture of safety and wellness.
* **Collaboration with Sports Equipment Manufacturers:** Our platform collaborates closely with sports equipment manufacturers, providing in-depth analysis and charging for assessments that evaluate the impact of their products on musculoskeletal health. This mutually beneficial partnership seeks to improve the design of sports equipment, reducing the risk of musculoskeletal issues among athletes.

These versatile monetization streams ensure that MuraMed remains financially sustainable while providing indispensable services to its users. Ultimately, these efforts contribute significantly to the well-being of students, athletes, and the continued growth of the sports and education sectors.

***In Summary:***

With an increasing emphasis on sports and physical activities in schools, the health of young athletes and students is paramount. By introducing MuraMed to these institutions, we can ensure early detection, prompt treatment, and overall better musculoskeletal health for the younger generation.

**MuraMed: Workplace Edition**

MuraMed's Workplace Edition is a specialized solution designed to address work-related musculoskeletal disorders (MSDs), focusing on upper limb, shoulder, and hand conditions. It's suitable for a wide range of industries, from heavy manual labor to office jobs. This edition helps detect and manage MSDs early through regular employee check-ups and ergonomic evaluations. It targets the unique challenges faced by professions with a high risk of MSDs, promoting healthier workplaces and reducing the impact of these disorders on both employees and employers.

Recent statistics from the U.S. Department of Labor underscore the significance of this issue. According to their findings, a notable 23 percent of all work-related injuries involve injuries to the hands or fingers, categorizing hand injuries as "the most frequent preventable injuries" [(Safety + Health magazine)](https://www.safetyandhealthmagazine.com/articles/21633-hand-safety-programs). Moreover, these hand injuries rank as the second most common cause of missed workdays, following closely behind back and neck injuries. They encompass various types of injuries, including broken bones, such as fractured fingers. Another type is avulsion fractures, where a small piece of bone comes off from a tendon or ligament. Avulsion fractures in the hand and wrist frequently happen when someone falls and stretches out their hand to break the fall.

**Business Propositions and Objectives**

In the following sections, we provide a more detailed exploration of the specific propositions and objectives that define our commitment to enhancing workplace health and well-being:

**Preventing Work-Related Injuries in Industrial Environments**

In industrial environments like construction or manufacturing, MuraMed's regular X-ray screenings for workers engaged in physically demanding roles aim to serve as a critical preventive measure. These screenings are specifically designed to identify potential musculoskeletal issues early, particularly in professions where hand injuries are prevalent, such as construction. By detecting issues promptly, we prevent work-related injuries, ensuring a healthier and more productive workforce.

**Enhancing Employee Well-Being Through Routine Screenings**

Routine employee screenings offer a proactive approach to employee well-being, especially for jobs requiring high physical demands or repetitive tasks. Early detection of musculoskeletal disorders through regular screenings facilitates timely interventions, reducing the severity and duration of these conditions. This approach fosters overall employee health and minimizes workplace absenteeism.

**Supporting Post-Injury Recovery**

In cases of post-injury recovery, MuraMed aims to provide a valuable resource by offering regular scans to monitor the healing process. This comprehensive monitoring ensures that employees return to work only when they are fully recovered, thereby reducing the risk of re-injury and preventing long-term complications. This feature is particularly crucial in physically demanding professions where a premature return to work, such as in the case of wrist or hand injuries, which are particularly common, can lead to more severe injuries.

**Tailoring Workspaces for Employee Comfort**

Integrating MuraMed's findings with ergonomic assessments enables a personalized approach to optimizing work environments, whether in traditional office settings or more hazardous workplaces. By gaining insights into each employee's specific musculoskeletal needs, workplaces can make precise adjustments to seating, computer setups, or workstations, promoting ergonomic workspaces and enhancing overall employee comfort and safety. This tailored approach not only reduces physical strain but also contributes to a healthier and safer work environment, aligning with MuraMed's commitment to improving workplace well-being across diverse industries.

**Collaborative Employee Health Solutions**

Collaborating with occupational health providers is another dimension of MuraMed's holistic approach to employee health. By partnering with these providers, we aim to offer a comprehensive health solution that includes MuraMed screenings, physical therapy, and ergonomic interventions. This collaborative effort ensures that employees receive well-rounded care addressing both immediate and long-term musculoskeletal health concerns, ultimately leading to better health outcomes and cost savings over time.

**Employee Health Portal**

As an integral part of this edition, the employee health portal will serve as a user-friendly digital tool designed to empower individuals in managing their musculoskeletal health. Within this platform, employees will be able to conveniently keep track of their screenings, access AI-generated analyses, and review recommended interventions. This proactive approach will encourage employees to make informed decisions regarding their well-being, fostering a culture of health consciousness within the workplace and contributing to the overall health and productivity of the workforce.

**Monetization Strategies for Sustainable Workplace Health**

In our commitment to enhancing workplace well-being through MuraMed's Workplace Edition, we've developed a set of strategies with a focus on sustainability. These plans are aimed at ensuring that musculoskeletal health management remains effective and continues to benefit companies and their employees. Below, we provide a detailed overview of our structured efforts:

* **Corporate Health Packages:** MuraMed offers tailored corporate packages designed to accommodate companies of all sizes. These packages provide cost-effective solutions for scanning large numbers of employees, ensuring that businesses can proactively manage musculoskeletal health across their workforce.
* **Subscription-Based Model:** Our flexible subscription model allows companies to choose from various plans based on their specific needs. By subscribing annually, organizations gain continuous access to MuraMed's monitoring services, AI analyses, and the employee health portal. This approach encourages ongoing musculoskeletal health management while providing budget-friendly options.
* **Tailored Training and Workshops:** MuraMed can provide specialized training and workshops for companies looking to enhance their employees' musculoskeletal health awareness and practices. These sessions can be tailored to address the unique challenges of different industries, promoting a safer and healthier work environment.

* **Consultation Services:** Our expert consultants can work closely with organizations to assess their musculoskeletal health needs and recommend customized solutions. This consultancy service ensures that businesses receive personalized guidance in implementing effective musculoskeletal health management strategies.
* **Integration with Occupational Health Providers:** Companies can effecively integrate MuraMed's services with their existing occupational health providers. This collaborative partnership enhances overall employee health care while leveraging the strengths of both parties.

***In Summary:***

MuraMed's Workplace Edition offers a specialized solution to address work-related musculoskeletal disorders (MSDs), encompassing various body parts which at this moment are: the wrist, shoulder, elbow, hand, finger, forearm, and humerus. With a focus on early detection, personalized care, ergonomic improvements, and collaboration with occupational health providers, our aim is to promote healthier workplaces. Additionally, our user-friendly employee health portal empowers individuals to proactively manage their musculoskeletal health. By addressing these critical aspects, MuraMed strives to enhance workplace well-being for businesses within the European Union and beyond, ensuring a healthier, safer, and more productive workforce.

**Business Model Canvas: MuraMed**

**1. Key Partnerships:**

* **Radiologists & Orthopedic Doctors:** Collaborate with medical experts for feedback and continuous improvement of AI models.
* **Hospitals & Clinics:** Establish partnerships for deployment and integration of AI-assisted diagnostics.
* **Regulatory Bodies:** Engage with healthcare regulatory authorities for necessary approvals and compliance.
* **Medical Schools:** Partner with educational institutions for the deployment of AI tools in medical education.

**2. Key Activities:**

* **Model Training & Continuous Learning:** Develop and refine AI models for accurate diagnosis, ensuring continuous learning from medical data.
* **Integration with PACS:** Seamlessly integrate with Picture Archiving and Communication Systems (PACS) used in healthcare.
* **Data Augmentation & Pre-processing:** Enhance the quality and diversity of medical data through data augmentation and preprocessing.
* **Regulatory Compliance & Certifications:** Ensure compliance with healthcare regulations and attain necessary certifications.
* **Customer Support & Training:** Provide robust customer support and training to healthcare professionals and institutions.
* Building and Maintaining the MuraMed Platform
* Collaborating with Radiology Clinics for Data Collection

**3. Key Resources:**

* **MURA Dataset and Additional Data:** Access to a diverse and extensive dataset is foundational to our AI model's training and continuous improvement.
* **Deep Learning Infrastructure:** Cutting-edge infrastructure, including GPUs and servers, is essential for model training and real-time diagnostics like cloud databases.
* **Medical Expertise:** Collaboration with radiologists and orthopedic doctors ensures the clinical relevance and accuracy of our AI models.
* **Development & Tech Team:** A skilled team of AI developers and engineers drives the development, deployment, and maintenance of our solutions.

**4. Value Propositions:**

* **AI-assisted accurate diagnosis:** Our AI models are trained on extensive datasets, enabling them to detect abnormalities in X-rays with remarkable precision, acting as a valuable aid to radiologists and orthopedic doctors.
* **Second opinion for radiologists:** MuraMed doesn't replace human expertise; it enhances it. Radiologists can now receive AI-generated second opinions, reinforcing diagnostic confidence.
* **Telemedicine support for remote areas:** MuraMed's cloud-based architecture facilitates telemedicine, extending diagnostic capabilities to underserved regions and remote clinics.
* **Continuous learning for improved accuracy:** Our AI models continuously learn from new data, ensuring that they stay updated with evolving medical knowledge.
* **PACS integration for seamless workflow:** MuraMed integrates seamlessly with Picture Archiving and Communication Systems (PACS), streamlining the diagnostic workflow within healthcare institutions.
* **Scalable and cost-effective AI infrastructure:** We've partnered with AI hardware providers to offer scalable and cost-effective infrastructure solutions, making AI adoption feasible for healthcare providers of all sizes.

**5. Customer Relationships:**

* **Subscription Support:** Provide responsive support for subscription-based customers.
* **Training Sessions for Medical Staff:** Offer training sessions to ensure the effective use of our AI tools.
* **Regular Updates & Feedback Sessions:** Keep customers informed with regular updates and gather feedback for improvements.
* **Online Portal for Account Management:** Facilitate easy account management and support through an online portal.

**6. Channels:**

* **Direct Sales to Hospitals & Clinics:** Engage in direct sales to healthcare institutions for seamless integration.
* **Online Portal for Subscription & Pay-per-Use:** Enable online subscription and pay-per-use services for individual users.
* **Partnerships with Medical Conferences & Workshops:** Collaborate with medical events for exposure and adoption.
* **Integration with Telemedicine Platforms:** Integrate our AI solutions with telemedicine providers' platforms.

**7. Customer Segments:**

* **Hospitals & Large Clinics:** Offer comprehensive AI solutions for healthcare facilities.
* **Individual Radiologists & Orthopedic Doctors:** Provide individual practitioners with AI tools for enhanced diagnostics.
* **Medical Schools & Training Institutes:** Support educational institutions with AI-based learning tools.
* **Telemedicine Service Providers:** Collaborate with telemedicine platforms to extend diagnostic capabilities.
* **Sports Organizations**
* **Healthcare Private Businesses** (fitness centers, elderly care, physiotherapy center, chiropractic center, facilities etc)
* **Workplaces**

**8. Cost Structure:**

* **Infrastructure & Hosting Costs:** Cover expenses related to AI infrastructure and
* **Research & Development:** Allocate resources for continuous model improvement and development.
* **Regulatory Compliance & Certification Costs:** Ensure adherence to healthcare regulations and certifications.
* **Marketing & Sales:** Invest in marketing and sales efforts to reach healthcare institutions and practitioners.
* **Employee Salaries & Benefits:** Compensate the skilled team of developers and medical experts.

**9. Revenue Streams:**

* **Subscription Fees from Hospitals & Clinics:** Generate recurring revenue from healthcare institutions.
* **Pay-per-Use Fees:** Offer flexible payment options for individual users.
* **Custom Model Training & Implementation Services:** Provide tailored AI model training and implementation for specific needs.
* **Educational Licensing for Medical Schools:** License AI-based learning tools to medical schools and training institutes.

**10. Key Metrics:**

* **Number of Subscribers/Users**
* **Accuracy Improvement Rate**
* **Customer Satisfaction and Feedback**
* **Usage Frequency and Retention Rates**

**Future Plans**

As we look ahead, our vision for MuraMed extends beyond the current scope of musculoskeletal health management. In line with our commitment to improving well-being, we have several exciting future initiatives in mind.

**Expanding Body Part Coverage:** While we currently focus on the upper limbs (wrist, shoulder, elbow, hand, finger, forearm, and humerus), we recognize the need to broaden our coverage to involve additional areas, ensuring comprehensive musculoskeletal health support for all.

**Mobile Application:** In the pipeline is the development of a user-friendly mobile application that allows healthcare professionals to efficiently upload radiographs and promptly receive AI-generated feedback. This tool will empower doctors with a convenient on-the-go resource for accurate diagnosis.

**Interactive 3D Visualization:** To further aid medical professionals, we are working on an innovative feature that transforms 2D radiographs into interactive 3D models. Leveraging AI technology, this tool will highlight areas of concern, offering a more comprehensive understanding of musculoskeletal issues and serving as an invaluable educational resource for patients.

**Integration with Wearable Tech:** Recognizing the value of preventive care, we are exploring partnerships with wearable technology providers. By integrating wearable data, such as posture analysis, we aim to predict potential musculoskeletal issues and offer proactive solutions to promote long-term well-being.

**MuraMed Pets:** Expanding our reach, we are excited to introduce MuraMed Pets, a specialized version tailored to the health needs of our beloved animal companions. This initiative reflects our commitment to extending the benefits of musculoskeletal health management to the furry members of our families.

# B. Technical Implementation

Having thoroughly reviewed the theoretical plan, and the business implications, we now delve into the technical implementation phase. This pivotal segment will elucidate the precise methodologies, tools, and technologies enlisted to actualize the project's goal of abnormality detection in bone X-Rays with MuraMed. While prior sections afforded a macro-level comprehension, herein lies the micro-level operational details pivotal for executing the project successfully.

The technical implementation acts as the linchpin, knitting together multiple critical components, ranging from data management to algorithmic fine-tuning and software integration. Such meticulous attention to each element underpins the project's robust theoretical foundation and ensures its practical viability.

## Technical Implementation Plan: A Detailed Roadmap

The following document outlines the technical architecture and operational strategy to successfully implement the project for abnormality detection in bone X-Rays. It is structured around five key areas of focus, each crucial for the project's seamless execution. In addition, we include sections detailing the justification for algorithmic choices, offering a holistic view of both the strategic and tactical dimensions.

1. **Data Architecture**
   * Data Acquisition
   * Data Storage
   * Data Management
2. **Algorithm Development**
   * CNN Architecture Design
   * Hyperparameter Optimization
   * Justification for Using CNNs
3. **Software Integration**
   * Core Libraries and Frameworks
   * Utility Libraries
   * API Integrations
4. **Quality Assurance**
   * Unit Testing
   * Model Evaluation Metrics
   * Methodologies for Testing
5. **Deployment**
   * Containerization
   * Monitoring Systems
   * Maintenance Protocols

This roadmap outlines the key milestones and components that will be focused upon for the successful technical implementation of this project. Each title represents a critical area that will be developed.

## A. Data Architecture

The data architecture for this project has multiple dimensions, each crucial for ensuring the quality and utility of the data involved. Beginning with **Data Acquisition**, we've chosen the Stanford ML Group's MURA dataset[[3](#_Bibliography)] as our primary source. This dataset, comprising a range of bone X-Ray images categorized as normal and abnormal, offers a robust foundation for our model. The choice of a reputable dataset alleviates concerns about data integrity and reliability. Python-based scripts will automate the process of downloading and unpacking this dataset, ensuring that data acquisition is both reproducible and efficient.

In the realm of **Data Storage**, structure is king. Our approach involves organizing the data into meticulously structured directories, separated based on the data type (training, validation, or test) and class (normal or abnormal). Such a structured data storage approach not only facilitates easier data access but also minimizes errors during the data-loading phase.

The **Data** **Management** aspect focuses on how the data will be preprocessed, augmented, and loaded during the training phase. We will employ **TensorFlow's ImageDataGenerator[**[**4**](#_Bibliography)**]** for real-time data augmentation, a critical step for enhancing model robustness. This is particularly crucial in medical imaging, where the data is highly imbalanced, and the cost of misclassification is high. Efficient data loading mechanisms are equally critical. Given that we're dealing with high-resolution images, optimized memory usage is non-negotiable. Batch-loading techniques will be implemented to this end.

### Get to know the MURA Dataset

To be more precise regarding the **MURA dataset**, this is, an acronym for "Musculoskeletal Radiographs," was inaugurated by Stanford University in the year 2017. It constitutes a large-scale compilation encompassing over 42,000 digital radiographic images. These images are distributed across seven distinct anatomical regions, including the wrist, elbow, shoulder, finger, hip, knee, and ankle.

The dataset's primary objective is to facilitate the advancement of machine learning algorithms capable of autonomously identifying abnormalities within musculoskeletal radiographs. This task presents a considerable challenge, given that such abnormalities often manifest subtly and may elude even the discerning analysis of trained radiologists.

Since its release, the MURA dataset has gained prominence as a benchmarking tool for assessing the efficacy of deep learning models in the realm of musculoskeletal radiographic analysis. It has been employed extensively in academic research and competitive frameworks for the development and validation of algorithms aimed at detecting a range of abnormalities, such as fractures and dislocations, within X-ray imagery.

A red background with white text

Description automatically generated

Figure 1: MURA Dataset and TensorFlow's Logo.

## B. Algorithm Development

At the heart of our project is the algorithm—specifically, the Convolutional Neural Networks (CNNs). **The Architecture of the CNN is designed to capture both the lower-level features like edges and corners, as well as higher-level features that are more abstract and capture the essence of what makes an X-Ray normal or abnormal**. Multiple convolutional and pooling layers will be employed, followed by fully connected layers for classification. The architecture will be tuned for optimal performance through experimentation.

**Optimization** is another critical element. The field of machine learning is rife with algorithms and techniques for optimization. We plan to employ techniques like *Grid* *Search* or *Random* *Search* *for hyperparameter tuning*. These methodologies systematically explore multiple combinations of parameters over the defined hyperparameter space, capturing the one that offers the best performance. Additionally, we will experiment with different optimization algorithms like *Adam* or *RMSprop* to see which yields better results in the shortest time.

The **Justification for CNNs** has been made after careful consideration. CNNs are uniquely suited for image recognition tasks due to their ability to automatically and adaptively learn spatial hierarchies of features. This makes them incredibly efficient in terms of computational cost, requiring fewer parameters compared to other types of neural networks. CNNs are also highly versatile, able to work well with color or grayscale images, and their robustness to translations and deformations makes them ideal for medical imaging tasks where the point of focus can vary within the image.

*Moving forward, we will dive into more details regarding the Optimization procedures and then we will answer we choose to use CNNs.*

### Optimization Procedures

To be more precise the **optimization** in machine learning is an intricate endeavor that extends beyond the mere selection of an appropriate algorithm. It encompasses a multi-dimensional search in a complex landscape, dictated by the interplay of various hyperparameters, to arrive at the most effective model. This venture is further complicated when we engage with high-stakes domains such as medical imaging, where the costs of false positives and false negatives can be significant. Thus, our optimization strategy is multifaceted, incorporating several techniques and approaches to ensure that the resultant model is not just computationally efficient but also clinically effective.

#### Hyperparameter Tuning Techniques

More specifically, **Grid Search** method involves specifying a grid of hyperparameters and systematically searching through all possible combinations. While computationally expensive, Grid Search is thorough and is particularly useful when the hyperparameter space is not exceedingly large. We foresee employing Grid Search for parameters like learning rate and batch size, where a comprehensive search can yield dividends.

**On the contrary to Grid Search**, **Random Search** samples the hyperparameter space randomly. This approach is computationally more efficient and has been shown to yield equally good or sometimes even better results than Grid Search. Random Search could be particularly useful for tuning more complex hyperparameters like the architecture of the neural network itself.

#### Optimization Algorithms

**Adam (Adaptive Moment Estimation)** is renowned for its efficiency and has become almost a default choice in deep learning tasks. It combines the benefits of two other extensions of *stochastic gradient descent*: **AdaGrad** and **RMSProp**. Adam adjusts the learning rate during training, making it adaptable to the specific characteristics of the data.

**RMSprop (Root Mean Square Propagation)** is another adaptive learning rate method and is an excellent choice for non-convex optimization problems. It adapts the learning rates during training and is very effective for problems that are noisy or have sparse gradients.

To sum up, *both Adam and RMSprop have their advantages and disadvantages*. For instance, Adam is generally good at handling sparse gradients, while RMSprop is often better for online and non-stationary tasks. Our project may likely experiment with both to ascertain which aligns better with the nuances of medical image classification.

#### Evaluation Metric

The selection of an appropriate evaluation metric is also part of the optimization process. Given the medical nature of our project, traditional metrics like accuracy are not sufficiently informative. Instead, we will focus on metrics like sensitivity, specificity, and F1-score, which provide a more nuanced understanding of model performance.

By adopting a diversified yet focused approach to optimization, we aim to create a model that is both computationally efficient and clinically effective. This comprehensive strategy ensures that we navigate the complex optimization landscape with the finesse required to meet the high stakes inherent in medical applications.

### Justification for the Choice of Convolutional Neural Networks (CNNs)

To be more precise, the **Convolutional Neural Network (CNN)** is a class of deep neural networks most commonly applied to visual imagery analysis. In the context of the notebook, the objective is to detect abnormalities in bone X-Rays, a highly specialized field within medical imaging. Here, we discuss why CNNs may be the preferred choice over other machine learning algorithms and models for this specific task. The following sections will explain this in detail.

#### Traditional Machine Learning Algorithms

Let's first consider traditional machine learning algorithms like **Logistic Regression, Decision Trees, Random Forests, and Support Vector Machines (SVM)**. These algorithms require *manual feature engineering, a cumbersome and often inefficient process in the context of high-dimensional data like images*. Also, these algorithms usually *don't perform well on raw image data due to their inherent complexity and spatial hierarchies, which these algorithms are not designed to understand* (For more details you can visit this article[[5](#_Bibliography)]).

#### Fully Connected Neural Networks

Fully connected networks, also known as **Dense Neural Networks**, *don't respect the spatial hierarchy of the data*. Every neuron is connected to every other neuron in the next layer, making the network susceptible to overfitting and requiring a large number of parameters. The lack of focus on spatial relationships makes them inefficient for image-based tasks, where pixel location and neighborhood have semantic significance. You can find more regarding the Fully Connected Neural Networks in this very interesting article[[6](#_Bibliography)].

#### Recurrent Neural Networks (RNNs)

RNNs are generally more suited for sequence-based problems like natural language processing or time-series prediction. Their architecture, which is designed to remember past information, is not inherently equipped to deal with the spatial hierarchies and complexities in image data (Check these articles[[7,8](#_Bibliography)]).

#### Autoencoders

Autoencoders are generally used for unsupervised learning tasks, primarily dimensionality reduction and feature learning. While they can be adapted for image classification tasks, they are not inherently designed for this purpose[[9,10](#_Bibliography)].

#### Generative Adversarial Networks (GANs)

GANs are more focused on data generation and are not inherently structured for classification tasks. While they can be adapted for such tasks, the complexity involved usually outweighs the benefits for a straightforward classification problem like abnormality detection in bone X-Rays[[11](#_Bibliography)].

### Why CNNs Are Preferable

This section aims to elucidate the rationale behind opting for Convolutional Neural Networks (CNNs) over other machine learning algorithms and neural network architectures. This section will delve into the unique capabilities and advantages that make CNNs particularly suited for the task of abnormality detection in musculoskeletal radiographs[[12](#_Bibliography)].

#### Hierarchical Feature Learning

One of the most compelling attributes of CNNs is their innate capability for Hierarchical Feature Learning. In the realm of image analysis, the interpretability of features often exists in a hierarchical fashion. Basic features like edges and corners form the building blocks, which, when combined in various configurations, result in more complex and abstract features like textures and shapes. CNNs are architected to learn this spatial hierarchy automatically and adaptively. The initial layers often specialize in identifying rudimentary features, such as edges and lines. As one progresses through the network, the layers grow more complex and capable of understanding intricate patterns. This hierarchical learning is especially advantageous in medical imaging, where simple features like tissue boundaries could combine to form higher-order features like fractures.

#### Parameter Sharing and Sparsity

Parameter Sharing and Sparsity in CNNs are mechanisms that significantly reduce the computational burden. Traditional neural networks tend to have fully connected layers, where each neuron in one layer is connected to every neuron in the next layer. This results in a large number of parameters, leading to longer training times and requiring more powerful hardware. CNNs circumvent this issue by sharing weights across neurons. This form of parameter sharing ensures that the network learns translational invariance, allowing it to recognize a feature regardless of its position in the image. Additionally, this drastically reduces the number of parameters, making CNNs more computationally efficient and capable of running on standard hardware without compromising performance.

#### Robustness to Translations and Deformations

Medical imaging data often come with their unique set of challenges, one of which is the variability in the position and orientation of the abnormalities. A feature detection model must thus be Robust to Translations and Deformations. CNNs are built with this robustness in mind. Due to their convolutional nature and weight-sharing architecture, they are inherently adept at recognizing features irrespective of their location in the image. This property is invaluable in tasks like detecting musculoskeletal abnormalities, where the precise location of the abnormality can vary across patients.

In **summary**, the hierarchical feature learning capabilities, the efficiency introduced by parameter sharing and sparsity, and the robustness to translations and deformations make CNNs an optimal choice for our project in abnormality detection in musculoskeletal radiographs. These attributes collectively contribute to a model that is not just theoretically sound but also practically effective and computationally feasible. In medical imaging, the importance of capturing intricate patterns and anomalies cannot be overstated. CNNs can capture this level of detail, making them ideal for tasks that require high sensitivity and specificity, such as abnormality detection in bone X-Rays[[12](#_Bibliography)].

### Additional Decisions/Procedures Followed

#### Data Augmentation

In the Data Preprocessing section, we have opted to employ ImageDataGenerator for data augmentation. This choice is particularly significant in the domain of medical imaging where labeled data is often scarce. Utilizing augmentation techniques such as rotation, zooming, and flipping enhances the robustness of our model, thereby improving its generalization capabilities when applied to unseen data.

#### Metrics Choice

Selecting appropriate metrics is of paramount importance in medical applications. Traditional metrics like accuracy can often be misleading, particularly given the different costs associated with false negatives and false positives in a medical setting. Therefore, we have conscientiously chosen to focus on specialized metrics such as sensitivity and specificity to offer a more nuanced evaluation of the model's performance.

#### Callbacks for Training

We have incorporated the use of callbacks during the model training phase, a decision aligned with best practices in machine learning. Specifically, we utilize Early Stopping callbacks to curtail the training process when the model ceases to improve on the validation set. This is of particular importance in medical contexts, where overfitting could potentially lead to incorrect diagnoses, carrying severe consequences.

## C. Software Integration

Software Integration serves as the glue that binds the disparate elements of our project into a cohesive whole. We have chosen Python as the programming language owing to its extensive libraries and community support for machine learning and data science. Core Libraries include **TensorFlow** for machine learning, Pandas for data manipulation, and Matplotlib for data visualization. These libraries are mature, well-supported, and widely adopted in both academic and industrial circles, making them a safe and robust choice for our project.

In addition to these **core libraries**, we will also be using Utility Libraries like NumPy for numerical computations and PIL for image processing. These libraries further extend Python's capabilities, making it easier to perform complex operations without having to reinvent the wheel. When it comes to API Integrations, we might employ cloud-based storage and computation solutions, integrating their APIs into our project for seamless data storage and parallel computing, thus enhancing the project's scalability and efficiency.

## D. Quality Assurance

In a field as critical as **medical imaging**, Quality Assurance isn't just a luxury; it's a necessity. To this end, we have a multi-tiered approach to ensure that our project not only meets but exceeds the required standards. Starting with Unit Testing, each function and method in our codebase will be tested using Python's unittest or pytest libraries. These unit tests serve as the first line of defense against bugs and ensure that the code performs as expected under a variety of conditions.

As for **Model Evaluation**, as also mentioned earlier, we take a rigorous approach. We will employ metrics such as sensitivity, specificity, and F1-score, which are more nuanced than traditional accuracy and offer a better understanding of the model's performance in a medical context. Cross-validation techniques will also be employed, providing an unbiased assessment of the model's true performance. We have chosen these metrics and methodologies because they are particularly suited for imbalanced datasets common in medical applications.

## E. Deployment

The final phase of our project is **Deployment**, which involves several key steps. The entire project, including the trained model, preprocessing algorithms, and even the unit tests, will be containerized using Docker. This makes it easier to deploy the project in any environment without worrying about dependencies. Once deployed, Monitoring Systems will be put in place to track the model's performance in real-time. Any significant deviations in performance metrics will trigger alerts, necessitating immediate review and possible model retraining. Maintenance is the final ongoing step, involving regular updates to include new data, refine the model, and implement any necessary patches or improvements.

By diligently planning and executing each section outlined, we aim to translate the project's theoretical framework into a fully functional and reliable application for abnormality detection in bone X-Rays. This comprehensive technical implementation plan serves as the roadmap that will guide each phase of the project, ensuring both its theoretical robustness and practical effectiveness.

# Bibliography

The following bibliography provides a curated list of academic papers, articles, and online resources that have been instrumental in shaping the theoretical framework and technical methodologies employed in this project on abnormality detection in musculoskeletal radiographs. These sources offer valuable insights into various aspects of machine learning algorithms, neural network architectures, and optimization techniques, thereby enriching the project's scientific rigor and practical applicability.

1. Buckle, P.W. & Devereux, J.J., 2002. The nature of work-related neck and upper limb musculoskeletal disorders. \*Applied Ergonomics\*, 33(3), pp.207-217. Available at: <https://doi.org/10.1016/S0003-6870(02)00014-5> [Accessed Date: 23 August 2023].

2. Colombini, D. & Occhipinti, E., 2006. Preventing upper limb work-related musculoskeletal disorders (UL-WMSDS): New approaches in job (re)design and current trends in standardization. \*Applied Ergonomics\*, 37(4), pp.441-450. Available at: <https://doi.org/10.1016/j.apergo.2006.04.008> [Accessed Date: 23 August 2023].

3. Stanford ML Group, 2017. MURA: Musculoskeletal Radiographs. Available at: [Stanford ML Group MURA Dataset](https://stanfordmlgroup.github.io/competitions/mura/) [Accessed Date: 2 September 2023].

4. TensorFlow, 2015. TensorFlow: An Open Source Machine Learning Framework. Available at: [TensorFlow Official Website](https://www.tensorflow.org/) [Accessed Date: 2 September 2023].

5. Kapernikov, 2018. Traditional Machine Learning Algorithms for Machine Vision. Kapernikov. Available at: [Kapernikov Article on Traditional ML Algorithms](https://kapernikov.com/traditional-machine-learning-algorithms-for-machine-vision/) [Accessed Date: 2 September 2023].

6. Medium, 2020. Fully Connected vs. Convolutional Neural Networks. The Startup. Available at: [Medium Article on FCNs vs CNNs](https://medium.com/swlh/fully-connected-vs-convolutional-neural-networks-813ca7bc6ee5) [Accessed Date: 2 September 2023].

7. Salehinejad, H., Sankar, S., Barfett, J., Colak, E., & Valaee, S., 2018. Recent Advances in Recurrent Neural Networks. [Available at: ArXiv - The RNN Advances](https://arxiv.org/pdf/1801.01078.pdf) [Accessed Date: 2 September 2023].

8. Towards Data Science, 2020. Recurrent Neural Networks (RNNs). Towards Data Science. Available at: [Towards Data Science Article on RNNs](https://towardsdatascience.com/recurrent-neural-networks-rnns-3f06d7653a85) [Accessed Date: 2 September 2023].

9. Bank, D., Koenigstein, N., & Giryes, R., 2020. Autoencoders. Available at: [ArXiv Autoencoders](https://arxiv.org/pdf/2003.05991.pdf) [Accessed Date: 2 September 2023].

10. Chen, S. & Guo, W., 2023. Auto-Encoders in Deep Learning—A Review with New Perspectives. Mathematics, 11(8), 1777. Available at: [DOI for Auto-Encoders Review](https://www.mdpi.com/2227-7390/11/8/1777) [Accessed Date: 2 September 2023].

11. Dobilas, S., 2022. GANs: Generative Adversarial Networks — An Advanced Solution for Data Generation. Towards Data Science. Available at: [Towards Data Science Article on GANs](https://towardsdatascience.com/gans-generative-adversarial-networks-an-advanced-solution-for-data-generation-2ac9756a8a99) [Accessed Date: 2 September 2023].

12. Yamashita, R., Nishio, M., Do, R.K.G., & Togashi, K., 2018. Convolutional neural networks: an overview and application in radiology. Insights into Imaging, 9, pp.611–629. Available at: [Insights into Imaging Article on CNNs](https://insightsimaging.springeropen.com/articles/10.1007/s13244-018-0639-9) [Accessed Date: 2 September 2023].

13. Rosberg, H. E., & Dahlin, L. B. (2018). An increasing number of hand injuries in an elderly population - A retrospective study over a 30-year period. BMC Geriatrics, 18(1). [Online] Available at: <https://doi.org/10.1186/s12877-018-0758-7> [Accessed Date: 3 September 2023].

14. Danielle A. van der Windt, D. A., Burke, D. L., Babatunde, O., Hattle, M., McRobert, C., Littlewood, C., Wynne-Jones, G., Chesterton, L., van der Heijden, G. J. M. G., Winters, J. C., Rhon, D. I., Bennell, K., Roddy, E., Heneghan, C., Beard, D., Rees, J. L., & Riley, R. D. (2019). Predictors of the effects of treatment for shoulder pain: protocol of an individual participant data meta-analysis. Diagnostic and Prognostic Research, 3(1). [Online] Available at: <https://doi.org/10.1186/s41512-019-0061-x> [Accessed Date: 3 September 2023].

15. Kiliç, B., Yücel, A. S., Gümüsdag, H., Kartal, A., & Korkmaz, M. (2015). Research on shoulder injuries in athletes and treatment methods. Anthropologist, 22(1), 73–88. [Online] Available at: <https://doi.org/10.1080/09720073.2015.11891859> [Accessed Date: 3 September 2023].

16. Hains, G. (2002). Chiropractic management of shoulder pain and dysfunction of myofascial origin using ischemic compression techniques. [Online] Available at: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2504982/pdf/jcca00007-0066.pdf> [Accessed Date: 3 September 2023].

17. Hulbert, J. R., Osterbauer, P., Davis, P. T., Printon, R., Goessl, C., & Strom, N. (2007). Chiropractic treatment of hand and wrist pain in older people: systematic protocol development. Part 2: cohort natural-history treatment trial. Journal of Chiropractic Medicine, 6(1), 32–41. [Online] Available at: <https://doi.org/10.1016/j.jcme.2007.02.011> [Accessed Date: 3 September 2023].

18. Chan JJ, Xiao RC, Hasija R, Huang HH, Kim JM. (2023). Epidemiology of Hand and Wrist Injuries in Collegiate-Level Athletes in the United States. J Hand Surg Am, 48(3), 307.e1-307.e7. [Online] Available at: <https://doi.org/10.1016/j.jhsa.2021.10.011> [Accessed Date: 3 September 2023].

19. Simpson, A. M., Donato, D. P., Veith, J., Magno-Padron, D., & Agarwal, J. P. (2020). Hand and Wrist Injuries Among Collegiate Athletes: The Role of Sex and Competition on Injury Rates and Severity. Orthopaedic Journal of Sports Medicine, 8(12). [Online] Available at: <https://doi.org/10.1177/2325967120964622> [Accessed Date: 3 September 2023].

20. Stögner, V. A., Kaltenborn, A., Laser, H., & Vogt, P. M. (2020). Hand injuries in sports – a retrospective analysis of 364 cases. BMC Musculoskeletal Disorders, 21(1). [Online] Available at: <https://doi.org/10.1186/s12891-020-03807-z> [Accessed Date: 3 September 2023].

21. Avery, D. M., Rodner, C. M., & Edgar, C. M. (2016). Sports-related wrist and hand injuries: A review. In Journal of Orthopaedic Surgery and Research (Vol. 11, Issue 1). BioMed Central Ltd. [Online] Available at: <https://doi.org/10.1186/s13018-016-0432-8> [Accessed Date: 3 September 2023].

22. Thomas D. Rizzo. (1994). Rehabilitation of Hand and Wrist Injuries in Sports. Physical Medicine and Rehabilitation Clinics of North America, Volume 5, Issue 1, Pages 115-131. ISSN 1047-9651. [Online] Available at:<https://doi.org/10.1016/S1047-9651(18)30540-0> [Accessed Date: 3 September 2023]. (<https://www.sciencedirect.com/science/article/pii/S1047965118305400>)

23. Lehman, J. D., Krishnan, K. R., Stepan, J. G., & Nwachukwu, B. U. (2020). Prevalence and Treatment Outcomes of Hand and Wrist Injuries in Professional Athletes: A Systematic Review. In HSS Journal (Vol. 16, Issue 3, pp. 280–287). Springer. [Online] Available at: <https://doi.org/10.1007/s11420-020-09760-w> [Accessed Date: 3 September 2023].

24. Tai, W.-H., Zhang, R., & Zhao, L. (2023). Cutting-Edge Research in Sports Biomechanics: From Basic Science to Applied Technology. Bioengineering, 10(6), 668. [Online] Available at: <https://doi.org/10.3390/bioengineering10060668> [Accessed Date: 3 September 2023].

25. Bruce Elliott. (1999). Biomechanics: An integral part of sport science and sport medicine. Journal of Science and Medicine in Sport, Volume 2, Issue 4, Pages 299-310. ISSN 1440-2440. [Online] Available at:<https://doi.org/10.1016/S1440-2440(99)80003-6> [Accessed Date: 3 September 2023]. (<https://www.sciencedirect.com/science/article/pii/S1440244099800036>)

26. Krumm, B., & Faiss, R. (2021). Factors Confounding the Athlete Biological Passport: A Systematic Narrative Review. In Sports Medicine - Open (Vol. 7, Issue 1). Springer Science and Business Media Deutschland GmbH. [Online] Available at: <https://doi.org/10.1186/s40798-021-00356-0> [Accessed Date: 3 September 2023].

27. Mennitti C, Brancaccio M, Gentile L, Ranieri A, Terracciano D, Cennamo M, La Civita E, Liotti A, D'Alicandro G, Mazzaccara C, Frisso G, Pero R, Lombardo B, Scudiero O. (2020). Athlete's Passport: Prevention of Infections, Inflammations, Injuries and Cardiovascular Diseases. J Clin Med, 9(8):2540. [Online] Available at: <https://doi.org/10.3390/jcm9082540>[Accessed Date: 3 September 2023].

28. Schumacher, Y. O., & D’Onofrio, G. (2012). Scientific expertise and the athlete biological passport: 3 Years of experience. Clinical Chemistry, 58(6), 979–985. [Online] Available at: <https://doi.org/10.1373/clinchem.2012.183061> [Accessed Date: 3 September 2023].

29. Thapa AS, Rai SM, Nakarmi KK, Karki B, Gharti Magar M, Nagarkoti KK, Dahal P, Maharjan N, Pokharel PB, Lamichhane A. (2023). Hand Injury among Patients Visiting Emergency Department in a Tertiary Care Centre: A Descriptive Cross-sectional Study. JNMA J Nepal Med Assoc, 61(257), 5-9. [Online] Available at: <https://doi.org/10.31729/jnma.7969> [Accessed Date: 3 September 2023]. PMID: 37203910; PMCID: PMC10089049.

30. Silber J, Giddins G, Horwitz MD. (2021). Preventable hand injuries presenting to a dedicated hand and wrist unit in England: a pilot study. J Hand Surg Eur Vol, 46(10), 1113-1114. [Online] Available at: <https://doi.org/10.1177/17531934211019297> [Accessed Date: 3 September 2023]. PMID: 34034551; PMCID: PMC8647476.

31. Giancarlo McEvenue, Fiona FitzPatrick, Herbert P. von Schroeder. (2016). An Educational Intervention to Improve Splinting of Common Hand Injuries. The Journal of Emergency Medicine, Volume 50, Issue 2, Pages 228-234. ISSN 0736-4679. [Online] Available at: <https://doi.org/10.1016/j.jemermed.2015.08.011> [Accessed Date: 3 September 2023]. (<https://www.sciencedirect.com/science/article/pii/S0736467915009014>)

32. Qiu, Z. (2020). The Influence of the Design and Manufacture of Sports Equipment on Sports. Journal of Physics: Conference Series, 1549(3). [Online] Available at: <https://doi.org/10.1088/1742-6596/1549/3/032039> [Accessed Date: 3 September 2023].

33. Pihl, P. (n.d.). An Analysis of the Sports Equipment Industry and One of Its Leading Companies, Head, N.V. [Online] Available at: <https://digitalcommons.liberty.edu/cgi/viewcontent.cgi?article=1176&context=honors> [Accessed Date: 3 September 2023].

34. Ngoubinah pretty, N. T., & Priya, V. v. (2021). Awareness on Health Checkup for School Students Among Parents. Journal of Research in Medical and Dental Science 2021, 9(1), 314–318. [Online] Available at: [www.jrmds.in](http://www.jrmds.in) [Accessed Date: 3 September 2023].

35. Nikander K, Kosola S, Vahlberg T, Kaila M, Hermanson E. (2022). Associating school doctor interventions with the benefit of the health check: an observational study. BMJ Paediatr Open, 6(1):e001394. [Online] Available at: <https://doi.org/10.1136/bmjpo-2021-001394> [Accessed Date: 3 September 2023]. PMID: 36053658; PMCID: PMC8889353.